DOI: 10.2478/sspjce-2025-0013

Green Building as a Solution of Climate Change

Elisaveta Luzay[1], Diana Shafieva[1], Štefan Petkanič[2], Peter Serfözö[2], Martina Zeleňáková[2*]

[1]Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia
[2]Technical University of Kosice, Faculty of Civil Engineering, Institute for Sustainable and Circular Construction, 042 00 Kosice, Slovakia
[*]e-mail: martina.zelenakova@tuke.sk

Abstract

Humanity during its existence seriously harms the world around it. One of the negative consequences of thoughtless human activity is the global warming. There are many physical reasons for this, one of them is uncontrolled emissions of harmful gases into the atmosphere, which entail a greenhouse effect. It is investigated that a large contribution to the heat emissions into the atmosphere is made by construction activity. In this article, we propose to use green walls as an effective solution to increase the energy efficiency of buildings by reducing heat emissions from them, which, accordingly, will improve the quality of the atmosphere. We analyzed different green wall systems, their characteristics and we have measured the internal and external temperatures. The result of the experiment showed that the best thermal performance was observed in the green wall module with sandy substrate with vegetation. The use of this system allows to reduce temperature by several degrees, depending on the type of vegetation. The green wall module demonstrated the highest thermal performance. This system can lower temperatures by several degrees, depending on the plant species used. For optimal thermal effectiveness, the substrate should retain enough moisture to support healthy plant growth, but not so much that it leads to consistently high thermal conductivity from oversaturation. Green walls are environmental elements of urban infrastructure that help inhabited cities reduce, in particular, the effects of their warming due to the climate change.

Keywords: green building, climate change, green wall systems

1 Introduction

Global warming is one of the most troubling problems of humanity. Climate change affects everyone on the planet and can completely change our habitat. For example, a rise in the average annual temperature leads to glacier melting and a rise in global sea levels and flooding of the lower territories. This also disrupts natural ecosystems, causing shifts in rainfall and snowfall patterns, temperature extremes, heat islands occurring and more frequent severe events like hurricanes, floods, and droughts and natural hazards occurrence. Scientists report that during the last decades, the planet's average temperature was 1.5 °C higher than the average recorded in the 19th century, when global temperature monitoring began. This marked the first time in modern history that the one-degree increase threshold was surpassed. Increasing temperature and earth warming happens when carbon dioxide (CO_2) and other airborne pollutants

accumulate in the atmosphere, absorbing sunlight and heat that would normally reflect off our planet surface and escape into space. People are responsible for the emission of large amounts of greenhouse gases due to their activity: the burning of carbonaceous fossil fuels (i.e., oil, gas, coal, etc.), industrial processes, and the deforestation of forests, which are the natural absorbers of carbon dioxide from the atmosphere. Also a large amount of heat comes from buildings. Buildings and their construction together account for 36 percent of global energy use and 39 percent of energy-related carbon dioxide emissions annually, according to the United Nations Environment Program [1]. Energy is consumed during the following activities:
manufacturing of building materials - "embedded" energy;
the transportation of materials from manufacturing sites to construction locations involves what's known as "grey" energy;
the building process itself consumes what is referred to as "induced" energy;
the energy used during the building’s life for daily functions is called "operational" energy; e) the energy involved in the building's demolition and the recycling of its components, when applicable.
Research indicates that more than 80% of greenhouse gas emissions occur during the operational phase, driven by energy demands for heating, ventilation, air conditioning, water heating, lighting, and the use of electronic devices for entertainment and communication [2,3,4]. In contrast, only about 10 to 20% of energy use is attributed to the production and transport of materials, construction, maintenance, and demolition activities. Without large-scale intervention, carbon emissions from buildings are projected to double by 2050 [5]. As the majority of these emissions stem from energy consumption, the most immediate and straightforward strategy to reduce them is through energy-efficient building design.
Emissions can be reduced by an effective energy consuption design. One of the brightest and most effective solutions is green building, namely the use of green walls in construction to increase the energy efficiency of buildings, which will subsequently reduce heat emissions.
There are many methods of increasing energy efficiency of buildings. The main purpose of this study is to evaluate the reduction of heat loss at the buildings with green walls.
To reach this goal, the following tasks were planned:
- explore different green wall systems;
- identify how they reduce heat loss;
- develop data of heat reduction of different systems;
- compare results of heat reduction of different systems;
- identify the most effective green wall system;
- make the conclusions about evaluated green wall systems.

