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Environmental assessment of the impact of a residential building's heat sources on air pollution

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Abstract. The implementation of energy efficiency measures is crucial for low-carbon development, a reliable energy supply and the country's energy security. One of the steps in implementing such measures is the introduction of new and modernisation of existing district heating systems, which allow for balanced resource use, a reduction in greenhouse gas emissions into the environment, and simplified operation and maintenance of buildings. The aim of the study was to compare the quantities of pollutant and greenhouse gas emissions generated during the production of thermal energy by individual and centralised heat supply systems in a residential building. A 72-apartment residential building was examined, the building envelope of which meets modern thermal engineering requirements. In the autonomous heating supply scenario, the heat sources were individual gas-fired double-circuit boilers, whereas in the centralised heating supply system, thermal energy was generated by a gas-fired boiler house. The amount of emissions released into the environment under individual heat supply was calculated in accordance with the Methodology for Calculating Emissions of Pollutants and Greenhouse Gases into the Air from Fuel Use for Household Needs. The amount

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of emissions released into the environment under centralised heat supply was calculated in accordance with the Sectoral Methodology for Calculating Harmful Emissions from Heat-Generating Installations of the Municipal Heat and Power Sector. The pollutants and greenhouse gases whose emissions are accounted for by these methodologies include carbon monoxide, carbon dioxide, nitrogen oxides, nitrogen dioxide, sulphur dioxide, methane and non-methane volatile organic compounds. It has been established that individual heat supply to a residential building generates 881.78 t/year of anthropogenic emissions, of which 879.96 t/year are greenhouse gases, whilst centralised heating generates 707.27 t/year of anthropogenic emissions, of which 703.52 t/year are greenhouse gases. The research results show that the use of centralised heat supply in a residential building generates 176.44 t/year less greenhouse gases than individual heat supply, i.e. a 20.0% reduction in emissions is observed

Keywords: energy efficiency; heating system; gas boiler; natural gas; emissions; greenhouse gases; pollutants

Introduction

One of the strategic priorities of state policy in Ukraine is energy efficiency. As of 2026, Ukraine has developed and adopted a legislative framework aimed at developing the energy efficiency sector, and the National Energy Efficiency Action Plan for the period up to 2030 has been approved. Improving the energy efficiency of buildings is being carried out in accordance with Ukraine's obligations under international and intergovernmental agreements, in particular the Association Agreement between Ukraine and the European Union. Adherence to the principles of energy efficiency is crucial for low-carbon development, a reliable energy supply and the country's energy security. At the same time, state policy is aimed not only at reducing energy consumption but also at cutting emissions and mitigating the effects of climate change.

According to S. Adamenko *et al.* (2024) and L. Arkhypova *et al.* (2025), climate change is leading to a reduction in snow cover in the Carpathians, which increases the risks of extreme weather events, whilst meteorological factors complicate the forecasting and control of pollutant concentrations from stationary sources, in particular such as district heating systems. In this context, energy efficiency is viewed not as an end in itself, but as a tool for achieving environmental and climate goals, in particular reducing the release into the atmosphere of greenhouse gases, pollutants or mixtures thereof, i.e. anthropogenic emissions. The energy efficiency of buildings depends directly on the efficiency of their building services systems.

Thermal energy for heating and hot water supply systems can be generated by individual or district heating systems. F. Vranay *et al.* (2025) described the advantages and disadvantages of implementing district and individual heating systems. In district heating systems, heat is generated at a single centralised heat source and then distributed via a heating network to multiple consumers for heating and hot water supply. In individual heating systems, heat sources are installed in each flat within multi-unit residential buildings. Many researchers, notably A. Mastrucci *et al.* (2025), believed that centralised heat supply systems should be used to improve the energy efficiency of buildings. Centralised heat supply diversifies and strengthens energy supply by utilising renewable energy sources and industrial surplus heat, enabling a balance in resource use and a reduction in greenhouse gas emissions. Economies of scale allow for cost savings by serving many users per metre of pipe, and simplify the operation and maintenance of buildings. Heating boilers, combined heat and power (CHP) plants, and cogeneration units – the operation of which was studied by N.S. Ganesha & M. Omprakash (2022), large-scale heat pumps, and solar thermal power plants, in particular the operation of hybrid solar collectors, which was studied by I. Venhryn *et al.* (2021). In this context, the heat source may utilise alternative energy sources, including biomass, waste heat, wastewater and geothermal water. Schematics of district heating systems using geothermal water were presented by O. Savchenko *et al.* (2023).

