sciendo CzOTO 2023, volume 5, issue 1, pp. 204-211

GREEN BUILDINGS IN PURSUIT OF HEALTHY AND SAFE HUMAN LIVING ENVIRONMENT

doi: 10.2478/czoto-2023-0022
Date of submission of the article to the Editor: 15/11/2023
Date of acceptance of the article by the Editor: 06/12/2023

Zuzana Vranayova[1] – *orcid id: 0000-0003-1172-6248*
Tetiana Tkachenko[2] – *orcid id: 0000-0003-2105-5951*
Anna Lis[3] – *orcid id: 0000-0001-9497-5754*
Olena Savchenko[4] – *orcid id: 0000-0003-3767-380X*
Frantisek Vranay[1] – *orcid id: 0000-0003-4901-4377*
[1]Technical University of Košice, **Slovakia**
[2]Kyiv National University of Construction and Architecture, **Ukraine**
[3]Czestochowa University of Technology, **Poland**
[4]Lviv Polytechnic National University, **Ukraine**

Abstract: Emission of harmful substances into the atmosphere resulting from the combustion of fuels in the energy production process and road traffic intensity are a key determinants of poor air quality in cities and the creation of an unfriendly environment for people to live in, which has a significant impact on their safety and health. The first step to reducing emissions is to reduce energy consumption. The ecological effect resulting from the thermal modernization of existing residential building stock was estimated. Nature-based solutions were proposed to compensate for the lost green areas in favor of gray infrastructure in the form of green roofs and walls. The possibility of improving environmental conditions by introducing this type of solutions into the urban tissue was assessed. Depending on the type of vegetation, one m^2 of green cover is able to absorb an average of 2.3 kg of CO_2 and 0.2 kg of particulate matter from the air per year. Renewable energy sources are an important element of green buildings. Heat pump may be the most advantageous solution in minimizing emissions combined with low operating costs. Obtaining energy from geothermal sources would be equally beneficial in terms of reducing emissions, but there are risks changes in groundwater levels or soil damage. Solar energy is one of the leading renewable energy sources, especially in hot water installations, where it is possible to reduce energy consumption by up to 50%.
Keywords: living environment, air pollutants, green building, energy efficiency, NBS, RES.

1. INTRODUCTION

More than half of the world's population is concentrated in large urban centers. This creates many problems that have a direct impact on the quality and safety of life in this environment. Air pollution and noise come to the fore and are some of the basic environmental causes of poor health, illness and premature death (Cardinali et al., 2023; Cilliers et al., 2023; WHO, 2023). Nearly 90% of humanity is exposed to air pollution

concentrations exceeding certain standards (97% in case PM2.5, 76% in case PM10, 64% in case BaP), and over 6.5 million die annually because of it. Exposure to long-term noise causes 12,000 deaths per year only in Europe (EEA, 2023; WHO, 2023; World Air, 2023). High concentrations of harmful substances are mainly related to the combustion of fuels in the energy production process and road traffic intensity. In the EU, the construction sector consumes nearly 40% of final energy consumption, mainly for heating and cooling buildings. This is associated with approximately 36% of greenhouse gas emissions, as well as other harmful substances such as PM10 and PM2.5 or PAH (EEA, 2023; Energy, 2023; World Air, 2023). However, the data does not take into account actual emissions from construction, renovation, demolition or the production and disposal of materials.

The EU's building stock includes nearly 260 million buildings, most of them residential buildings, and their area accounts for 75% of the total. There are approximately 6.5 million residential buildings in Poland and over 1.2 million in Slovakia. Nearly 85% of the stock was built in the last century, and 42% of non-residential buildings and 38% of residential buildings were built before the widespread adoption of energy efficiency measures. It is estimated that 75% of buildings in Europe are energy inefficient (Energy, 2023; European Commission, 2020). The basic material of the urban tissue is the so-called gray infrastructure, but the lost green space can be compensated by introducing vegetation on roofs and walls. Implementing nature-based solutions (NBS) helps improve the resilience of cities, reduce emissions by eliminating the causes of global warming, and also has a positive impact on the quality of life and health of residents (Doan et al., 2023; Fonseca et al., 2023; Kuok Ho, 2023; Kuzior et al., 2022; Srbinovska et al., 2021).

