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Orginal Article

Environmental aspects of the production and use of autoclaved aerated concrete with low density

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Abstract: The purpose of the article is to investigate the state of carbon dioxide emissions generated as a result of wall materials production and the construction industry as a whole. The paper provides a comparative analysis of housing construction in Ukraine and in some CIS countries. Against the background of the indicators of low housing availability and low relative volumes of housing construction, the issue of high energy consumption remains valid. The absolute and relative volumes of greenhouse gas emissions from economic activity of the population of Ukraine are given. The projected consequences for Ukraine from continued CO_2 emissions on the same level and temperature rise are estimated. It is deemed that the most suitable wall material for countries with emerging economies is autoclaved aerated concrete (AAC); since it is a structural and thermal insulating material, it can solve the problem of housing construction.

The paper shows the key priority of low energy consumption and makes emphasis on lowering the density of the produced aerated concrete, reducing mineral additives and cement production expenses.

Keywords: greenhouse gases, energy saving, construction, autoclaved aerated concrete, low density

1. Introduction

The construction industry continues to be the largest consumer of energy and fresh water in the world. It is also responsible for producing 40% of global greenhouse gas emissions. Being a fund-forming industry, construction is directly related to energy consumption and greenhouse gas emissions levels. The energy consumption of buildings depends greatly on the wall enclosure. Today, autoclaved aerated concrete (AAC) has replaced traditional wall materials from the construction market, such as ceramic bricks, silica bricks and claycrete. The main reason for this is because they are energy-intensive in production and not energy-efficient at the stage of operation. Its share in wall materials in European countries is 40-60% and 53% in Ukraine.

A classic example of the formation of the AAC production industry is the experience of China and Poland. Back in 1947, Poland bought the technology and part of the equipment from the Swedish company “Siporex” with the right to replicate the equipment. As a result, its production capacity increased to 5-7 million m^3 of AAC per year. At the end of the 1950s 10 plants were sold to the former Soviet Union and 7 plants to the former Czechoslovakia. China has 2,300 plants, most of them were built by China itself, with a total production capacity of 220 million m^3/year. They also export their plants to other countries around the world.

The analytical agency for market research [1], which brings together professionals in global market information and includes 1,700 research groups from 81 countries, has presented its forecast for the growth of the AAC global market. According to this forecast, the AAC global market will grow from 18.8 billion USD in 2020 to 25.2 billion USD by 2025 at an average annual growth rate of 6.0% during 2020-2025.

Many years of experience in AAC production have shown that the energy cost for its production is 320 kWh/m^3, while it requires 900 kWh/m^3 to produce dense bricks, and 600 kWh/m^3 for hollow bricks [2].

Ukrainian construction industry is facing several major challenges, such as:

- increasing the relative volumes of housing construction from 0.22 m^2/person per year to the level of international standards – about 1 m^2/person per year;
- insulating the existing housing stock built in 1960-1980s with low thermal resistance of envelopes;
- switching to construction of energy efficient buildings using modern energy efficient wall materials;
- achieving a significant increase in the use of alternative energy sources;
- reducing greenhouse gas emissions through the rational use of hydrocarbons and new technologies for their utilization.

Due to low energy efficiency of production, according to the Ministry of Economy of Ukraine, the country’s financial losses in 2018 amounted to almost 1.5 billion USD. According to [3] Ukraine has a huge potential for energy savings in the housing sector (34%), production sector (28%) and in the energy transformation sector of thermal power plants (21%). Service industry and agriculture make up 12% and 4% of the energy saving potential, respectively.

According to the Energodata annual global research, the level of energy intensity of the gross domestic product of Ukraine twice exceeds the average number throughout the world . In particular, for example, in Poland this indicator is 2.5 times lower than in Ukraine; in Germany it is 3.3 times lower. The enclosing structures of the outer walls of residential buildings from 1960s – 1980s were built mainly from claydite concrete in the form of ceramic and silicate wall panels, and bricks with a density of 1400-1900 kg/m^3. Nowadays in Ukraine 1.5 times more energy is used to heat a unit area than in the U.S., and about 3 times more than in Sweden.

Energy saving should be considered not only in terms of economic losses, but it can also help reduce greenhouse gas emissions from the combustion of fossil hydrocarbons. According to the Kyoto Protocol, 6 gases are considered greenhouse gases: carbon dioxide, methane, nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride (SF_6). Of these 6 gases, 3 are of paramount importance, and they are closely related to human activities.