In Ukraine, district heating systems serve approximately 50% of consumers. Thermal energy is generated predominantly in heating plants (≈65%) and combined heat and power plants (≈25%). In the energy balance, as of December 2024, the main fuel for heat-generating enterprises was natural gas, which accounted for an average of 92% of thermal energy production. Despite Ukraine's national climate policy, the issue of emissions in district heating systems and their impact on the environment has received little attention in scientific publications. Most publications claim a reduction in energy consumption when using various heat sources, largely without support from analytical or experimental studies. For example, Yu. Selikhov *et al.* (2023) stated that replacing obsolete boiler equipment with modern boiler units allows for a 30% reduction in energy consumption, yet they do not provide supporting calculations. O. Savchenko *et al.* (2025) described the refurbishment of heat supply systems, which reduces heat loss from heating networks by 30%, leading to a reduction in greenhouse gas emissions; however, quantifying these emissions was not the aim of the publication.

With regard to individual heating systems, the energy efficiency of gas condensing boilers in such systems, compared to gas heating boilers, was examined by G. Luzhanska *et al.* (2025). They found that the gas fuel saving per 1 kW of thermal energy is 0.023 m^3/h, which corresponds to a 19% reduction in gas consumption. Yu. Selikhov *et al.* (2025) compared the energy efficiency of single-circuit solar systems for domestic hot water supply and space heating with that of gas heating boilers. The results of the studies showed that the use of 210 m^2 of solar collectors reduces harmful emissions by 300 kg. As can be seen from the sources cited, the existing literature pays insufficient attention to determining anthropogenic emissions during the operation of heat supply systems. Furthermore, there is no environmental assessment of the choice of heat source in heat supply systems based on the amount of greenhouse gases and pollutants released into the atmosphere. Therefore, the aim of this study was to conduct an environmental assessment of the choice of heat source and to compare the amount of anthropogenic emissions generated during the production of thermal energy by individual and centralised heat supply systems in a residential building.

Materials and Methods

The study presents an analytical comparison of pollutant and greenhouse gas emissions for individual and centralised heating systems in a multi-unit residential building. Greenhouse gases are gases in the Earth's atmosphere that are capable of absorbing thermal radiation from the planet's surface and clouds and reflecting it back, thereby heating the atmosphere. Water vapour (H_2O), which accounts for about 1% of the atmosphere by volume, plays the greatest role in the excessive greenhouse effect on Earth. The concentration of water vapour in the atmosphere is not directly dependent on human activity and varies by region. However, human activity indirectly increases global temperatures and water vapour production, thereby intensifying atmospheric warming. According to Annex A of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (1997), six main greenhouse gases have been identified as having the greatest impact on climate change, namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons and sulphur hexafluoride (SF_6). Greenhouse gas emissions are equal to the sum of emissions of these gases. Globally, greenhouse gas emissions are increasing every year and, as of 2024, according to H. Ritchie *et al.* (2024), amount to 54.43 billion tonnes of carbon dioxide equivalent (CO_2e). In Ukraine, greenhouse gas emissions have been decreasing over the last 35 years; however, this is not due to the use of energy-efficient technologies and production processes, but rather to a decline in population and industrial capacity. Figure 1 shows greenhouse gas emissions in Ukraine between 1990 and 2023, as determined by the Ministry of Environmental Protection and Natural Resources of Ukraine & the Budget Institution "National Centre for GHG Emission Inventory" (2025).

