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Research Article

The Effects of Green Wall Applications on Heating Load and Carbon Emissions: Karadeniz Technical University

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Keywords

Green Wall, Energy Efficiency, Carbon Emissions, Building Simulation, Sustainable Architecture.

Abstract Green roof and wall systems are sustainable architectural practices that offer environmental benefits such as increasing energy efficiency, reducing carbon emissions, and mitigating the urban heat island effect. These systems, which are integrated into building façades to reduce indoor and outdoor temperature differences, optimise heating and cooling requirements while also providing advantages in terms of aesthetics, acoustics, and air quality. This study investigates the effect of the green wall system integrated into the south façade of Karadeniz Technical University Hasan Polat Indoor Sports Hall on energy performance. The simulation analyses show that the green wall reduces the annual heating load by 6.84% and operational carbon emissions by 4.54% compared to the existing façade. However, an increase of 13.1% in the amount of embodied carbon was observed. The humid and mild climatic conditions of the Eastern Black Sea region can increase the effectiveness of green wall systems, keeping vegetation alive throughout the year. It can also contribute to the preservation of building materials by stabilising condensation caused by high humidity levels. As a result, green wall systems can be considered as an important strategy for energy saving and sustainability in such climate zones.

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1. Introduction

The phenomenon of urbanisation has led to significant changes in land use, particularly the reduction of urban green spaces (UGS), with profound impacts on ecological health and urban liveability. As cities expand, the demand for land for housing, infrastructure and commercial activities results in the occupation and degradation of green spaces. Pauleit et al. (2005) emphasise that urbanisation in China has resulted in a gradual decline of green spaces as parks and gardens are replaced by built environments along with population growth. This trend is echoed in the findings of Neuenschwander et al. (2014), who state that rapid urbanisation leads to the shrinkage of UGS, negatively affecting local ecosystems and biodiversity. Furthermore, Chen et al. (2021) emphasise that urban population is a critical driver of changes in green space, as increasing demand for ecological services is associated with urban growth. The relationship between urbanisation and green space is complex; while economic growth often increases investments in NGS, it can also lead to their decline when mismanaged. For example, the study by Huo et al. (2012) suggests that urban planning should consider the balance between development and green space protection in order to reduce carbon emissions and increase urban sustainability.

The impacts of reduced green space go beyond ecological concerns, affecting critical issues such as urban climate and water management. Yao et al. (2015) show that urban green spaces play an important role in reducing urban runoff, with highly vegetated areas significantly reducing runoff compared to highly developed areas. This is supported by research showing that green roofs and green walls can effectively manage stormwater and alleviate pressure on urban drainage systems by reducing peak runoff volumes (Carter & Jackson, 2007; Doll et al., 2002). Furthermore, the spatial configuration of UGS is critical to the effectiveness of its benefits. Studies show that the arrangement of green spaces directly affects urban heat islands and overall thermal comfort in cities (Nur Ramdiana & Yola, 2023; Song et al., 2020). The findings of Terfa et al. (2020) emphasise that the spatial characteristics of green spaces are vital for their effectiveness in cooling urban environments, especially in densely populated areas.

Sabbagh et al. (2019) emphasise that green walls and roofs provide healthy indoor conditions to building occupants while saving energy and water and play a key role in creating sustainable built environments. The study by Anshebo et al. also supports this view and shows that green buildings can save up to 36% of total energy use (Anshebo et al., 2022).

In addition to energy efficiency, green roofs and walls are designed to improve indoor air quality and occupant health (Eghbali & Didari, 2018). Furthermore, the green building concept is in line with the triple bottom line framework, which includes environmental, economic, and social sustainability (Zuo & Zhao, 2014). This holistic approach ensures that the benefits of green buildings go beyond mere energy savings, leading to improved quality of life and community resilience.

Although the use of green roofs and walls is often associated with modern sustainable architecture, it has historical precedents dating back to ancient civilisations. For example, the Mesopotamians insulated the roofs of the houses they built using adobe bricks and thatch by covering them with vegetation, while the Vikings used grass roofs to protect against the harsh Scandinavian climate (Manzer, 2017). Similarly, the Vikings are known to have built grass roofs that not only harmonised with the surrounding landscape but also provided protection against the harsh Scandinavian climate (Köhler, 2008). These historical practices show that the idea of integrating vegetation into building design is not a new concept, but rather a long-standing practice to enhance environmental comfort.

1.1. Green Roof and Green Wall in Architecture

The integration of green features, especially green roofs and walls, into buildings is increasingly favoured in urban architecture due to their contribution to environmental sustainability, energy efficiency and occupant well-being. These systems not only enhance the aesthetic appeal of buildings, but also increase energy efficiency by reducing heating and cooling costs, improve air quality and provide occupants with a more comfortable living space.