In 2015, 197 nations signed the Paris Agreement on reducing greenhouse gas emissions, committing to prevent an average air temperature increase of 2°C by the end of the century. This requires adapting the power economy, construction sector, manufacturing industry, agriculture, and the entire economy to reduce CO_2 emissions. The International Monetary Fund insists that taxation of CO_2 emissions is the most effective tool for limiting the use of fossil fuels and related CO_2 emissions.

Environmental problems and climate change are now dominant for the development of civilization. The state of the construction complex (housing construction, production of building materials, insulation and maintenance of the housing stock) largely reflects the efficiency of the rational use of fossil hydrocarbons and greenhouse gas emissions.

2. Environmental problems

Environmental problems and climate change remain a huge concern for humankind. According to expert forecasts, climate change in Ukraine can cause a decrease in agricultural yields up to 30% in the nearest future and will likely cause other cataclysms. Catastrophic storms, extreme heat and life-threatening pollution are possible.

According to NASA and the National Oceanic and Atmospheric Administration (NOAA), 2019 was the second hottest year on record. Every decade since the 1960s has been warmer than the decade before with the past decade being the warmest on record [4]. According to the 2018 Global Emissions Gap Report, 55.3 gigatons of greenhouse gasses were emitted into the atmosphere, compared to 53.5 gigatons in 2017. If these carbon dioxide emission trends remain, by the end of this century the Earth's temperature will rise by 3.2 °C and will bring devastating consequences for the entire planet. The European Parliament calls on the EU to submit a strategy for achieving climate neutrality to the UN Convention on Climate Change as soon as possible, but no later than 2050. MEPs call on the European Commission to include a 55% greenhouse gas emission reduction target to the European Green Deal by year 2030.

As can be seen from Fig. 1, the average rate of temperature increase has changed significantly since 1981. Land and ocean temperatures have risen at an average rate of + 0.13 °F or + 0.07 °C each year.

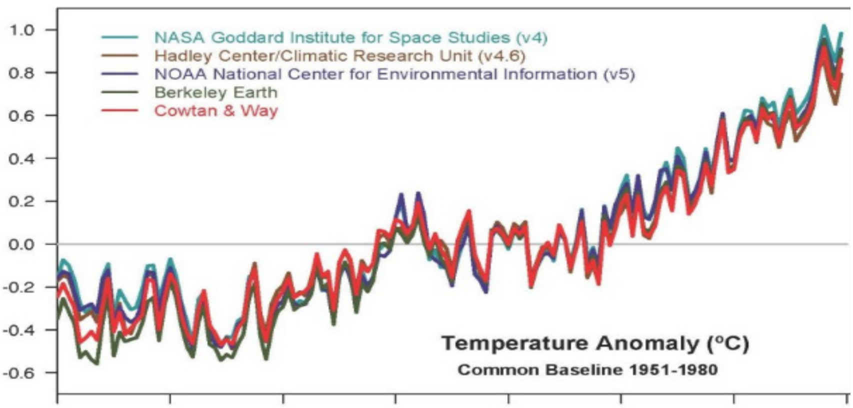

Fig. 1. Average annual changes in the average global temperature of the Earth. *Source*: [21]

The main sources of carbon dioxide formation are shown on fig.2. The main pollutants of the atmosphere are thermal power plants (TPP), transport vehicles, manufacturing industry, housing and communal services. TPPs only produce more than 30% of all emissions [5].