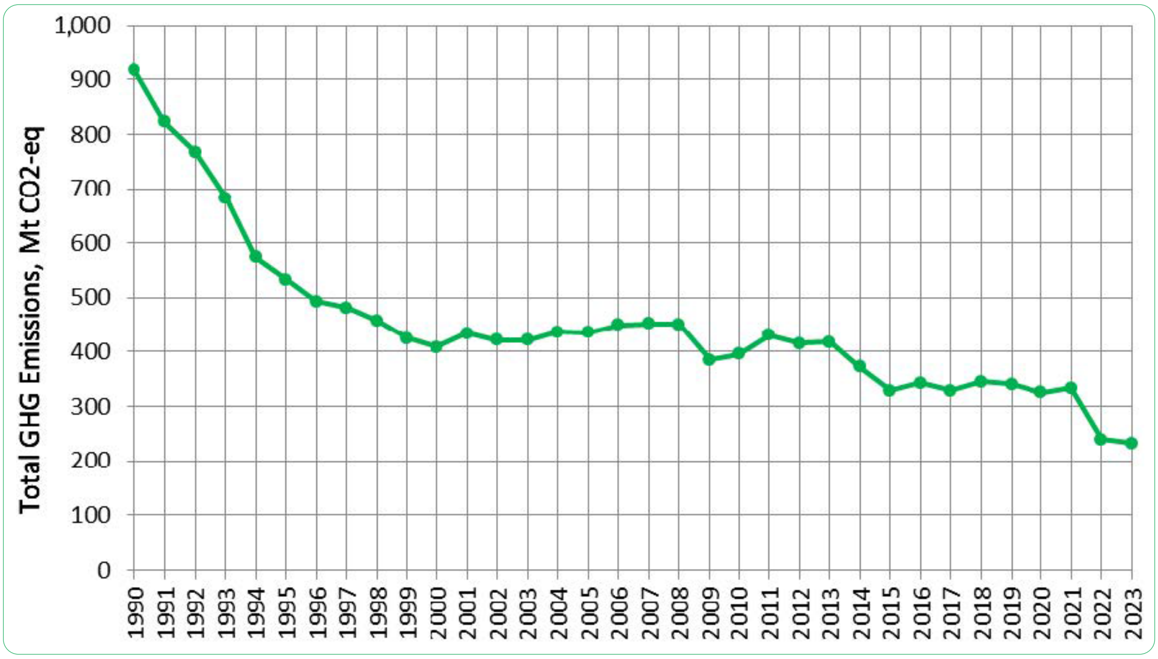

Figure 2. GHG emissions in Ukraine (including LULUCF), Mt CO_2-eq
Source: Ministry of Environmental Protection and Natural Resources of Ukraine & the Budget Institution "National Centre for GHG Emission Inventory" (2025)

Each gas contributes differently to global greenhouse gas emissions; thus, as of 2024, according to H. Ritchie *et al.* (2024), carbon dioxide accounts for 77.2% of global greenhouse gas emissions, methane for 17.5%, and nitrous oxide for 5.4%. Consequently, carbon dioxide has the greatest impact on the greenhouse effect and climate change, a significant amount of which is emitted as a result of human activity. The quantity of pollutants emitted during the operation of heat supply systems is determined using two different methodologies, depending on the type of building's heat supply system – centralised or individual.

To determine the amount of pollutants emitted by heat-generating plants in Ukraine's municipal heating sector (centralised heat supply systems), the sectoral methodology for calculating harmful emissions is used (Order of the Ministry of Construction of Ukraine No. 67, 2006). In this methodology, the determination of gross emissions of pollutants from the combustion of natural gas in municipal sector boilers is based on the calculation of the pollutant emission factor. The emission factor characterises the mass of the pollutant per unit of energy released during gas combustion. When calculating emissions of pollutants into the atmosphere during the combustion of natural gas in boiler houses, the following emission factors are used: $kNO_x = 64.311 \cdot 10^{-6}$ g/GJ; $kCO = 248.75 \cdot 10^{-6}$ g/GJ; $kCO_2 = 58{,}748.13 \cdot 10^{-6}$ g/GJ; $kN_2O = 0.1 \cdot 10^{-6}$ g/GJ; $kCH_4 = 1.0 \cdot 10^{-6}$ g/GJ. The gross emission of a pollutant, in tonnes, is then determined by the formula:

$$E = k_i \cdot Q_{low} \cdot B, \tag{1}$$

where k_i is the emission factor for the i-th pollutant; Q_{low} is the lower heating value of natural gas; B is the mass flow rate of natural gas per year. The mass flow rate of natural gas is determined by the formula:

$$B = q \cdot \rho, \tag{2}$$

where q is the annual volumetric flow rate of natural gas; ρ is the density of natural gas (mass density). The annual volumetric flow rate of natural gas is determined from the known value of the calculated natural gas flow rate q_h and the number of operating hours of the heat supply system . The calculated flow rate of natural gas burned in the heat supply system boiler is determined by the formula:

$$q_h = \frac{Q \cdot 3{,}600}{Q_{low} \cdot (\eta/100)}, \tag{3}$$

where Q – nominal thermal capacity of the boiler; Q_{low} – lower heating value of natural gas; η – boiler efficiency.