Green roofs offer significant advantages in urban environments where space is limited. They reduce energy consumption by providing insulation and mitigate the urban heat island effect. Kim and Kim (2023) emphasise that green roofs improve thermal efficiency and reduce energy consumption by protecting buildings from excessive solar radiation. In addition, green roofs absorb rainwater, reducing flood risk and contributing to urban water management (Liu & Chui, 2019). This versatile functionality makes green roofs play a critical role in modern urban planning. Similarly, green walls or vertical gardens also offer significant advantages in terms of improving thermal comfort and supporting environmental sustainability. Sheweka and Mohamed (2012) state that green walls significantly reduce surface temperatures on building façades, thus improving the thermal performance of the building. In addition, these systems contribute to air quality by absorbing pollutants and carbon dioxide, creating healthy indoor conditions for building occupants. The psychological benefits of green walls are also noteworthy; studies show that the presence of plants can positively affect individuals' mood and productivity (Han et al., 2022).

The integration of green features into building designs is not only limited to environmental benefits, but it also provides economic advantages. Eichholtz et al. found that green buildings have higher market values and increased rental yields compared to conventional buildings (Eichholtz et al., 2013). This trend stands out as an important factor supporting the economic viability of green buildings. Similarly, a study conducted in Nigeria found that green features are preferred in residential buildings for both environmental and economic motivations (Adejumo et al., 2022). Such preferences emphasise the importance of integrating green technologies into building designs to meet the demands of environmentally conscious consumers.

The integration of green systems in contemporary architecture, especially in roofs and façades, is becoming increasingly common. Green roofs have a great potential for energy saving as well as environmental benefits. According to Kováč (2022), green roofs reduce urban heat island effects, improve air quality and reduce runoff by managing rainwater. In addition, thanks to their insulating properties, they increase energy efficiency by reducing heating and cooling costs (Mahmoud et al., 2017). Research by Stovin reveals that these systems reduce the need for air conditioning by promoting evaporative cooling and play a critical role in urban sustainability (Sailor, 2008). In addition, green roofs support biodiversity by providing habitat for wildlife in urban areas (Yalcinalp et al., 2017). Another important component of green systems is green façades known as vertical greening systems (VGS). These systems contribute to energy efficiency by improving the thermal performance of buildings and offer aesthetic value. Pérez et al. (Pérez et al., 2017) emphasise that green façades reduce solar heat gain by providing shade, thus saving energy. This effect is particularly observed in hot climates with high cooling demand. Furthermore, green façades improve air quality, making the urban environment more liveable (Okwandu et al., 2024).

1.2. Energy Efficiently Design and Green Roofs-Walls

The impact of green roofs and walls on energy efficiency has received considerable attention in recent years as urban areas increasingly seek sustainable solutions to combat increasing energy demands and reduce the urban heat island effect. By incorporating vegetation into building designs, green roofs and walls can improve thermal performance, reduce energy consumption, and increase overall building efficiency.

Green roofs are known to provide significant thermal insulation, which can lead to significant energy savings in buildings. Studies show that green roofs can lower the internal surface temperatures of buildings and thus reduce cooling loads in hot weather. For example, Qin et al. (2023) show that green roofs can effectively moderate building thermal performance, especially in extremely hot climates, leading to less energy consumption for cooling. Similarly, Spangenberg et al. emphasise that lower surface temperatures of roofs and façades due to vegetation cover contribute to reduced cooling loads, thus improving energy efficiency (Akbari et al., 2001). Research by Jaffal et al. (2012) supports these findings by reporting that the addition of a green roof can lead to a 6% reduction in annual energy demand for a single-family home. This reduction is attributed to the cooling effect of vegetation, which lowers the temperature of the roof surface and subsequently reduces the energy required for air conditioning. The comparative energy saving potential of green roofs and walls has also been investigated. Kubota and Toe (2015) state that the thermal environment and cooling energy utilisation are closely linked and that the application of green roofs can significantly improve the thermal performance of buildings in hot climates. This is in line with the findings of Kamel et al. (2012) who report energy savings of 15-32% in air-conditioned residential buildings with green roofs in desert climates.