2 Methods

In this article we have evaluated the energy efficiency of using green walls in building construction. The article presents data on various systems of greening walls and used methods of comparative analysis, as well as measurements of average internal temperatures of the models. For making sense of this issue, we have analyzed the main systems of green walls and the components' impact on reducing heat loss. There are three main types of green wall systems: modular, hydroponic and container systems (Figure 1).

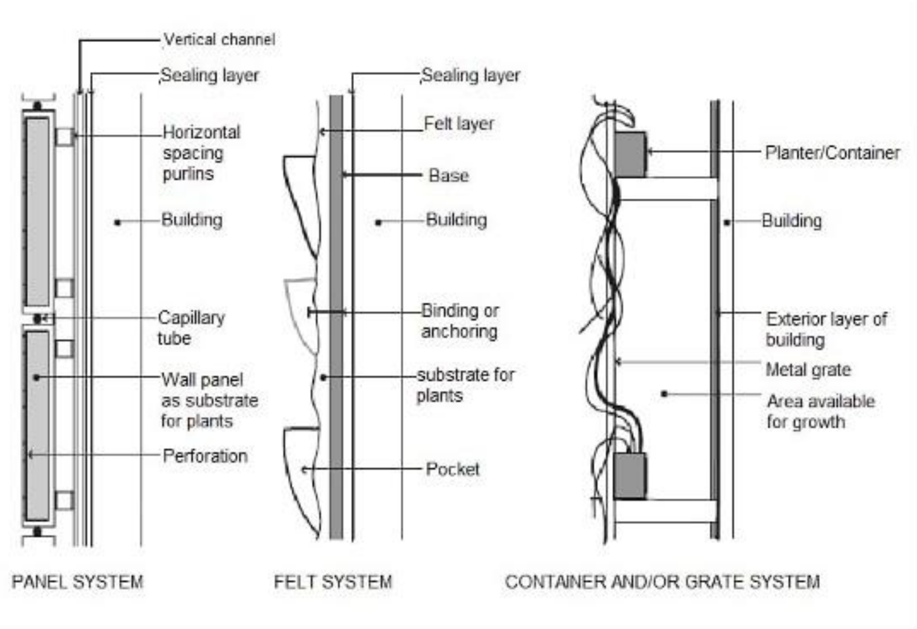

Figure 1: The structures of the three types living wall systems

Modular systems use panels filled with growing material that supports plant growth. This material supplies nutrients, and water is provided through irrigation systems placed at different heights on the wall. These systems usually come with plants already growing and can be installed on both indoor and outdoor surfaces, like in Figure 2.

Figure 2: Modular systems at Simferopol airport (author: Elisaveta Luzay, 2021)