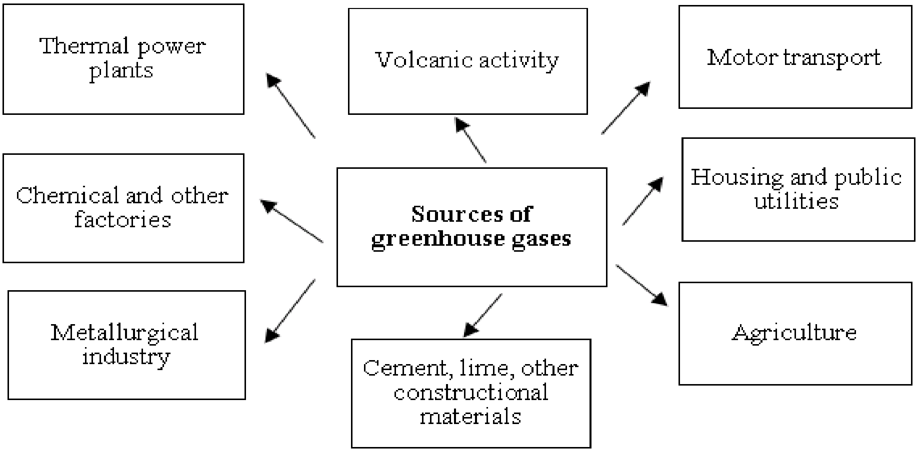

Fig. 2. Main sources of carbon dioxide emissions. *Source*: own study

The functioning of the fund-forming construction industry is provided by cement, metallurgical, chemical and other enterprises of the building materials industry, transport and enterprises in the energy sector of the economy. According to the latest IEA data, global cement production causes 10% of total CO_2 emissions.

Energy consumption and greenhouse gas emissions are associated with the maintenance of housing and other industrial and public facilities. The world's biggest energy consumers are buildings (31%), industry (29%) and transportation (29%). The rest of 11% of the world's energy consumption is shared between other fields.

Table 1 shows coefficients of CO_2 emissions from combustion of different fuels for a detailed estimation of emissions. The carbon tax depends on the type of hydrocarbons and their carbon content. The CO_2 emissions tax was first introduced in Ukraine in 2011. Its rate was purely symbolic (from 0,0086 EUR to 0,014 EUR per ton of CO_2 emissions). Since January 1, 2019 the tax rate has increased 24,4 times up to 0.33 EUR per one ton of CO_2 emissions. Meanwhile, the EU countries have high taxes on carbon dioxide emissions. On average, this tax is 50 euros per ton of CO_2 emissions. However, Ukraine plans to gradually increase the ecological tax on CO_2 by 2024. This tax should be paid by those economic entities where the total annual volume of CO_2 emissions exceeds 500 tons.

Carbon taxes have a significant impact on reducing greenhouse gas emissions with their high rate and long lead times. Canada plans to raise the charge per ton of greenhouse gas emissions to 170 USD (150 EUR) by 2030 and to achieve zero greenhouse gas emissions by 2050. This was announced by the Prime Minister at the 2021 Climate Summit in Glasgow.

Table 1. Coefficients for calculating CO_2 emissions from fuel combustion

Type of fuel	CO_2 emissions
Natural gas	1,85 tons of CO_2 / (thousand m^3)
Coal	2,7–2,8 tons of CO_2 per ton (depending on the grade of coal)
Peat	~1,5 tons of CO_2 per ton, one ton of peat gives ~2 times less energy than a ton of coal
Motor spirit Furnace oil Diesel fuel Aviation kerosene	3,0 tons of CO_2 per ton or 2,1–2,3 kg CO_2 per litre depending on the temperature of the fuel and its brand (summer fuel is more dense, and winter fuel is less dense)
Fuel wood and agricultural waste	CO_2 emissions are considered to be zero, since CO_2 released into the air during combustion was previously absorbed from the atmosphere during plant growth (a closed cycle is formed that does not lead to an increase in CO_2 concentration in the atmosphere)

As seen in Table 1, it is preferable to use wood fuel and natural gas, which minimize carbon dioxide emissions during combustion. The future of global energy is tied to renewable energy sources. The phasing out of coal, gasoline and diesel in some EU countries is part of the commitment to fight climate change.

According to the European Commission's research center, Ukraine continued to reduce its CO_2 emissions in 2019. They amounted to 196 million tons, for comparison, in 2018 emissions were at 203 million tons, and in 1990 – 783 million tons. Ukraine's per capita emissions have also decreased. Last year in 2020, they were nearly 4.5 tons per year, down from 4.6 tons a year earlier and more than 15 tons in 1990. The average global emissions per capita are 4.9 tons of CO_2.

In November 2021, at the UN climate summit COP26 in Glasgow, more than 40 countries pledged not to invest in the construction of coal-fired power plants. Coal-consuming countries, including Canada, Poland, Ukraine, Vietnam, and others, will gradually reduce using coal.