The nominal thermal output of the boiler Q is determined by the thermal load on the heat supply system Q_{DHS}. As mentioned above, the heat supply system for residential buildings covers the requirements of the heating Q_{HS} and hot water supply Q_{DHW} systems, with the heating system operating only during the heating season and the hot water supply system operating all year round. In calculations, the number of operating hours for the hot water supply system is taken as $N = 365$ days × 24 hours = 8,760 hours per year. The operating duration of the heating system depends on the city of construction, and the duration of the heating season for the selected city zop is determined from DSTU-N B V.1.1-27:2010 (2010). Then $N_w = z_w$ days × 24 hours, and the annual volume consumption of natural gas required for heat generation at the centralised heat supply source is determined by the formula, m³/year:

$$q = N_w \cdot q_h^{HS} + N \cdot q_h^{DWH}, \tag{4}$$

where q_h^{HS} and q_h^{DWH} are the calculated natural gas consumption rates required, respectively, for the heating system and the hot water supply system, determined using formula (3) for the heat load values Q_{HS}, and Q_{DHW}, respectively. The calculation of the heat load for the heating requirements of premises, groups of premises, flats and buildings is determined in accordance with DSTU EN 12831-1:2017 (2017).

Since gas-fired boilers are manufactured in specific increments of nominal heat output, the boiler model and, consequently, its Q are selected based on the nearest, not lower, value of the heat load on the heating system Q_{DHS}, i.e. $Q \geq Q_{DHS}$.

To determine emissions of pollutants and greenhouse gases into the air from the use of fuel for domestic purposes in households (for example, in individual heating systems), the methodology for calculating emissions of pollutants and greenhouse gases is used (Order of the State Statistics Committee of Ukraine No. 98, 2011). The methodology provides for the determination of emissions from the combustion of coal and coal briquettes, peat and peat briquettes, firewood, natural gas and liquefied petroleum gas. The calculation of emissions of pollutants and greenhouse gases from the use of fuel for domestic purposes in households is carried out using the formula:

$$B_j = M_{gi} \cdot A_j, \tag{5}$$

where B_j – emissions of the j-th pollutant and greenhouse gas from the use of the i-th type of fuel in households in settlements; M_{gi} – volumes of gas used in households by settlement; A_{ij} – average specific emissions of the j-th pollutant and greenhouse gas from the use of the i-th the j-th type of fuel in households; j – number of the pollutant and greenhouse gases. For centralised heating systems, the quantity of pollutants is determined using formula (1), and for individual heating systems – using formula (5).

The simplifications and assumptions made when determining pollutant emissions depend on the purpose and subject of the research. In such studies, the site is always linked to the construction location, so the duration of the heating season in that area is known. The characteristics of the heating system that influence the determination of emission quantities include the type of heating system (individual or centralised), the capacity of the heating system, the presence of systems served by the heating system (heating, hot water supply, ventilation, process requirements), their thermal load and operating duration, the type of heat-generating equipment, and the methods of regulating heat output in the heat supply system. The parameters of heat-generating equipment taken into account when determining the quantity of pollutant emissions are the amount of fuel used and the boiler's efficiency (efficiency coefficient).

The amount of fuel used to generate thermal energy depends on the fuel's physical and chemical properties, whilst the boiler's efficiency depends on its design and technical condition. Depending on the purpose of the study, the physical and chemical properties of the fuel may be taken as known average values for the industry, or determined in detail depending on its type, place of extraction, composition, etc. As can be seen from Equations (1), (2) and (3), the physicochemical parameters used in methodologies for calculating pollutant emissions are the lower heating value of the fuel and its density. In actual calculations of pollutant emissions, the type of heat-generating equipment is known, and consequently, the type of fuel it uses is known.

In theoretical calculations, particularly for selecting a heat source in heat supply systems, different types of heat-generating equipment using different types of fuel may be compared. Given the large number of determining factors that influence the thermal load of a heat supply system, and consequently the quantity of pollutant emissions, analytical studies require simplifications and assumptions to streamline the calculations.

It should be noted that the aforementioned methodologies use different terminology regarding emissions. In particular, the Sectoral Methodology for Calculating Harmful Emissions from Heat-Generating Plants of Ukraine's Municipal Heat and Power Sector uses the term "emissions of pollutants", whereas the Methodology for Calculating Emissions of Pollutants and Greenhouse Gases into the Air from Fuel Use for Household Needs uses a broader definition – "emissions of pollutants and greenhouse gases". In accordance with the definition in the Law of Ukraine No. 3991-IX (2024), the generalised term "anthropogenic emissions" is used in this study to unify approaches.

Results and Discussion

An environmental assessment is carried out to describe and evaluate the consequences of the choice of heat source for a 9-storey residential building. The building has two entrances, with 36 flats in each entrance, making a total of 72 flats in the building. There are eight flats on each floor: two one-bedroom flats, one two-bedroom flat, three three-bedroom flats and two four-bedroom flats. The building's envelope complies with the requirements of DBN V.2.6-31:2021 (2021). The heating supply system is designed to provide thermal energy for the building's heating and hot water supply systems. Heat flows for the heating and hot water supply of the residential building, as mentioned above, were determined in accordance with DBN V.2.5-64:2012 (2012) and DSTU EN 12831-1:2017 (2017). Preliminary calculations have established that heat losses in flats range from 1,483 to 3,531 W, depending on the number of rooms, the floor on which they are located, and so on. The total heat loss of the building is 193.415 kW. The maximum heat flux to the flat's hot water supply system was taken to be equal to the heat loss of that flat, and for the building it amounted to 237.581 kW. The total heat load on the building's centralised heat supply system is 430.996 kW.