Supporting the development of renewable energy sources is one of the key elements of sustainable development and the zero-emission program. Renewable technologies, which are clean, widely available and complementary energy sources in natural processes, minimize the negative impact on the environment both in terms of emissions and the amount of waste (El Badaoui and Touzani, 2022; Idzikowski and Cierlicki, 2021; Knut et al., 2023). Obtaining this form of energy is one of the priorities of the EU's climate and energy policy and has shown a clear upward trend in recent years. The share of energy from renewable sources in gross final energy consumption in 2020 was 17.3% in Slovakia and 16.1% in Poland (Energy from renewable, 2022. Both countries exceeded the national targets set by the EU in this regard. The share of renewable sources in Ukraine's energy mix was lower for now and amounted to 9.2%.

Due to the significant potential for energy modernization of buildings, which translates directly into improved air quality, an analysis was made of the possibility of reducing pollutant emissions into the atmosphere as a result of reducing energy consumption for heating residential buildings, which constitute the basis of the building stock. The energy and ecological effects of this type of activities were presented. Green roof and wall solutions were presented and their impact on improving the quality of the environment was assessed. The ability to reduce emissions by using selected solutions such as geothermal sources, heat pumps and solar collectors was estimated.

2. REDUCTION OF AIR POLLUTION AS A RESULT OF IMPROVING THE ENERGY PERFORMANCE OF BUILDINGS

The greatest potential for rationalizing energy consumption occurs in residential buildings, which are one of the main energy consumers in modern economies of developed countries. The energy quality of buildings depends on the period of their construction and

their current technical condition (Zhelykh, 2023). The analysis of the possibilities of reducing energy consumption in residential buildings, and thus pollutant emissions, clearly indicates the highest efficiency for activities undertaken in the field of space heating, which accounts for approximately 70% of the building's energy consumption. Based on data from the National Census of Population and Housing (National, 2013) and the long-term building renovation strategy (Long, 2022), as well as own research, a simplified quantitative characterization of the potential effects of activities reducing energy consumption for heating residential buildings was made on a Polish scale. The output value was the average value of the final energy demand index (EK). Since single-family buildings constitute over 90% of the analyzed structure of residential buildings, the target value for the estimated savings potential was the applicable value of the non-renewable primary energy (EP) index for single-family buildings, i.e. 65 kWh/(m^2year) less the value of the non-renewable primary energy index for non-renewable fuels. i.e. by 11%. The energy saving potential associated with thermally retrofitted activities of residential buildings is presented in Table 1.

Table 1
Energy saving potential related to thermal modernization of residential buildings

Years of construction	Number of buildings	Average EK value	Average demand	Demand difference	Reduction
		kWh/(m^2year)	PJ/year	PJ/year	%
before 1918	404,610	360	88.5	74.2	83.9
1918-1944	809,220	280	94.7	75.1	79.3
1945-1970	1,363,480	240	157.8	119.7	75.8
1971-1978	654,027	205	94.2	67.6	71.7
1979-1988	753,794	165	95.3	61.8	64.8
1989-2002	670,655	143	69.4	41.2	59.4
2003-2011	526,547	105	39.6	17.7	44.8

Source: (own research based on Long, 2022; National, 2013)

For approximately 5% of existing buildings, the date of their construction could not be determined. It has been evaluated that their average EK value is approximately 200 kWh/(m^2year). Their energy efficiency potential was estimated at 7.2 PJ/year.

The scale of the economic effect resulting from activities leading to a reduction in the energy consumption of buildings can be obtained by analyzing already carried out thermal modernization programs. The financial benefits resulting from investing in thermal modernization may exceed one and a half times the value of energy savings. Reducing the demand for energy for heating purposes will result in reduced emissions of pollutants, especially carbon dioxide, which is so harmful to the climate, and particulate matter, which is particularly dangerous for people. It was estimated that the possibilities of reducing CO_2 emissions resulting from the use of buildings by 2030 may amount to 3.7 Gt, of which China comes first with a 20% potential and the USA and Canada together with nearly 21%. Europe and Russia, however, have about 10% CO_2 reduction potential. Reducing emissions also has a direct impact on the economic effect in the form of lower costs related to treatment and sickness absence.