Research shows that the energy efficiency improvements provided by green walls vary significantly depending on climate, building orientation, design, and installation conditions. For instance, Tan et al. (2020) found that a traditional climbing plant wall on a north façade reduced heat loss by about 25%, highlighting its insulating effect. Similarly, Alexandri and Jones (2008) reported that a vertical greenery system in Hong Kong reduced cooling loads by up to 66%, demonstrating its high potential in hot and humid climates. Additionally, Al-Kayiem et al (2023) observed that integrating green walls with shading strategies could lower cooling energy use by approximately 18.3% in educational buildings, showing that notable savings are possible even in temperate climates.

The energy-saving potential of green walls and green roofs is highly context-dependent, influenced by building type, climate, and system design. Studies have shown that green roofs can significantly reduce cooling loads through enhanced insulation and evaporative cooling (Qin et al., 2023; Zheng & Chen, 2023), while green walls provide shading and insulation benefits, particularly effective in tropical climates (Pragati et al., 2023). A comparison by Azis et al. (2019) on residential buildings in Malaysia revealed that green walls achieved greater annual energy savings than green roofs, suggesting their vertical configuration better disrupts heat transfer on sun-exposed façades. Additionally, simulation results by Pragati et al. (2023) indicated that combining green roofs and walls can lower cooling loads by up to 36.8%, emphasizing that both systems offer complementary benefits depending on building orientation and exposure.

In conclusion, integrating green roofs and walls into building designs significantly improves energy efficiency by reducing cooling loads, mitigating urban heat islands, and promoting passive cooling techniques. As cities continue to grow and face environmental challenges, the adoption of these green technologies will be essential to create sustainable and energy-efficient urban environments.

2. Method and Materials

2.1. Method of the Study and Contribution

The main objective of this study is to evaluate the effects of green wall systems on the energy efficiency and environmental sustainability of buildings. In particular, the effects of a green wall system integrated into the south façade of Karadeniz Technical University Hasan Polat Indoor Sports Hall on factors such as heating load, operational carbon and embodied carbon are analysed. The study aims to evaluate the potential of green wall systems to provide insulation in winter months and prevent excessive heat gain in summer months and to reveal how these systems contribute to sustainable building practices. In addition, the performance of green wall applications in the humid and mild climatic conditions of the Eastern Black Sea region was also analysed. A functional diagram of the methodology of the study is given in Figure 1.

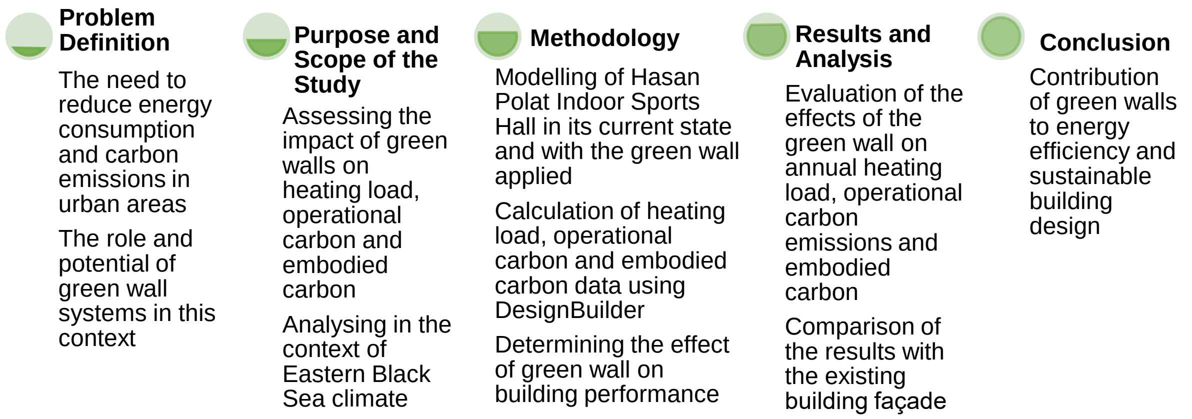


Figure 1. Phases of the study (created by the author).

In the study, simulation method is used for comparative evaluation of energy consumption and carbon emissions. Building modelling was carried out using DesignBuilder software and in the simulations, the existing building façade and green wall integrated façade scenarios were compared. In this context, heating load, operational carbon, and embodied carbon parameters are analysed to determine the effect of green wall on building performance. In addition, through a literature review, the general advantages of green wall systems, their application potential and their contribution to sustainable building design are analysed.