The article considers two options for the building's heating system. The first option is individual heating from gas-fired combi boilers, which are installed in the kitchens of the building's flats. The boiler's heat output is taken as the sum of the flat's heat loss and the maximum heat flow to the hot water supply system. Since the standard sizes of combi boilers are available in specific increments, for one- and two-bedroom flats a boiler with the nearest nominal heat output of 6 kW was selected, and for three- and four-bedroom flats – with an output of 9 kW. Thus, the calculation established that the building is equipped with 27 boilers with a capacity of 6 kW and 45 boilers with a capacity of 9 kW. The second option is district heating, with the heat source being a boiler room equipped with a gas boiler, the capacity of which must be no less than the total heat load of the heating system. The gas boiler with a nominal heat output of 450 kW is the closest in terms of capacity.

The following simplifications and assumptions were taken into account in the studies. The city of construction is Lviv; therefore, according to DSTU-N B V.1.1-27:2010 (2010), the duration of the heating season, i.e. the duration of the heating system's operation, is 179 days, which equals $179 \times 24 = 4{,}296$ hours/year. During this period, the heat supply system provides thermal energy to the heating and hot water supply systems. The hot water supply system operates year-round; the duration of the non-heating period is $8{,}760 - 4{,}296 = 4{,}464$ hours/year. There is no regulation of heat transfer fluid flow, i.e. the boilers operate at their rated thermal load. Natural gas is used for combustion in the boilers, with a lower heating value of 33,078 kJ/m^3 and a density of 0.723 kg/m^3. The efficiency (η) of boilers for individual and district heating is 90%.

According to formula (3), the calculated natural gas consumption for individual heat supply, for combustion in boilers with a rated thermal output of 6 kW, is 0.72 m3/h, and for those with a rated thermal output of 9 kW, it is 1.08 m3/h. Taking into account the operating duration of the heating and hot water supply systems, as well as the calculated natural gas consumption, the gas consumption required by the building to generate thermal energy, according to formula (4), is 444,165.12 m^3/year. For the specified quantity of natural gas, the volumes of anthropogenic emissions generated during its combustion were determined using formula (5). The results of the calculations of pollutant gas emissions for individual heat supply to a residential building are summarised in Table 1.

Table 1. Volumes of anthropogenic emissions from individual heat supply to a building

Pollutant / greenhouse gas	Average specific emissions A_{ij}, kg/1,000 m^3	Emissions, kg/year	Emissions, t/year
CO	1.8	799.4972	0.799497
NO_2	2.088	927.4168	0.927417
SO_2	0.036	15.98994	0.01599
NMVOC	0.18	79.94972	0.07995
SN_4	0.108	47.96983	0.04797
N_2O	0.036	15.98994	0.01599
CO_2	1,981	879,891.1	879.8911

Source: compiled by the authors based on data from Order of the State Statistics Committee of Ukraine No. 98 (2011)

As shown in Table 1, the total amount of anthropogenic emissions generated annually from individual heat supply to flats is 881.78 t/year, including greenhouse gas emissions (CO_2, CH_4, N_2O) – 879.96 t/year. The main component of anthropogenic emissions from individual heat supply is carbon dioxide (CO_2), accounting for 879.89 t/year, or over 99.8% of total emissions. This is because natural gas consists mainly of methane (CH_4), and upon its complete combustion, the primary reaction product is CO_2. In addition to carbon dioxide, other pollutants and greenhouse gases are produced in small quantities. Nitrogen oxides (NO_x, accounted for as NO_2 in this study) are formed as a result of the oxidation of atmospheric nitrogen at high temperatures in the combustion zone. Carbon monoxide (CO) and non-methane volatile organic compounds (NMVOCs) are products of the incomplete combustion of natural gas. Methane (CH_4) in emissions indicates losses of unburned fuel, whilst nitrous oxide (N_2O) is formed in negligible quantities during high-temperature combustion. Sulphur dioxide (SO_2) is present in minimal concentrations due to the low sulphur content in natural gas.