Taking as a basis the presented potential for reducing energy demand, the achievable ecological effect resulting from adapting the energy characteristics of residential buildings to the standards applicable in Poland in this area was determined.

Table 2
Ecological effect of improving the energy performance of residential buildings

Pollutants emitted into the atmosphere	Pollutants emission	Reduce of emissions
	thou. of tons	thou. of tons
Carbon dioxide	49,440,568	3,336,716
Methane	120.873	81.58
Non-methane VOC	102.769	69.36
Particulate matter $PM_{2,5}$	61.348	41.40
Particulate matter PM_{10}	103.756	70.02
Nitrogen oxides	67.506	45.56
Sulfur oxides	219.180	147.92
Carbon monoxide	1,622.308	1,094.89
Benzo(a)pyrene	0.1230266	0.08
Ammonia (NH_3)	0.510	0.34
Hexachlorobenzene	2.8	1.89
Dioxins and furans	134.9	91.04

Source: (own research)

3. REDUCTION OF AIR POLLUTION AS A RESULT OF IMPLEMENTING NBS

The walls and roofs of buildings occupy a significant part of the city's area, which can be used to create biologically active areas. Green walls and roofs, among others reduce heat losses from buildings, capture air pollutants, produce oxygen, absorb a specific range of sound waves, prevent excessive rainwater runoff, limit the urban heat island phenomenon, contributing to climate protection and improving human health safety (Azkorra-Larrinaga et al., 2023; Pongkua et al., 2023; Tan et al., 2023; Venuh et al., 2023). Based on research conducted in Kiev (Ukraine), significant opportunities were found to reduce CO_2 emissions while reducing energy demand for cooling buildings by greening the wall with wild grapes (Tkachenko et al., 2019a). It was estimated that the energy reduction for cooling with a wall thermal resistance of 3.3 $(m^2K)/W$ is approximately 8.1 kJ/m^2, taking into account the dependence of the cooling effect on wind speed. The cooling effect was on average 1.23 K. It was also found that in calm conditions the cooling effect of this structure was higher compared to the horizontal greening Lolium perenne by 0.478 K. Reducing the amount of energy translated into a reduction in CO_2 emissions. The demonstrated ecological effect concerns indirect emissions, without taking into account CO_2 absorption by plants. Calculations were made assuming the production of electricity from coal and gas for the entire cooling period. The CO_2 emission reduction for coal was 632 g/m^2 and 372 g/m^2 for gas. Depending on the type of plants used, a square meter of green wall can absorb an average of 2.3 kg of CO_2 from the air per year, which further enhances the ecological effect of such a solution.

Another analysis of the potential of green structures was related to reducing the harmful impact of emissions from heavy road traffic on the health safety of city residents through the implementation of green roofs (Tkachenko et al., 2019b). Field research was carried out in Kiev, at the level of a busy avenue (Exposition A) and on the roofs of two buildings located in its vicinity. One is a roof with a traditional covering (Exposition B), the other is a green roof, with various assortments of plants placed on its individual fragments. The first part of the roof (Exposition C) was planted with Calamagrostis epigejos, Salvia officinalis, Achillea millefolium, Tsuga canadensis, Coreopsis tinktoria, Berberis thunbergii,

Buxus sempervirens, Pinus mugo. On the second fragment (Exposition D) was placed Carex, Hosta and Hydrangea alba, and in the third (Exposure E) Lolium perenne. The CO_2 concentration level at individual measurement points is presented in Table 3.

Table 3
CO_2 concentrations at the tested exposures

Measurement points	Carbon dioxide concentration
	ppm
Exposition A - at avenue level, near the buildings	501
Exposition B - traditional roof without plants	452
Exposition C - inside	320
In the passage between Exposition C and D	415
Exposition E - inside	329
In the passage next to the Exposition E	410

Source: (own research)