This study evaluates the effects of green wall systems on building energy performance and environmental sustainability and makes the following contributions to the literature:

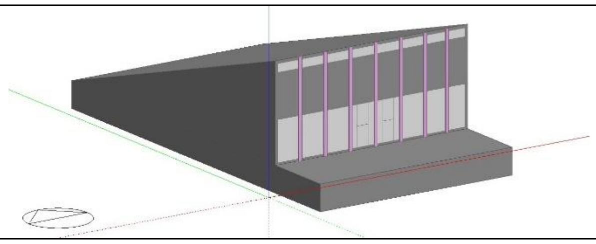
- The effects of green wall systems on heating energy consumption, which are generally considered theoretically in the literature, are based on quantitative data with simulation-based analyses in this study.
- The study evaluates the long-term environmental benefits of green wall applications in terms of operational carbon and embodied carbon and provides a new perspective on the impact of these systems on the carbon footprint.
- In the study, the effects of a green wall on energy efficiency in a region with a humid and temperate climate were evaluated and the role of regional differences on the effectiveness of green wall systems was assessed.
- This study, which is specific to Karadeniz Technical University, provides important data on how green wall applications can be evaluated within the scope of sustainable building solutions in academic campuses.

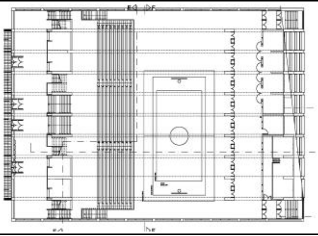
2.2. Study Case, Parameters and Building Model

Karadeniz Technical University (KTU) is located in the province of Trabzon in north-eastern Türkiye. Located on the Black Sea coast, the university is situated between the sea and the mountains and has a humid and rainy climate. Under the influence of the Eastern Black Sea climate, the region receives abundant rainfall throughout the year and has high humidity. Summers are cool and winters are mild; temperatures rarely reach extreme values. These climatic conditions can be advantageous for sustainable designs such as green wall systems, supporting the growth of plants and contributing to energy efficiency. According to the data obtained from the General Directorate of Meteorology (2024), the average maximum temperature of the region is 18.2°C and the minimum temperature is 11.8°C. The region is rainy 37.6% of the year.

The main campus of Karadeniz Technical University (KTU) is Kanuni Campus and is located in Ortahisar district. Hasan Polat Indoor Sports Hall, which is the building selected within the scope of the study, is located in this campus. Hasan Polat Indoor Sports Hall building was modelled with DesignBuilder software for simulation and the necessary structural element information was entered into the programme. The necessary information and two-dimensional drawings were obtained through Karadeniz Technical University Project Production Centre (PÜM). The building is heated by natural gas and central heating system but there is no cooling mechanism. The interior environment is ventilated by natural ventilation and there are ventilation grilles on the upper axis of the south façade. ‘Dry sports hall’ in the programme library was selected for the building activities. The heating temperature of the building is 22°C and the heating setback value is set as 18°C (Manning et al., 2007). Air exchange is entered into the programme as 0.5 ach/h (Conceição et al., 2019). The structural element and U-value values entered into the model for the sample building are shown in Table 1.

Table 1. Hasan Polat Indoor Sports Hall Building elements and materials (created by the author).





Elements	Layers	Material Thick.	Total thickness	U-Value
Exterior Wall	Gypsum plastering Brick Brick Air gap Brick Cement plaster	0,020 m 0,135 m 0,050 m 0,135 m 0,030 m	0,370 m	1, 271 W/m²K
Interior Wall	Gypsum plastering Brick Gypsum plastering	0,025 m 0,135 m 0,025 m	0,185 m	2,073 W/m²K
Ground Floor	PVC/Rubber floor Floor/Roof screed Cement screed Cast concrete Gypsum plastering	0,006 m 0,002 m 0,010 m 0,150 m 0,020 m	0,188 m	2,382 W/m²K
Basement floor	Ceramic – clay tiles Cement screed Cast concrete Cast concrete (light) Gravel Earth, common	0,050 m 0,030 m 0,500 m 0,100 m 0,150 m -	0,830 m	0,708 W/m²K
Exterior Floor	Basalt Cement screed Cast concrete (light) Polyethylene, high den. Polypropylene XPS – CO_2 Blowing Felt Cast concrete (light) Concrete Reinforced Gypsum plastering	0,040 m 0,030 m 0,050 m 0,001 m 0,030 m 0,050 m 0,010 m 0,050 m 0,150 m 0,020 m	0,431 m	0,259 W/m²K
Elements	**Layers**	**Material Thick.**	**Total thickness**	**U-Value**
Interior floor	Ceramic – clay tiles Cement screed Cast concrete Gypsum plastering	0,030 m 0,020 m 0,150 m 0,020 m	0,220 m	2,328 W/m²K
Windows/Door	PVC frame Dbl LoE Clr 3/13 mm	0,006 m	0,006 m	2,253 W/m²K
Roof	Metal surface Metal deck	0,001 m 0,010 m	0,011 m	7,258 W/m²K

The building is located in an area with high student circulation and its main façade faces south. This is the façade where the green wall is planned to be integrated. The ‘prefabricated planter box’ green roof system was chosen to be integrated into the deaf surfaces of the façade.