For a district heating system during the heating season, the calculated natural gas consumption for combustion in a boiler with a rated thermal output of 450 kW, in accordance with formula (3), is 54.42 m^3/h. Additionally, the amount of gas required for the hot water supply system during the non-heating season is also taken into account, which is determined by formula (3) for a heat load of 237.581 kW. Taking into account the duration of operation of the heating and hot water supply systems over the year, the annual volume of natural gas for heat production in the district heating system is 362,024 m^3/year. The mass flow rate of natural gas for district heating is determined by formula (2) and equals $B = 261{,}745$ t/year. The lower heating value of natural gas is determined as:

$$0.723 \cdot 38{,}078 = 45{,}751\ MJ/kg.$$

Gross emissions of pollutants into the environment from district heating are determined separately for each pollutant using formula (1). The results of the calculations are summarised in Table 2.

Table 2. Volumes of anthropogenic emissions from district heating of a building

Pollutant / greenhouse gas	Emission factor, g/GJ	Emissions, t/year
CO	$248.75 \cdot 10^{-6}$	2.97879278
NO_x	$64.311 \cdot 10^{-6}$	0.7701272
CH_4	$1 \cdot 10^{-6}$	0.01197505
N_2O	$0.1 \cdot 10^{-6}$	0.0011975
CO_2	$58{,}748.13 \cdot 10^{-6}$	703.511579

Source: compiled by the authors based on data from Order of the Ministry of Construction of Ukraine No. 67 (2006)

As can be seen from Table 2, the total amount of anthropogenic emissions generated annually by the central heating boilers of the building is 707.27 t/year, of which greenhouse gas emissions (CO_2, CH_4, N_2O) account for 703.52 t/year. The calculation results show that when using district heating for a multi-apartment residential building, there are 881.78 – 707.27 = 174.51 t/year fewer anthropogenic emissions, in particular greenhouse gases (CO_2, CH_4, N_2O) are reduced by 879.96 – 703.52 = 176.44 t/year, i.e. emissions are reduced by 20.0%. A similar emission profile is observed with district heating. Carbon dioxide also accounts for the largest share of total anthropogenic emissions, whilst the contribution of other gases is comparatively insignificant. This is due to the fact that the mass of CO_2 produced during the complete combustion of natural gas exceeds the mass of other emission components by several orders of magnitude. Thus, the observed reduction in total anthropogenic emissions from district heating is primarily due to lower CO_2 emissions resulting from lower annual natural gas consumption compared to individual heating.

To determine the impact of the efficiency of district heating boilers on the quantity of pollutant emissions, anthropogenic emissions were calculated for efficiency values in the range of 70-90% in 5% increments. To this end, when determining the calculated gas consumption in Equation (3), the value of η was varied, whilst subsequent calculations using Equations (4), (2) and (1) were carried out without change. Figure 2 shows the values of anthropogenic emissions for district heating (DHS) depending on the boiler efficiency in the range of 70-90%, as well as the volume of anthropogenic emissions for individual heating (IHS) using boilers with an efficiency of 90%.

As can be seen from Figure 2, the efficiency of centralised heat supply boilers significantly influences the amount of pollutants generated during the combustion of natural gas in them. The lower the boiler efficiency, the greater the amount of anthropogenic emissions generated. Within this efficiency range, the highest level of anthropogenic emissions occurs at an efficiency of 70%, specifically 909.35 t/year. However, as can be seen from Figure 2, district heating systems with boilers having an efficiency of 75-90% produce fewer emissions than individual heating systems with boilers having an efficiency of 90%. This is because as boiler efficiency decreases, the natural gas consumption required to produce the same amount of thermal energy increases. Since carbon dioxide accounts for over 99% of anthropogenic emissions, an increase in natural gas consumption leads to a practically proportional increase in total emissions.

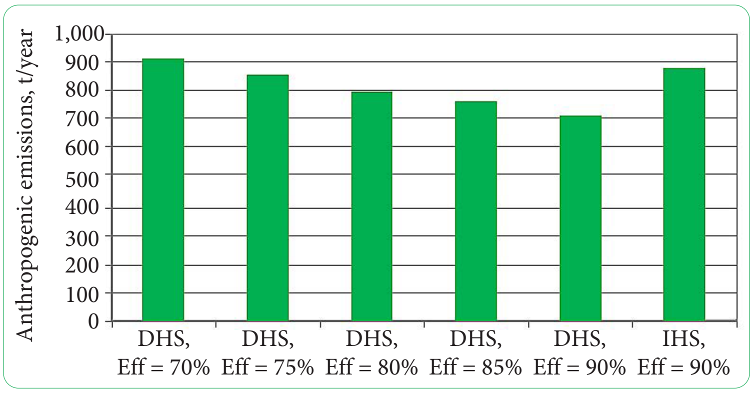

Figure 2. Volumes of anthropogenic emissions generated during the production of thermal energy by district heating (DH) and individual heating (IH) systems with different boiler efficiency values
Source: developed by the authors using Order of the Ministry of Construction of Ukraine No. 67 (2006) and Order of the State Statistics Committee of Ukraine No. 98 (2011)