The solution to the problem of greenhouse gas emissions is essentially related to the reduction of energy consumption, primarily in the construction sector of the country through the insulation of the previously built housing stock and the construction of new buildings using energy-efficient building materials. The housing complex of Ukraine consumes about 40% of all energy used in the economy of the country. With the trend of increasing the share of construction of low-rise residential buildings in the total volume of housing construction the need for wall construction materials increases. Being an energy efficient and affordable wall material, AAC is rapidly gaining popularity and occupies the first position in the structure of wall materials.

3. Improvement of autoclaved aerated concrete production

AAC as a construction material has been known for more than 70 years in the construction market. Because of its high vapor permeability, there have been opinions about the possibility of changing the properties of the material over time with prolonged carbonation. Recent works on the examination of existing for a long time aerated concrete walls and buildings [6] and the results of other studies [7] confirmed that the process of carbonization in AAC does not bear a direct threat to the safety of buildings over a long life cycle.

An important fact is that aerated concrete combines thermal insulation and structural properties. Low-density aerated concrete allows to reduce the cost of the foundations by 30%, energy costs for heating – up to 35%, transportation costs – by 30%, the cost of housing – up to 20%. [8]. After the completion of buildings, AAC can be completely recycled for reuse (Fig. 3).

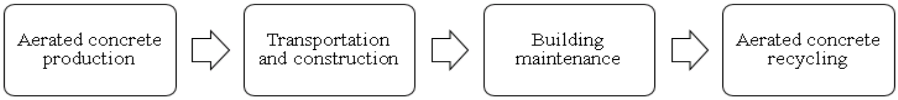

Fig. 3. Life cycle assessment of aerated concrete. *Source*: own study

Affordable materials such as sand, lime, cement and gas-forming agents are used for AAC production. Modern approaches to assess the environmental and economic effect of the production of any building material dictate the need for a comprehensive energy assessment of it at all stages of the life cycle. Of the given stages of the creation and operation of AAC (Fig. 3), the greatest energy saving effect and positive environmental consequences seem possible to obtain at the first and third stages of the life cycle of the use of this material – during the long-term operation of buildings

A comparative analysis of the energy intensity of the production of basic building materials is presented in [9]. It becomes obvious that the largest energy intensity of production falls on steel. One needs to spend 32290 MJ of thermal energy to produce 1 ton of the material; to produce 1 ton of portland cement 8 times less thermal energy is needed, 12 times less when producing bricks, 16 times less for reinforced concrete and 25 times less to produce cellular concrete

During AAC production high-energy consuming components such as cement and lime are used. Their firing temperature is respectively 1450-1500 ºC and 800-1200 ºC. According to [10] cement production takes a significant place in environmental pollution. It is characterized by the withdrawal of natural resources, atmospheric pollution, wastewater discharge, as well as the impact on the Earth's climate. Enterprises of the cement industry account for about 70% of industrial emissions of solid substances and 44% of gaseous substances.

Large reserves of cement savings in the production of AAC are brought by the right choice of silica components and active mineral additives. Under conditions of high temperature (about 200°C) and saturated steam at excessive pressure (1.2-1.4 MPa) such additives act as a component of the mineral binder. In many countries of the world, fly ash is used as a siliceous component [7][11]. As is known, the world leaders in the use of fly ash are China, Poland and Great Britain. In Ukraine, Belarus, Kazakhstan fly ash is not used, in the Russian Federation about 10% of plants are using it in AAC production.

Blast furnace granulated slag in autoclaved aerated concrete is activated by lime and cement and, in fact, acts as a mineral binder. Natural mineral additives such as rottenstone and gauze save in mineral binders [12, 13].

Zeolites, a group of minerals mainly represented by aqueous calcium and sodium aluminosilicates, may be an alternative to a part of cement in the technology of aerated concrete production. Zeolite is used as an active mineral additive in the production of Portland cement, in the manufacture of silicate bricks and dry building mixtures.

In [14] the results of study of samples containing clinker minerals and highly dispersed chalk with different ratios of components are considered. It has been proved by IR-spectroscopy methods that addition of highly dispersed chalk leads to reduction of $Ca(OH)_2$ portlandite amount in cement stone composition. In addition, it leads to the decrease of basicity of hydrosilicates of calcium. The amount of clinker minerals in the cement stone decreases, while the amount of portlandite does not decrease.

Carbonate additives increase cement hydration and create low-base calcium hydrosilicate. It is the main carrier of strength of autoclaved concrete and cement materials in general [15]. At the same time, dispersed calcium carbonate compacts the microstructure of the silicate material. When converting to the production of low-density aerated concrete, carbonate additives also act as a "protector", increasing the carbonization resistance of low-density aerated concrete.