Mir (2011) categorises vertical green systems into three categories: green façades, wall vegetation and living wall systems (LWS). These categories also branch within themselves according to whether the plants will be grown in the ground, box or prefabricated. A diagram of vertical green systems is given in Figure 2.

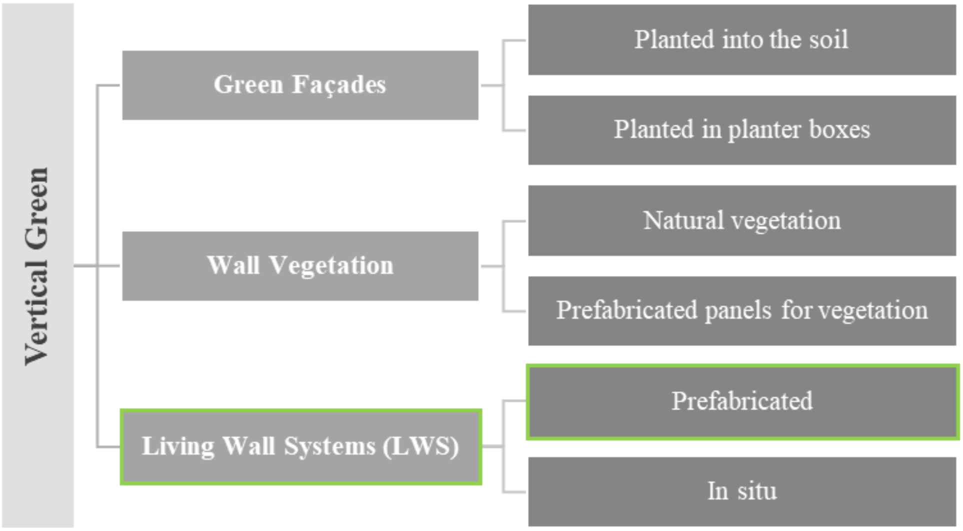


Figure 2. Diagram of the vertical green systems (revised from author) (Mir, 2011).

Green façade systems, in which plants rooted in the soil naturally grow by clinging to the façade, do not require an irrigation system and cover the entire surface over time, are divided into two as plants that climb directly on the wall or plants that are guided by support structures. In the planter box system, since the plants are planted in pots that require irrigation rather than directly in the soil, it takes time for the wall to be completely greened and plant growth is limited; therefore, the wall can be closed faster by placing the pots at each floor level.

Wall vegetation refers to a natural type of green wall with an irregular structure that grows spontaneously in different parts of the wall (especially in cracks and joints). It is natural vegetation that often grows spontaneously on old walls, historic buildings and gardens, growing unevenly depending on the level of wear of the binding materials. In addition, porous concrete panels, a new green wall technology that can absorb rain and snow water by filling with soil to support the growth of plants, can also be used.

Living wall systems are vertical greening systems that support plants in a wall-independent growing environment, can be applied in different climatic conditions, and have a wide variety of plants but require regular maintenance and irrigation. Prefabricated living walls are modular systems consisting of pre-planted panels or integrated fabric systems that support various plant species and are mounted on a structural wall or frame. In situ living walls are partially pre-prepared systems with layers of felt into which plants are inserted after installation on façades. The factors considered for the green wall type selected in this study are as follows:

- The green plant should be applicable to an existing exterior wall surface or can be added as a stand-alone system.

- It should be able to store excess water as the climate characteristics of the green wall are humid and temperate.
- If desired, it should be integrated into the irrigation system.

In this direction, Living Wall Systems (LWS) was selected because it has a modular structure, has a high water retention capacity, can use rainwater and maximise sunlight, is easy to install and can be applied quickly due to its panel shape. This system will provide the advantage of diverting excess water while providing natural insulation on the external wall of the gymnasium. It will also increase the aesthetic appearance and environmental benefits in large-scale buildings such as gymnasiums (Figure 3 and 4).

Figure 3. Rendering of the indoor sports hall before and after the green roof renovation (created by the author).