Hydroponic systems are quite thin even in multiple layers. The type of plants on the mat should be limited because the thin mat cannot support too high plants. There is a waterproof membrane between the mat and the building surface for the high moisture within the mat. The nutrients are provided through the irrigation system which water cycle circulation from top to bottom.
Container systems grow plants in pots or containers, with the plants climbing up trellises. Drip irrigation lines are typically used to manage watering and feeding [6].
The fundamental principles behind green systems that help regulate temperatures are consistent for both indoor and outdoor environments. Green wall systems contribute to lowering both interior and exterior temperatures, support energy efficiency, and help reduce the urban heat island effect through several key mechanisms.
One such mechanism is humidity regulation: in dry conditions, plants enhance evaporation, while in humid environments, water vapor condenses on the cooler leaf surfaces. Through the process of evapotranspiration, a significant portion of solar radiation is transformed into latent heat, resulting in a temperature drop around the building—this is known as "evaporative cooling." The effectiveness of this cooling process depends on the plant species used and the surrounding climate.
The amount of solar radiation reaching the exterior wall surface decreases exponentially as the density of foliage increases. This density is commonly measured using the Leaf Area Index (LAI), which represents the ratio of total leaf surface area to a given unit area of façade or ground. LAI also reflects additional plant characteristics, including leaf size, the thickness of the plant layer, and overall vegetation density.
The amount of solar radiation transmitted to the exterior wall surface decreases exponentially with foliage density, which is typically expressed with leaf area index (LAI) [7,8]. According to Grabowiecki et al. (2017) [9] plant layers with dense foliage—indicated by high leaf area indices—and leaves oriented parallel to the wall, which corresponds to high attenuation coefficients, are generally the most effective at lowering façade surface temperatures and reducing heat transfer through the building envelope. The most important heat-related properties of the soil are its reflectivity (albedo), its ability to store heat (thermal capacity) and how easily heat moves through it (thermal conductivity).
The "albedo" coefficient is the reflection power of a surface, and varies depending on the basic color of the soil, the roughness of the surface and the inclination of the incident radiation in relation to the surface. The drier, brighter and softer the soil surface, the higher the albedo and the lower the surface temperature, while dark soils absorb more heat than soft, light-colored soils and therefore heat up faster. Thus, the more a surface reflects radiation energy, the less it heats up and the greater its albedo [10].
Thermal capacity is defined as the amount of heat that a body needs to receive or give in order for its temperature to vary by one unit. In summary, green wall materials naturally have more mass and, as a result, they need more thermal energy for the temperature to vary, and this factor varies mainly depending on the density of the solid phase of the substrate, the apparent density and soil moisture [10].
The thermal conductivity represents the amount of heat transferred through a unitary area of the conducting body in unit time under a unitary temperature gradient, it depends particularly on the soil moisture content, porosity and the thermal conductivity of the solid fraction [10].
The green layer creates shading effect, reducing how much solar radiation the bare wall absorbs. Using plants for shading lowers the temperature difference between the inside and outside surfaces of buildings. This means less heat passes through the walls, less air leaks inside, and

the building uses less energy overall [11]. Hoyano (1988) studied the shading effect of Ivy cover on a concrete building in Tokyo, with the existence of plants, the external surface temperature of the west facing wall was reduced by 18% and the indoor air temperature by 7°C [12].
The design of green walls can be varied depending on the substrate, the type and position of the plant and drainage system devices. Each of these components can influence the thermal potential of walls. The objective of this article is to identify how the components of the systems impact on their effectiveness, as well as identify possible relations between different substrates of models, substrate temperature and internal temperature of structures. We have studied 4 models of green walls:

M1 - Model of green wall module with sandy substrate without vegetation;
M2 - Model of green wall module with sandy substrate with vegetation;
M3 - Model of green wall module with organic matter substrate without vegetation;
M4 - Model of green wall module with substrate of organic matter with vegetation.

Statistical analysis was conducted for each hour of the day, totaling 24 analyses, with 30 repetitions (days) and 4 treatments per analysis. The difference in texture among the substrates is crucial to understand how each type of soil affects the thermal performance of green walls, given that they have distinct physical and chemical properties. The modules used measured 1m by 1m, varied in configuration, and featured different vegetation systems. To monitor both internal and surface temperatures of the prototypes, capacitive and digital sensors (AM2302 DHT-22 and DS18B20) were utilized, all connected to an Arduino Mega microcontroller.

3 Results and discussion

In order to be able to clearly analyze which models actually have significantly different thermal performance, we have analyzed the data, presented in the Table 1 below, which contains the results of the statistical analysis of the average temperatures that are displayed according to each hour of the day.

Table 1: Average internal temperature of the models throughout the day.

Hour	M1	M2	M3	M4
00:00 - 01:00	10	10	20	10
01:00 - 02:00	10	10	20	10
02:00 - 03:00	10	10	20	9
03:00 - 04:00	9	9	9	9
04:00 - 05:00	9	9	9	9
05:00 - 06:00	9	9	9	9
06:00 - 07:00	9	9	9	9
07:00 - 08:00	10	10	10	10
08:00 - 09:00	11	11	11	11
09:00 - 10:00	13	12	12	12
10:00 - 11:00	15	14	14	14
11:00 - 12:00	18	17	18	18