Solutions inspired by nature on roofs and facades are most often found in city centers, mainly on new or modernized residential buildings. As research conducted in Kosice (Slovakia) has shown, promoting this type of solutions should be an important element of the revitalization of urban areas, especially industrial ones (Čákyová et al., 2023). It was proposed to transform a highly urbanized industrial area using NBS solutions extensively. Various types of green infrastructure were designed and constructed, including: green walls, plant roofs with various substrate thicknesses, extensive roofs, wet roofs or plant roofs in symbiosis with photovoltaics. The next step is to monitor the behavior of the constructed structures and their impact on the surroundings. The proposed solutions will make it possible to determine optimal procedures and solutions not only for Slovakia, but also for the climatically similar region of Central Europe.
The use of appropriate plant species on facades and roofs also allows for the reduction of compounds such as SO_2 or NOx. Research has shown that one square meter of green surface can absorb about 0.2 kg of particulate matter per year. Some plant species can also absorb harmful elements, including: heavy metals and incorporate them into your tissues (Vera et al., 2021; Ysebaert et al., 2021). An additional advantage is the production of oxygen. In the process of photosynthesis, one square meter of green surfaces produces approximately 1.7 kg of oxygen per year. Research has also shown that a 12 cm layer of plant substrate reduces the sound level to 40 dB, and a 20 cm layer to 50 dB.

4. REDUCTION OF AIR POLLUTION AS A RESULT OF THE USE OF RES

Roof and wall surfaces can also be a place to introduce renewable energy sources into urban space. Such infrastructure is the source of the so-called green energy consistent with the idea of climate neutrality. Its use translates directly into the elimination of emissions of harmful substances into the atmosphere. Solar energy is one of the leading renewable energy sources widely used to produce both heat and electricity (Shapoval et al., 2020; Voznyak et al., 2023). An analysis was made to assess the efficiency of solar energy use in hot water supply systems. Single-circuit thermosyphon solar systems for preparing domestic hot water were compared in selected cities in Poland: Częstochowa, Białystok, Lublin, Szczecin and Warsaw (Savchenko and Lis, 2021). The hot water installation was designed for a house with a daily hot water consumption of 80 l/day. The

auroTHERM classic VFK135/2D flat solar collector was proposed to receive solar radiation. The assumed cold water temperature was 5ºC in the cold period, 15ºC in the warm period, and the heating temperature was 50ºC. The use of a solar installation to heat water allowed us to save up to 50% of energy and thus reduce emissions compared to the use of conventional energy sources.

Geothermal waters are a valuable raw material used in many areas of the economy, and geothermal investments, compared to other renewable energy sources, are characterized by stable operation and constant production over time, regardless of weather conditions. Geothermal waters in the Lviv region are characterized by temperatures ranging from 90-95°C. The possibility of using these waters for district heating supply systems was considered (Lis and Savchenko, 2022). The optimal solution here is a "double" system where geothermal water from deep aquifers is transported to the surface through a receiving well and fed to the peak boiler room for heating, and then to the heat exchangers of heating and hot water systems to heat their coolants. After releasing the heat, the geothermal water is pumped back to the aquifers through an injection well. Two wells can provide from 0.4 to 4.5 MW of thermal energy.

The use of heat pumps is an energy-saving and therefore environmentally friendly solution that provides both heating and cooling. Under favorable technical conditions in the heat supply system, they are a solution that minimizes emissions and operating costs while ensuring thermal comfort conditions. The convenience of the system increases due to the ability to quickly switch between cooling and heating depending on conditions. The benefits of using a water-to-water heat pump in the energy supply system of an administrative building located in Kosice, Slovakia were assessed (Vranay et al., 2021). The building was selected as a model facility for gradual transformation into a green building, ultimately zero-energy, meeting the principles of sustainable development. With the introduction of a capillary heating and cooling system, the building reached the standard of an almost zero-energy building. Gradual adaptation of the building together with energy management shows energy savings of 71%. CO_2 emissions have been reduced by 98%.

5. CONCLUSION

Thanks to the implementation of the idea of green construction, tools are created to improve human safety in the urban environment, both at the stage of the production process (production of building materials, implementation of construction works) and during the operation of already constructed facilities (Sonkar et al., 2023; World Green, 2021). The basis here is the improvement of the energy characteristics of existing building by thermal modernization. Based on the presented analysis, a significant potential for increasing energy efficiency in this area was demonstrated, which will translate directly into the amount of avoided emissions of harmful substances into the atmosphere. Only by adapting the parameters related to thermal protection of residential buildings in Poland to the applicable requirements could emissions be reduced by 70%. Nature-based solutions are the next step towards green buildings. The research presented above indicates the advisability of implementing green walls and roofs in the urban fabric, both in connection with the possibility of reducing emissions by intensifying the process of cooling buildings and limiting heat losses, as well as in the process of capturing harmful substances from the environment. It is estimated that m2 of green cover is able to absorb an average of 2.3 kg of CO_2 and 0.2 kg of particulate matter from the air per year. Both Slovakia, Poland