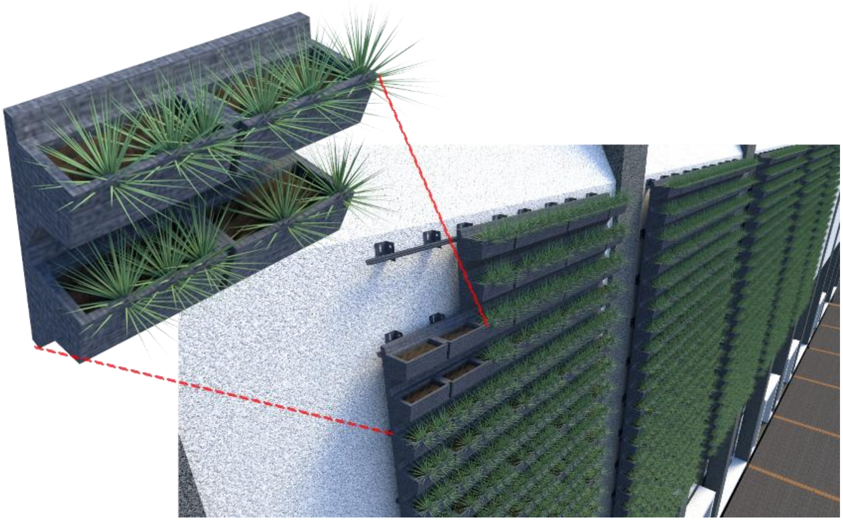
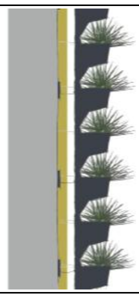


Figure 4. Living Wall Systems (LWS) modular system and wall mounting (created by the author).

In this direction, the wall materials of the selected LWS modules were determined in the DesignBuilder software as shown in Table 2. The green wall was placed 10 cm away from the existing wall for fire safety and to prevent damage to the existing wall over time by preserving the existing wall structure. A 5 cm thick stone wool was added outside the existing wall for thermal insulation. The modular planter material was determined as HDPE and the thickness of the planter was entered into the programme as 1 cm. The dimensions of the modular pots are designed as 50x60 cm. The pot width is 20 cm. Table 2 shows the green wall layering and details entered into DesignBuilder.

Table 2. Proposed green wall reinforcement, system layering and materials (created by the author).

LWS	Layers	Material Thick.	Total thickness	U-Value	
	Gypsum plastering	0,020 m			
	Brick	0,135 m			
	Air gap	0,050 m			
	Brick	0,135 m			
Exterior Wall	Cement plaster	0,030 m	0,770 m	0,404 W/m^{2}K	
	Stone wool	0,050 m			
	Air gap	0,050 m			
	HDPE	0,010 m			
	Green wall soil	0,180 m			
	HDPE	0,010 m			

The details of the plant characteristics of the green wall system are provided in Table 3. Since the pot spacing is specified as 20 cm, the plant size is assumed to be approximately 18 cm, and sedum-type plants have been used. Sedum species are widely used in green walls due to their compact, mat-forming growth habits, drought tolerance, and ability to easily establish themselves in the typical challenging conditions of vertical installations. For example, sedum spurium is frequently used in living wall systems; its low, spreading growth habit helps form a continuous carpet that provides aesthetic appeal and functional benefits such as rainwater retention and temperature regulation (Fejes & Gerzson, 2006; Ostendorf et al., 2021; Ryu et al., 2014).

Table 3. Green roof features in the simulation programme (created by the author).

Green Roof Properties	Values
Height of plants (m)	0.18
Leaf area index	2.70
Leaf Reflectivity	0.22
Leaf Emissivity	0.95

3. Results and Discussions

As a result of the analysis, significant differences were observed between the existing wall and the proposed green wall in terms of monthly and annual heating load. In January, the green wall had approximately 6.9% lower heating load compared to the existing wall, while in February this reduction rate was again around 6.8%. In March the difference increased to 7.1% and in April the similar trend continued with a reduction of 6.6%. In spring and summer, especially in May and June, the difference became more notable, with savings of 6.2% and 1.2% respectively. In July and August, a difference of about 3% occurred, while in autumn the reduction ranged from 3.0% to 4.8%. In December, the green wall required 6.6% less heating load compared to the existing wall. On an annual basis, the total heating load of the green wall was found to be about 6.84% lower than the existing wall (Figure 5). These results show that the green wall provides some insulation in winter, has a cooling effect in summer, but does not provide the expected contribution in autumn.