12:00 - 01:00	16	16	16	16
01:00 - 02:00	17	17	17	17
02:00 - 03:00	18	17	18	18
03:00 - 04:00	18	17	18	18
04:00 - 05:00	18	17	18	18
05:00 - 06:00	17	16	17	17
06:00 - 07:00	16	15	16	15
07:00 - 08:00	14	14	14	14
08:00 - 09:00	13	13	13	13
09:00 - 10:00	12	12	12	12
10:00 - 11:00	11	11	11	11
11:00 - 00:00	11	11	11	11
Daily average	13.1	12.8	14.3	12.9

(M1 - Model of green wall module with sandy substrate without vegetation, M2 - Model of green wall module with sandy substrate with vegetation, M3 - Model of green wall module with organic matter substrate without vegetation, M4 - Model of green wall module with substrate of organic matter with vegetation).

The prototype vegetation on the sandy substrate (M2) proved suitable for reducing external temperatures, retaining heat in the prototype during the coldest times of the day. This is explained by the phenomenon of thermal inertia, where it takes time to exchange thermal energy between the indoor and outdoor environment, which explains that heat absorbed during the day is released during the night. Table 1 shows that the substrate with vegetation (M2) tends to have lower temperatures compared to the one without vegetation (M1). This can be explained by benefits of vegetation layer, which helps lower the temperature through evaporation, adds mass to increase termal inertia, reduces termal conductivity due to the air between the plants, provides shading, and ultimately reduce direct sunlight on the surface, leading to a higher albedo [13].
During periods of higher temperature, the prototype organic matter substrate with vegetation (M4) had higher internal temperature than the prototype sandy substrate with vegetation (M2), with significantly lower water retention capacity. It is because of the naturally lower apparent density of the organic matter substrate (0.29 g/cm^3) compared to the sandy substrate (1.47 g/cm^3), which contributes to the initially lower thermal inertia of the system. The main reason, however, lies in connection with another physical property - thermal conductivity. Since water entering the soil pores tends to occupy the space previously filled by air, which is a more efficient insulator than water, the average thermal conductivity of soil tends to increase, overriding the benefits gained by thermal inertia. As an example, Sailor, Hutchinson, and Bokovoy (2008) [14] found that for saturated soils the thermal capacity and thermal conductivity increase by 40% and 100%, respectively, compared to dry soil. They suggest that soil with high water - holding capacity is not ideal for thermal insulation because, as moisture content increases, thermal conductivity rises 2.5 times faster than thermal inertia. This makes sandy soil, with its high porosity and low water retention, better for thermal performance. Because higher water relation is not ideal for thermal insulation, the M4 prototype – made of organic matter and vegetation is expected to perform as well as or better than the others, since it retains the least water. But it wasn't, because of the very low apparent density of this substrate (0.29 *g/cm^3*), which consequently contributes to the lowest heat capacity among the substrates used.

4 Conclusion

The application of green walls is primarily attributed to their ability to influence heat transfer between a building's interior and exterior environments. Key external factors that affect heat transfer through a building's façade include solar and thermal radiation from the atmosphere and ground, air temperature, and relative humidity. This results in reduced heat transfer through the façade, leading to decreased energy consumption for heating and cooling. Research on energy-efficient technologies and green building practices is being conducted by scientists worldwide [15-33].

In general, the plant layer serves as an additional thermal insulation barrier and enhances the thermal performance of a building façade by:

Shading the exterior wall from incoming solar radiation.

Cooling the temperature of the air adjacent to the exterior wall.

Enhancing the thermal insulation value of the exterior wall, especially when the vegetated façade includes a layer of planting medium (such as soil or inorganic media) placed along the façade.

It was involved by this experiment that are models with different substrate can effect on thermal properties of the wall in decreasing order: the sandy vegetation substrate (M2); organic matter substrate with vegetation (M4); sandy substrate while not vegetation (M1); organic matter substrate without vegetation (M3).

Relating to physical characteristics, thermal conduction seems to be a more relevant issue than meter thermal capability (thermal inertia). Finally, as for the substrate to provide ideal thermal performance, it should retain just enough water to support plant growth, but not so much that it stays saturated and increases heat conduction.