and Ukraine have significant potential for the development of renewable energy, but Slovakia is currently leading in the share of energy from renewable sources in final energy consumption. Green energy is widely available, replenished on an ongoing basis in natural processes and emission-free. As indicated in the examples presented, the use of renewable energy sources eliminates the problem of concentration of substances dangerous to humans in the urban environment. The development of technology will allow us to reduce costs and intensify the implementation of these solutions.

REFERENCES

Azkorra-Larrinaga, Z., Erkoreka-González, A., Martín-Escudero, K., Pérez-Iribarren, E., Romero-Antón, N., 2023. *Thermal characterization of a modular living wall for improved energy performance in buildings*, Building and Environment, 234, 110102, DOI: 10.1016/j.buildenv.2023.110102.

Čákyová, K., Vertal, M., Vargová, A., Vranayová, Z., Lis, A., 2023.*Transforming urban areas in accordance with the principles of Nature-Based Solutions,* Construction of Optimized Energy Potential, 12, 94-106, DOI: 10.17512/bozpe.2023.12.11.

Cardinali, M., Balderrama, A., Arztmann, D., Pottgiesser, U., 2023. *Green walls and health: An umbrella review*, Nature-Based Solutions, 3, 100070, DOI: 10.1016/j.nbsj.2023.100070.

Cilliers, E. J., Ghosh, S., Ndaguba, E. A., 2023. *Reclaiming Healthy Cities Through Nature-Based Planning Solutions.* In: Biloria, N., Sebag, G., Robertson, H. (eds) The Empathic City. An Urban Health and Wellbeing Perspective, Springer, Cham.

Doan, D.T., Kumarasiri, B., Ghaffarian Hoseini, A., 2023. Green Building. In: Brinkmann, R., (eds.) The Palgrave Handbook of Global Sustainability. Palgrave Macmillan, Cham.

EEA European Environment Agency. Available with: www.eea.europa.eu (24.11.2023).

El Badaoui, M., Touzani, A, 2022. *AHP QFD methodology for a recycled solar collector*, Production Engineering Archives, 28(1), 30-39, DOI: 10.30657/pea.2022.28.04.

Energy. European Commission, Available with: https://ec.europa.eu/energy/ (24.11.2023).

Energy from renewable sources, 2022. Statistics Poland, Warsaw.

European Commission, 2020. *A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives*, COM 662.

Fonseca, F, Paschoalino, M, Silva, L., 2023. *Health and Well-Being Benefits of Outdoor and Indoor Vertical Greening Systems: A Review*, Sustainability, 15(5), 4107, DOI: 10.3390/su15054107.

Idzikowski, A., Cierlicki, T., 2021. *Economy and energy analysis in the operation of renewable energy installations - a case study*, Production Engineering Archives, 27(2), 90–99, DOI: 10.30657/pea.2021.27.11.

Knut, P., Kocúrková, M., Vranayová Z., 2023. *Biosolar panels: An innovative solution for sustainable construction*, Construction of Optimized Energy Potential, 12, 172-181, DOI: 10.17512/bozpe.2023.12.19.

Kuok Ho, D. T., 2023. *Green walls as mitigation of urban air pollution: A review of their effectiveness*, Research in Ecology, 2(5), 5710, DOI:10.30564/re.v5i2.5710.

Kuzior, A., Vyshnevskyi, O., Trushkina, N., 2022. *Assessment of the impact of digitalization on greenhouse gas emissions on the example of EU Member States.* Production Engineering Archives, 28(4), 407-419, DOI: 10.30657/pea.2022.28.50.

Lis, A., Savchenko O., 2022. *Possibilities of using the energy potential of geothermal waters in the case of Poland and Ukraine*, Construction of Optimized Energy Potential, 11, 181 - 194, DOI: 10.17512/bozpe.2022.11.21.