Due to its high dispersibility, limestone fills the space between the clinker grains and improves the interaction between them by reacting chemically with the aluminate and aluminiferous phases to form calcium hydrocarbon aluminates [16].

In recent years, highly active metakaolin as a highly effective pozzolanic additive has become popular. The introduction of this additive into the composition of cellular concrete makes it possible to increase its strength at a given density. This happens due to two factors: increasing the strength of interstitial partitions by increasing the strength of cement stone and improving the pore structure of aerated concrete [17].

When the clay is fired at 650 °C, chemically bound water volatilizes and it turns into an active pozzolanic additive. Kaolinite has a wide temperature interval between dehydration and recrystallization, which greatly contributes to the formation of metakaolin, which is an additional cementitious material [18].

In contrast to the dense concrete, the use of active mineral additives of natural and man-made origin in the technology of autoclaved aerated concrete affects the water-hardness ratio of the mixture, swelling, increasing the plastic strength of the raw material and the formation of macro and microstructure of gas concrete. The aerated concrete mixture must quickly gain the plastic strength necessary to cut it into blocks. This creates certain difficulties of mass transition to the production of light autoclaved aerated concrete. The process of swelling of aerated concrete mixture itself (the end of gassing) should be balanced with the time of its setting and ensure the formation of macro pores of the correct shape. The compressive strength of the final product depends on the strength of the newly formed silicate stone and on the regularity of the macropores of the aerated concrete [19].

4. Energy Efficiency of Reducing AAC Density

The reduction of aerated concrete density while saving and increasing its strength properties remains a constant aim for manufacturers. Aerated concrete with density 300 kg/m^3 and compressive strength 2.5 MPa, as a wall construction-insulating aerated concrete is produced at the best enterprises of the industry.

Earlier wall blocks in Ukraine had an average density of 643 kg/m^3, nowadays more and more wall blocks with density 300-400 kg/m^3 are produced. The production of such blocks is less resource and energy intensive. During autoclave processing duration of product soaking can be reduced by 1,5-2 hours. This is due to a more porous structure of the aerated concrete mixture, which allows the saturated steam to penetrate deeper into the massif and warm it up faster.

Modern AAC plants operate on waste-free technology. Reducing the consumption of raw materials can be achieved by various means. For instance, the upper layer of the massif is cut off and returned to the aerated concrete mixer in the form of return sludge, as well as raw waste. The share of return sludge in the composition of the raw aerated concrete mixture can contain 16-20%.

The use of steam transfer from one autoclave to another provides a significant reduction in energy consumption during autoclave treatment of aerated concrete. The transition to the production of low-density AAC provides savings in material, energy resources and allows to get additional energy and environmental effect at production and operation stage. At the same time, this requires additional engineering and technological research to restructure the entire technological process of AAC production.

The European standard EN 771-4 [20] allows usage of the lowest class bulk density 300 kg/m^3 and operating moisture under operating conditions at 4-8%, which gives it high thermal insulation properties.

The advantages of the transition to the production of AAC with density 300 kg/m^3 and 400 kg/m^3 are quite obvious. The walling structures of domestic buildings in 1960–1980-s were built from ceramsite-concrete wall panels, ceramic and silicate bricks with density 1400-1900 kg/m^3, as well as hollow blocks, which are characterized by a high coefficient of heat transfer.

Improvement of production technology and reduction of AAC density while maintaining its performance characteristics leads to lower consumption of energy-intensive components, such as cement and lime. Due to higher vapor permeability during autoclaving, AAC with lower density heats up faster. Thus, it is possible to reduce consumption of steam (energy) for heating of aerated concrete mass and duration of autoclaving treatment.

The duration of the autoclave treatment mode after transition to the production of low-density AAC at Aeroc plants was reduced by 3 hours, and the turnover rate of the autoclave per day increased from 2.1 to 2.45 cycles. The increase in the autoclave turnover ratio provides a comprehensive effect of reducing power and gas consumption, greenhouse gas emissions and, as a result, intensifies AAC production.