Acknowledgments

This work was supported by the Slovak Research and Development Agency under contract no. APVV-20-0281, APVV SK-BG-23-0015 and a project funded by the Ministry of Education of the Slovak Republic VEGA/0588/24 "Research of extreme hydroclimatic phenomena in watersheds and mitigation proposals in the context of natural based solutions".

References

[1] Global Alliance for Buildings and Construction. (2019). *Global Status Report for Buildings and Construction 2019*. Retrieved date of access, from https://www.iea.org/reports/global-status-report-for-buildings-and-construction-2019

[2] Junnila, S. (2004). *The Environmental Impact of an Office Building Throughout its Life Cycle*. Helsinki: Helsinki University of Technology.

[3] Ferrara, D. S., Tedeschi, L., Frison, G., Brusini, G., Rizk, D. E. E., Bener, A., Ezimokhai, M., Hassan, M., Micallef, R., Suzuki, M. & Oka, T. (1998). Estimation of life cycle energy consumption and CO_2 emission of office buildings in Japan. *Energy and Buildings*, 28, 159–166. DOI: 10.1016/S0378-7788(98)00010-3.

[4] Adalberth, K., Almgren, A. & Petersen, E. H. (2001). Life cycle assessment of four multi-family buildings. *International Journal of Low Energy and Sustainable Buildings*, 2, 1–21.

[5] Curbed. (2019). *Buildings and carbon emissions*. Retrieved date of access, from https://archive.curbed.com/2019/9/19/20874234/buildings-carbon-emissions-climate-change

[6] Hui, S. C. M. & Zhao, Z. (2013). Thermal regulation performance of green living walls in buildings. *Vertical Greenery Systems (VGS) for Energy Saving in Buildings*.

[7] Cuce, E. (2016). Thermal regulation impact of green walls: An experimental and numerical investigation. *Applied Energy*. DOI: 10.1016/j.apenergy.2016.09.079.

[8] Schmidt, M. (2020). *Influence of the composition of the substrate on the thermal performance of green roofs*. Dissertation, State University of Western Paraná, Cascavel, Brazil. Retrieved from http://tede.unioeste.br/handle/tede/4991

[9] Grabowiecki, K., Jaworski, A., Niewczas, T. & Belleri, A. (2017). Green solutions – climbing vegetation impact on building – energy balance element. *Energy Procedia*, 111, 377–386. DOI: 10.1016/j.egypro.2017.03.199.

[10] Hoyano, A. (1988). Climatological uses of plants for solar control and the effects on the thermal environment of a building. *Energy and Buildings*, 11(1–3), 181–199.

[11] Tolderlund, L., Bousselot, J., Russell, V., Celik, S., Retzlaff, B., Morgan, S., Buffam, I., Coffman, R., Williams, J., Mitchell, M., Backer, J. & DeSpain, J. (2020). Green Roof Research in North America: A Recent History and Future Strategies. *Journal of Living Architecture*, 7(1). DOI: 10.46534/jliv.2020.07.01.027.

[12] Sailor, D. J., Hutchinson, D. & Bokovoy, L. (2008). Thermal property measurements for ecoroof soils common in the western U.S. *Energy and Buildings*, 40(7), 1246–1251. DOI: 10.1016/j.enbuild.2007.11.004.

[13] Coma, J., Perez, G., de Gracia, A., Burés, S., Urrestarazu, M. & Cabeza, L. F. (2017). Vertical greenery systems for energy savings in buildings: A comparative study between green walls and green facades. *Building and Environment*, 111, 228–237. DOI: 10.1016/j.buildenv.2016.11.014.

[14] Lam, T., Vu, T., Dien, V., Korol, E. & Bulgakov, B. (2019). Properties and thermal insulation performance of light-weight concrete. *Magazine of Civil Engineering*, 84, 173–191. DOI: 10.18720/MCE.84.17.

[15] Bevilacqua, P., Mazzeo, D., Bruno, R. & Arcuri, N. (2016). Energy performance of green roofs. *Energy and Buildings*, 122. DOI: 10.1016/j.enbuild.2016.03.062.

[16] Bevilacqua, P., Mazzeo, D. & Arcuri, N. (2018). Thermal inertia assessment of an experimental extensive green roof in summer conditions. *Building and Environment*, 131, 264–276. DOI: 10.1016/j.buildenv.2017.11.033.