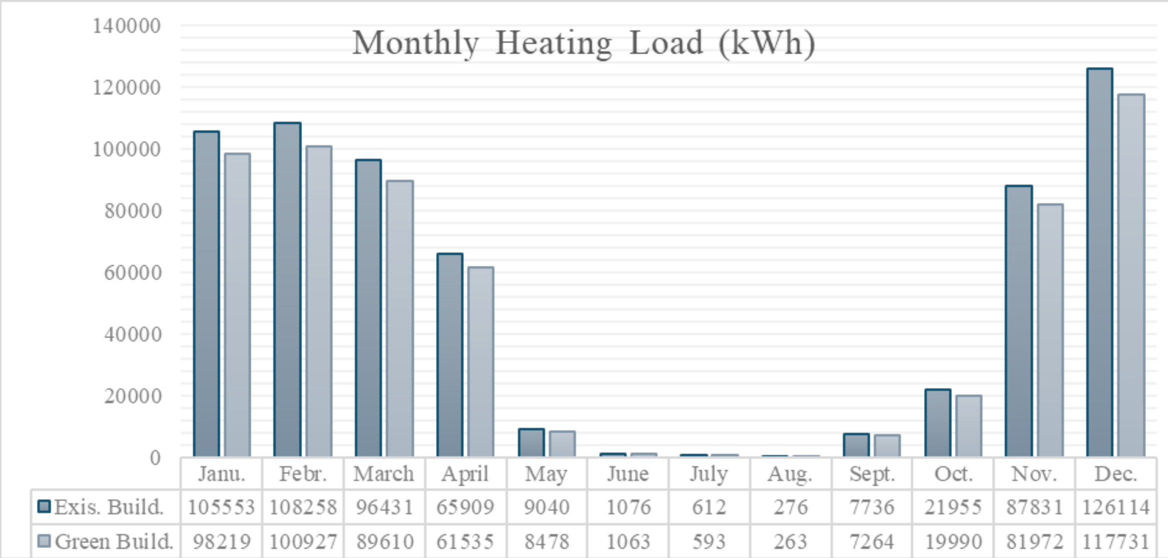


Figure 5. Effect of existing and green wall retrofitting on monthly heat load of the building (created by the author).

In January, the green wall had approximately 5.34% lower operational carbon emissions compared to the existing wall. In February, this difference increased to 5.35%, while a decrease of 5.28% was observed in March and 4.77% in April. The difference remained at 2.94% in May, 2.44% in June and 2.47% in July. In August and September, the difference was around 2.47% and 2.90%, reaching 4.22% in October and 4.98% in November. In December, the difference in terms of operational carbon emissions was very low and remained at 5.36% (Figure 6). Looking at the total annual values, the operational carbon emissions of the green wall were found to be approximately 4.5% lower compared to the existing wall. Although this difference may seem small, it can make a significant contribution to sustainability in the long term.

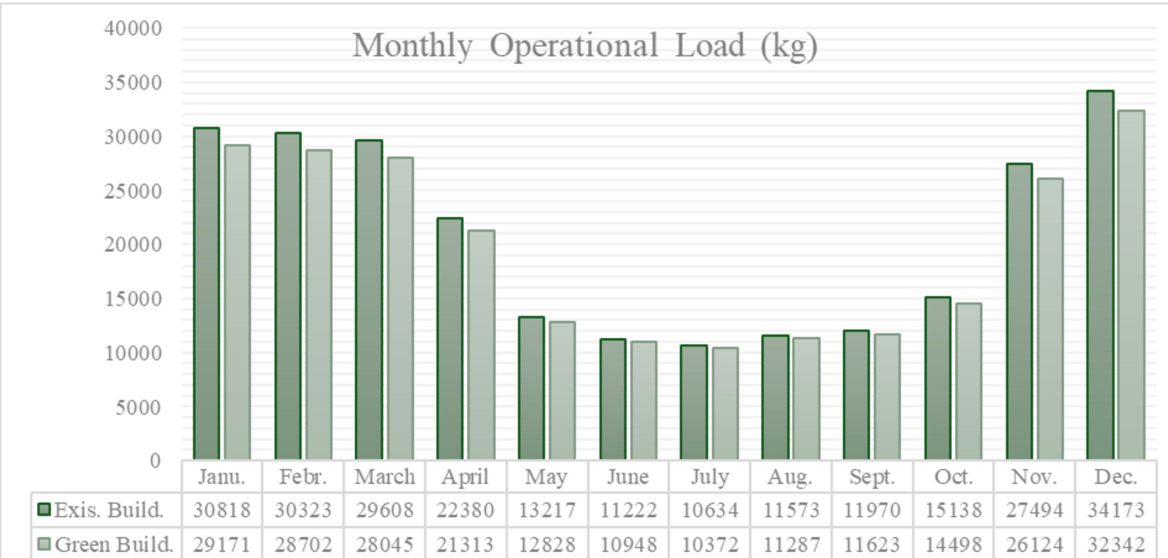


Figure 6. Effect of existing and green wall retrofitting on monthly operational carbon of the building (created by the author).