It has been established that when the efficiency of a district heating boiler exceeds 72%, total anthropogenic emissions are lower than in the case of individual heating from gas boilers with an efficiency of 90%. The threshold value obtained is of practical significance in the preliminary assessment of the feasibility of using district heating and determines the minimum level of energy efficiency of boiler equipment at which a district heating system has an environmental advantage. The results presented were obtained for the assumed modelling conditions, which did not take into account heat losses in heating networks, variable boiler operating modes, and weather-dependent heat supply regulation. Taking these factors into account may affect the absolute emission values, but does not alter the established pattern of decreasing anthropogenic emissions as the efficiency of boiler equipment increases.

A comparison of the results obtained with studies by other authors confirms the advantages of centralised heat supply systems in reducing anthropogenic emissions, particularly greenhouse gases, compared to individual gas boilers, although efficiency depends on energy sources, regional and other factors. According to Q. Cai *et al.* (2024), energy consumption during the operation of a building's engineering systems – specifically heating, cooling, hot water supply and electricity supply systems – accounts for 94.4% of primary energy consumption over the building's life cycle. A.X. Malcher *et al.* (2025) noted that in the European Union, heating systems account for 42% of primary energy consumption and 15% of global pollutant emissions. Therefore, reducing the use of energy resources and, consequently, reducing anthropogenic emissions during the operation of a building's engineering systems is a key challenge for energy efficiency and decarbonisation.

In the work by A.X. Malcher *et al.* (2025), based on an analysis of 42 life-cycle assessment studies for 160 heating configurations, it is shown that cogeneration plants reduce emissions by 16-70% compared to traditional boilers, and heat pumps by an average of 64% compared to gas-fired ones. This is consistent with the results obtained, in particular the 20% reduction in anthropogenic emissions when switching to a centralised boiler plant with 90% efficiency, but highlights the greater potential when integrating renewable sources, which have not been taken into account in our case. Similarly, L. Balode *et al.* (2023), when analysing the potential for using renewable energy sources in one of Latvia's municipalities, found that district heating powered by gas has CO_2 emissions of 202 g/kWh, similar to individual gas boilers, but when renewable components, such as heat pumps, are added, the reduction reaches 72%. This indicates that the estimate obtained is a baseline scenario without decarbonisation, where the benefit of 176.44 t/year is lower than what is possible with the use of renewable energy sources.

In a study by S. O'Brien *et al.* (2025) for the Baltic region, a biogas cogeneration plant in a district heating system reduces annual emissions by 72.9% compared to natural gas cogeneration plants, with a focus on the life cycle, where embodied emissions are higher for waste heat (402,000 kg CO_2 eq versus 256,000), but operational emissions are lower. This complements the calculations of gross emissions obtained without a life-cycle assessment, demonstrating the potential for further reductions in the Ukrainian context. L. Ho (2022), in a UK context, reports a 3.2-fold reduction in emissions for district heating compared to individual gas boilers, citing the example of Nottingham, where emissions avoided amounted to 27,000 tonnes of CO_2 per year due to centralised energy generation from waste. Y. Ju *et al.* (2022) assessed the CO_2 reduction potential in district heating for a German demand-response system (a mechanism for flexible management of heat demand in district heating systems), focusing on savings, although without a direct comparison with individual systems.

J. Rey-Hernández *et al.* (2023) achieved a 92.69% reduction in CO_2 emissions for a Spanish campus with a biomass-fired district heating system, alongside a 96.19% saving in non-renewable primary energy. Due to the use of biomass, this significantly exceeds our 20%, but illustrates the potential for Ukraine with alternative fuels. H. Dorotić *et al.* (2021) highlighted the importance of allocation in cogeneration plants, where district heating reduces emissions to 0.04-0.09 t CO_2/MWh compared to 0.23 for individual gas boilers, i.e. almost five times less. Finally, in their study, F. Neirotti *et al.* (2020) conducted a life-cycle assessment for Italian networks, which showed that emissions from district heating amount to 0.10-0.47 kg CO_2 eq/kWh depending on allocation, compared to 0.27 for individual gas boilers. The authors emphasise the need to account for gas imports and other factors, but do not take network losses into account. Overall, the available studies confirm the findings regarding a reduction in anthropogenic emissions when using district heating, but point in particular to greater potential with alternative energy sources, which should be taken into account in future work for the Ukrainian context.