[17] Bevilacqua, P., Mazzeo, D., Bruno, R. & Arcuri, N. (2017). Surface temperature analysis of an extensive green roof for the mitigation of urban heat island in southern Mediterranean climate. *Energy and Buildings*, 150, 318–327. DOI: 10.1016/j.enbuild.2017.05.081.

[18] Dunichkin, I., Naboni, E., Korobeinikova, A. & Poddaeva, O. (2019). Issues of wind mode visualization and pedestrian comfort assessment when designing residential buildings on sloping territories in the Arctic zone. *SHS Web of Conferences*, 64, 03013. DOI: 10.1051/shsconf/20196403013.

[19] Korol, E. & Shushunova, N. (2016). Benefits of a modular green roof technology. *Procedia Engineering*, 161, 1820–1826. DOI: 10.1016/j.proeng.2016.08.673.

[20] Korol, E. & Shushunova, N. (2016). Research and development for the international standardization of green roof systems. *Procedia Engineering*, 153, 287–291. DOI: 10.1016/j.proeng.2016.08.117.

[21] Korol, E., Shushunova, N. & Rerikh, S. (2019). New green roof and green wall systems for implementation in the coverings. *E3S Web of Conferences*, 97, 06023. DOI: 10.1051/e3sconf/20199706023.

[22] Korol, O., Shushunova, N., Lopatkin, D., Zanin, A. & Shushunova, T. (2018). Application of high-tech solutions in ecodevelopment. *MATEC Web of Conferences*, 251, 06002. DOI: 10.1051/matecconf/201825106002.

[23] Hao, X. & Lin, Y. (2019). Experimental investigation on the thermal performance of a vertical greening system with green roof in wet and cold climates during winter. *Energy and Buildings*, 183, 105–117. DOI: 10.1016/j.enbuild.2018.10.038.

[24] Abd Ghafar, A., Kabiru Haruna, A., Said, I. & Jasmani, Z. (2018). Vertical greenery systems and its effect on campus: A meta-analysis. *Zenodo*. DOI: 10.5281/zenodo.3361319.

[25] Al-Kayiem, H., Koh, K., Riyadi, T. & Effendy, M. (2020). A comparative review on greenery ecosystems and their impacts on sustainability of building environment. *Sustainability*, 12, 8529. DOI: 10.3390/su12208529.

[26] Jozay, M., Rabbani, M. & Kazemi, F. (2021). The impact of humic acid solutions and types of growing media on morphophysiological and biochemical features of plants in interior green wall conditions. *Plant Archives*, 21, 2240–2252. DOI: 10.51470/PLANTARCHIVES.2021.v21.S1.370.

[27] Khan, H. & Asif, M. (2017). Impact of green roof and orientation on the energy performance of buildings: A case study from Saudi Arabia. *Sustainability*, 9, 640. DOI: 10.3390/su9040640.

[28] Polo-Labarrios, M., García, S., Sánchez-Mora, H., Escobedo-Izquierdo, M. & Espinosa-Paredes, G. (2020). Comparison of thermal performance between green roofs and conventional roofs. *Case Studies in Thermal Engineering*, 21, 100697. DOI: 10.1016/j.csite.2020.100697.

[29] Poupart, F., Sundsdal, O., Christiansen, M., Melhus, O. & Chaudhuri, A. (2021). Numerical analysis of the performance of green façades. In *Proceedings of the Building Simulation Conference* (pp. 31–38). DOI: 10.3384/ecp2017631.

[30] Trlica, A., Hutyra, L. R., Schaaf, C. L., Erb, A. & Wang, J. (2017). Albedo, land cover, and daytime surface temperature variation across an urbanized landscape. *Earth's Future*, 5. DOI: 10.1002/2017EF000569.

[31] Liu, Y., Huang, X., Yang, Q. & Cao, Y. (2021). The turning point between urban vegetation and artificial surfaces for their competitive effect on land surface temperature. *Journal of Cleaner Production*. DOI: 10.1016/j.jclepro.2021.126034.

[32] Feinberg, A. (2020). Urban heat island amplification estimates on global warming using an albedo model. *SN Applied Sciences*, 2. DOI: 10.1007/s42452-020-03889-3.