Figure 7 illustrates the differences between the existing wall and the green wall in terms of annual embodied carbon, operational carbon, and heating energy consumption. The green wall's embodied carbon is 13.1% higher, reflecting the impact of building materials. However, a 4.54% reduction in operational carbon emissions and a 6.84% decrease in annual heating energy consumption indicate improved energy efficiency and thermal performance. Despite higher embodied carbon, the green wall offers long-term sustainability benefits through reduced energy use and operational emissions.

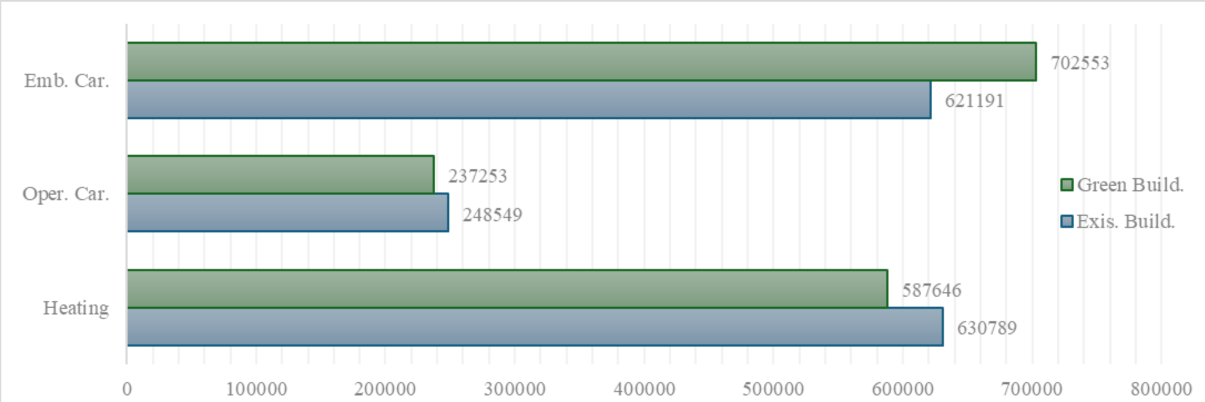


Figure 7. Effect of existing and green wall retrofitting on yearly embodied carbon, operational carbon and heating load of the building (created by the author).

4. Conclusion

Green roofs and green walls stand out as sustainable building solutions in modern urbanisation processes. These systems are integrated into building surfaces to increase energy efficiency, reduce carbon emissions and mitigate the urban heat island effect. At the same time, they increase the comfort of building users by improving indoor air quality and offer advantages in terms of water management. These applications, which have the potential to compensate for the loss of green space caused by dense urbanisation, support environmental sustainability at the building scale.

This study aims to evaluate the effects of a green wall system integrated into the south façade of Karadeniz Technical University Hasan Polat Indoor Sports Hall on energy performance. Through simulation-based analyses, the effects of the green wall on factors such as heating energy consumption, operational carbon and embodied carbon emissions are investigated. The main objective of the study is to present a viable model for sustainable building design by revealing the contributions of the green wall on energy efficiency.

The findings show that the green wall results in 6.84% lower heating energy consumption and 4.54% lower operational carbon emissions on an annual basis compared to the existing wall. However, there is a 13.1% increase in the amount of embodied carbon. This shows that although the green wall provides energy and carbon savings in the long term, and material carbon impact should be taken into account.

Overall, this study revealed that green wall systems offer certain advantages in terms of energy efficiency and environmental sustainability. However, the effectiveness of the system varies depending on the materials used, plant species and climatic conditions. In order to achieve higher performance, it is recommended to integrate the green wall with insulated systems or double skin façades. Future studies could incorporate detailed life cycle assessments (LCA) to more comprehensively evaluate the environmental impacts of green wall applications. Such applications can make significant contributions to increase energy savings and reduce carbon footprint in the future.

Declaration of Ethical Standards

The article complies with national and international research and publication ethics.

Ethics Committee Approval was not required for the study.

Conflict of Interest

There was no conflict of interest.

Authors' Contributions

The author contributed alone to the article and takes full responsibility for the content and any modifications made during this process.

Declarations

In this study, Grammarly software was used for grammar checking, while the ChatGPT artificial intelligence model was utilized to enhance word and paragraph flow.

Originality Report

The article has been confirmed that it does not contain any plagiarism according to the originality report obtained from the iThenticate software.

Notes

This study is evaluated under the double-blind peer review system.

Please use **livenarchjournal@ktu.edu.tr** email address for submitting ethical statements.

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