Large-scale production of AAC with an average density of 500 kg/m^3 prevails in most European countries. From the websites of the companies producing AAC we can see that in each country the leading companies in terms of total production volumes and product density have been determined. The Russian Federation produces the largest quantity of AAC in Europe (13.73 million m^3), with Russian company "BONOLIT group" owning more than 20% of the AAC market with density from D200 to D600. The average AAC density in Russia is 505.7 kg/m^3. Poland ranks third in Europe with SOLBET having 30% of the market, producing aerated concrete with density D400-D700. According to the Statistics Poland Office, in 2020 5.4 million m^3 of AAC was produced. About 4 million m^3 of AAC was produced in Ukraine, being fourth in Europe in terms of total production volumes.

A special place in the European AAC market is held by the transnational concern Xella International (Germany). The "Ytong" wall aerated concrete blocks have compressive strength in the range of 2-5 MPa and average density 300-700 kg/m^3. The concern owns 95 factories with a staff of more than 7 thousand people and has a Research and Development Center which controls the quality of raw materials and technology of its factories. In 2021 Xella Russia presented the Ytong A++ aerated concrete blocks with a density rating of D300 and compressive strength of at least 2.5 MPa.

In the EU countries the heat transfer coefficient U of the outer walls is gradually reduced. In Poland after January 1, 2021 it is $U \leq 0.20$ W/m^2 K ($R \geq 5.00$ m^2 K/W). In 2021 new state standards for construction were adopted in Ukraine. According to them, the thermal resistance of building envelopes should be increased by 20% $U \leq 0.25$ W/m^2 K ($R \geq 4.00$ m^2 K/W). This index can be reached using D350 Ytong Energo aerated concrete blocks without additional insulation, as well as by using AAC blocks with a density of D300.

Xella International is a manufacturer of the "lightest" thermal insulation aerated concrete. For more than 15 years Ytong Multipor aerated concrete slabs with a density of 100-112 kg/m^3 have been used as insulation in many countries in Europe. This is an environmentally friendly, non-combustible, mineral-based insulation with high durability indicators. They are used to insulate buildings and two-layer masonry walls of energy-efficient buildings, and are certified for compliance with the international standard ISO 14025.

Because of the long-term economic crisis, the volume of AAC production in Ukraine decreased from 1.2 million m^3 in 1991 to 100 thousand m^3 in 2000, and has increased 40 times by 2020. The largest producers of AAC in Ukraine and Europe are "Orientir-Budellement" (32% of the market) and "Aeroc" (shares 28% of the market). Both of these manufacturers are located in the Kyiv region.

"Aeroc" was the first company in Ukraine to stop production of D600 AAC blocks. It also started mass production of energy-efficient aerated concrete with 300 and 400 kg/m^3 density and compressive strength class C2.0. The company has mastered the large-scale production of D150 insulating aerated concrete.

In 2020, the company's two plants sold 1.14 million m^3 of aerated concrete: D400 – 55%; D300 – 23%; D500 – 21% and D150 brand – 1% or about 8 thousand m^3 of mineral thermal insulation. Fig. 4 shows the dynamics of AAC production by density.

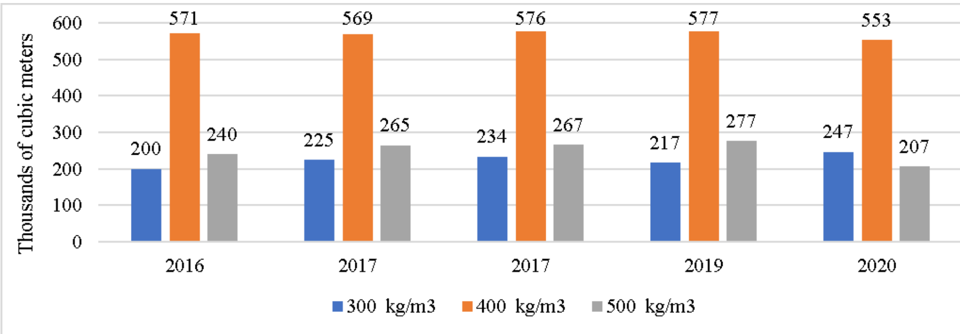

Fig. 4. Dynamics of aerated concrete production by density produced by "Aeroc". *Source*: own study

"Aeroc" initiated the amendments to the State Standard of Ukraine "Cellular concretes. General Specifications", according to which the insulating concrete can be now considered as aerated concrete with average density 100, 150, 200, 250, 300 and 350 kg/m^3. Aerated concrete density D300 and above with a compressive strength of 2.5 MPa is classified as structural and insulating aerated concrete, which corresponds to the regulatory requirements of the European standard EN 771-4.