Long-term building renovation strategy, 2022. Council of Ministers, Warsaw.
National Census of Population and Housing from 2011, 2013. Statistics Poland, Warsaw.
Pongkua, W., Sriprapat, W., Thiravetyan, P., Treesubsuntorn, Ch., 2023. *Active living wall for particulate matter and VOC remediation: potential and application*, Environmental Science and Pollution Research, 30, 37428325, DOI: 10.1007/s11356-023-28480-2.
Savchenko, O., Lis, A., 2021. *Efficiency of solar energy use in domestic hot water systems in Poland*, Construction of Optimized Energy Potential, 10(2), 45-52, DOI: 10.17512/bozpe.2021.10.06.
Shapoval, S., Zhelyh, V., Venhryn, I., Myroniuk, K., Hensetskyy, M., 2020. *Examination of the thermal efficiency of the solar collector integrated into the light transparent building façade*, Theory and Building Practice, 2(1), 30-37, DOI: 10.23939/jtbp2020.01.030.
Sonkar, A., Kumar, M., Gupta, R., Dixit, D., Rahul, R., 2023. *Review on green building*, International Journal of Scientific Research in Engineering and Management, 7(4), DOI: 10.55041/IJSREM18766.
Srbinovska, M.; Andova, V.; Mateska, A.; Krstevska, M., 2021. *The effect of small green walls on reduction of particulate matter concentration in open areas*, Journal of Cleaner Production, 279, 123306, DOI: 10.1016/j.jclepro.2020.123306.
Tan, T., Kong, F., Yin, H., Cook, L. M., Middel, A, Yang, S., 2023. *Carbon dioxide reduction from green roofs: A comprehensive review of processes, factors, and quantitative methods*, Renewable and Sustainable Energy Reviews, 182, 113412, DOI: 10.1016/j.rser.2023.113412.
Tkachenko, T., Mileikovskyi, V., Hunchenko, O., 2019a. *Assessment of energy savings and indirect reduction of CO_2 emissions by vertical gardening,* Ventilation Illumination and Heat Gas Supply, 31, 16-23, DOI: 10.32347/2409-2606.2019.31.16-23.
Tkachenko, T., Mileikovskyi, V., Ujma, A., 2019b. *Field Study of Air Quality Improvement by a "Green Roof" in Kyiv*, System Safety: Human - Technical Facility - Environment, CzOTO, 1(1), 419-424, DOI: 10.2478/czoto-2019-0054.
Venuh, Z., Thaneshwari, T., Raut, S., Kombey, P., 2023. *Green wall for healthy and sustainable urban society: A review*, Journal of the Greens and Gardens, 5(15-16), 1-9.
Vera, S., Viecco, M., Jorquera, H., 2021. *Effects of biodiversity in green roofs and walls on the capture of fine particulate matter*, Urban Forestry & Urban Greening, 63, 127229, DOI: 10.1016/j.ufug.2021.127229.
Voznyak, O., Spodyniuk, N., Antypov, I., Dudkiewicz, E., Kasynets, M., Savchenko, O., Tarasenko, S., 2023. *Efficiency Improvement of Eco-Friendly Solar Heat Supply System as a Building Coating*, Sustainability, 15(3), 2831, DOI: 10.3390/su15032831.
Vranay, F., Vranayova, Z., Lis. A., 2021. *Building´s heat potential on resources in respect to CO_2 emissions and primary energy reduction*, Materials Science and Engineering, 1203, 022139, DOI: 10.1088/1757-899X/1203/2/022139.
WHO World Health Organization, 2023. *Air quality and healt*h, WHO*, Geneva.*
World Green Building Trends, 2021. Dodge Construction Network Research, Bedford.
World Air Quality Report 2022, 2023.IQAir, Goldach.
Ysebaert, T., Koch, K., Samson, R. & Denys, S., 2021. *Green walls for mitigating urban particulate matter pollution. A review*, Urban Forestry & Urban Greening, 59, 127014, DOI: 10.1016/j.ufug.2021.127014.
Zhelykh, V., 2023. *Characteristics of heat exchange in the energy-efficient exterior wall of a passive house*, Construction of Optimized Energy Potential, 12, 143-153, DOI: 10.17512/bozpe.2023.12.16.