Conclusions

In Ukraine, roughly the same number of consumers use individual and district heating systems for heat production. To confirm the environmental sustainability of centralised heat supply systems compared to individual heat supply systems, an environmental assessment was carried out. The environmental assessment was conducted for heat supply systems that met the heating and hot water supply needs of a 72-apartment residential building. Individual gas-fired double-circuit boilers, installed in each flat of the residential building, were adopted as the heat source in individual heat supply systems, whilst in the centralised heat supply system, a single gas boiler was used in the heating plant.

The main components of anthropogenic emissions during the operation of heat supply systems, specifically during the combustion of natural gas in boilers, are carbon monoxide, carbon dioxide, nitrogen oxides, nitrogen dioxide, sulphur dioxide, methane and non-methane volatile organic compounds. The quantities of pollutant emissions and greenhouse gases released into the environment were determined using Ukrainian state methodologies. The environmental assessment found that individual heating of a residential building generates 881.78 t/year of anthropogenic emissions, of which 879.96 t/year are greenhouse gases, whereas centralised heat supply generates 707.27 t/year of anthropogenic emissions, of which 703.52 t/year are greenhouse gases. Consequently, the use of district heating in a residential building results in 176.44 t/year fewer greenhouse gas emissions than with individual heating, i.e. a 20.0% reduction in emissions is observed.

Lower greenhouse gas emissions from district heating compared to individual heating are also observed when the efficiency of the gas boiler in the boiler room decreases. A reduction in the boiler efficiency of the boiler house below 72% leads to an increase in greenhouse gas emissions compared to individual heat supply from gas boilers with an efficiency of 90%. When using district heating from gas boilers with an efficiency >73%, greenhouse gas emissions are lower than with individual heating from gas boilers with an efficiency of 90%. Therefore, in order to reduce the environmental impact when designing new and modernising existing heat supply systems, it is advisable to opt for centralised heat supply systems. Further research should involve an environmental assessment of centralised heat supply systems using alternative fuels.

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Conflict of Interest

None.

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Екологічна оцінка впливу джерел теплоти житлового будинку на забруднення атмосферного повітря

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Анотація. Реалізація заходів з енергоефективності має вирішальне значення для низьковуглецевого розвитку, надійного енергозабезпечення та енергетичної безпеки країни. Одним з кроків реалізації таких заходів є впровадження нових та модернізація існуючих систем централізованого теплопостачання, які дозволяють збалансувати ресурсокористування, зменшити викиди парникових газів у довкілля, спростити експлуатацію та технічне обслуговування будівель. Метою роботи було порівняння кількості викидів забруднюючих речовин та парникових газів, які утворюються під час виробництва теплової енергії індивідуальною та централізованою системами теплопостачання житлового будинку. Розглянуто 72-квартирний житловий будинок, огороджувальні конструкції якого відповідають сучасним теплотехнічним вимогам. У варіанті автономного теплопостачання джерелами теплоти були індивідуальні газові двоконтурні котли, тоді як у централізованій системі теплопостачання теплова енергія вироблялася газовою котельнею. Кількість викидів, які надходили у довкілля за індивідуального теплопостачання, було розраховано відповідно до «Методики визначення викидів забруднюючих речовин та парникових газів у повітря від використання палива на побутові потреби в домогосподарствах». Кількість викидів, які надходили у довкілля за централізованого теплопостачання, було розраховано відповідно до «Галузевої методики розрахунку шкідливих викидів, які надходять від теплогенеруючих установок комунальної теплоенергетики». До забруднюючих речовин та парникових газів, викиди яких враховують вказані методики, належать оксид вуглецю, діоксид вуглецю, оксиди азоту, діоксид азоту, діоксид сірки, метан та неметанові леткі органічні сполуки. Встановлено, що за індивідуального теплопостачання житлового будинку утворюється 881,78 т/рік антропогенних викидів, з них 879,96 т/рік парникових газів, а за централізованого теплопостачання утворюється 707,27 т/ рік антропогенних викидів, з них 703,52 т/рік парникових газів. Результати досліджень свідчать, що під час використання централізованого теплопостачання житлового будинку утворюється на 176,44 т/рік парникових газів менше, ніж за індивідуального теплопостачання, тобто спостерігається зменшення викидів на 20,0 %

Ключові слова: енергоефективність; система теплопостачання; газовий котел; природний газ; викиди; парникові гази; забруднюючі речовини