It should be expected that due to environmental reasons and combustibility, the use of traditional thermal insulation (mineral wool, polystyrene foam) will be displaced by environmentally friendly mineral insulation – lightweight gas concrete, especially for the internal insulation of buildings.

Table 2 shows the comparative characteristics of low-density AAC produced by Ytong, Aeroc and Bonolit Group.

Table 2. Characteristics of low-density insulation aerated concrete

Material properties	Type of mineral aerated concrete insulation		
	Ytong Multipor	Aeroc Energy	Bonolit Group
Density, kg/m^3	D100 – D115	D150	D200
Thermal conductivity, W/m·K	0,045	0,05	0,055
Compressive strength, MPa	≥ 0,35	0,5	0,5
Fire resistance	Euroclass A1		
Vapor permeability, mg/(m * h* Pa)	0.3	0.3	0.3

The main properties of manufactured light insulating aerated concrete are very similar. While Ytong Multipor products are widely used on European markets, AAC produced by Aeroc and Bonolit Group is produced for domestic consumption. Aeroc is working out the technology of AAC production with the density of 125-130 kg/m^3. TheTurkish company EGE Gazbeton and some Russian manufacturers share information about the production of individual batches of insulating aerated concrete of D200 brand.

Table 3 shows the data on energy intensity of Aeroc AAC production with different densities and the dynamics of the relative consumption of the binders (cement and lime). Binder consumption of the heaviest aerated concrete brand D500 is taken as 100%.

Table 3. Consumption of raw materials and resources for AAC produced by Aeroc (Ukraine)

Rate	500 kg/m^3	400 kg/m^3	300 kg/m^3	150 kg/m^3
Cement and lime consumption, %	100	93	93	75
Electricity consumption during sand grinding, KW / m^3	8	6,8	5,6	9
Gas consumption, m^3/m^3	7,5	6,2	5,4	4,5

It can be clearly seen that as the density of AAC decreases, the relative consumption of binders decreases. Natural gas consumption in the production of aerated concrete decreases as its density decreases.

Fig. 6 shows the priority organizational and technological solutions at Aeroc for reducing the energy intensity of AAC production.

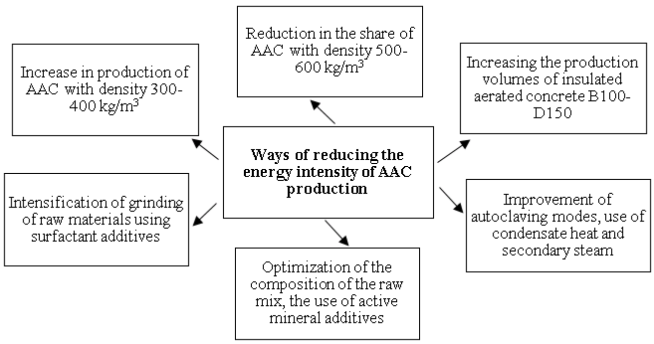

Fig. 6. Organizational and technological solutions aimed at reducing energy consumption of AAC production. *Source*: own study

5. Conclusions

According to the IEA, up to 40% of all energy in the world is used to maintain buildings. The main source of greenhouse gas emissions is the combustion of hydrocarbons, which has reached critical levels.

The share of construction of individual low-rise buildings (up to 3 floors) is increasing in many countries. As a result, construction of low-rise buildings requires more walling materials.

AAC is one of the most popular wall materials in Ukraine and other countries. Its advantages are low energy consumption as compared to traditional wall materials and higher thermal insulation properties. The share of AAC in the structure of wall materials of European countries is 20-30%, in post-soviet countries it reaches up to 40-60%.

The problems of energy saving remain a matter of pressing concern. That is why reducing greenhouse gas emissions in production of walling materials should be considered as a priority. It can be achieved by using active mineral additives, as well as by switching to production of low density blocks (300-400 kg/m^3).

The energy-ecological policy of Aeroc (Ukraine) is aimed at sustainable development by improving the structural quality of AAC, increasing the share of structural-insulating D300-D400 brand AAC and increasing production of environmentally friendly mineral heat insulation with a density below 150 kg/m^3.

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