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Using The CO_2 Removal Capability of Green Walls as Architectural Design Parameter+

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Abstract

Nowadays architectural designs, besides the functionality and aesthetic elements, the effects of design on the natural environment have become an important element. One of the most critical parameters that can be used in determining the effects of design on the natural environment is the carbon footprint. After the goals were set on a global scale in terms of reducing carbon footprint, architects started to use carbon footprint reducing elements in their designs. In this study, the effects of green walls, a dynamic method that can be used to reduce emissions that cause global warming, on reducing the carbon footprint of an architectural design were examined. For this purpose, a model building to be used as a residence was designed, and its carbon footprint was determined with the Tier 1 approach. The annual carbon footprint of the model building was calculated as 32521 kgCO_2-eq. The highest rate of carbon footprint belongs to natural gas consumption (16665 kg CO_2-eq/ year). In the analysis of the greenhouse gas emissions (CO_2-eq) that the green wall system in the building design will uptake if different plant species are used, the highest value was obtained in the *Z. matrella* plant with 1753 kgCO_2-eq/m^2 year. The amount of CO_2-eq that can be uptaken by using all plant species together was found to be 1147 kgCO_2-eq/m^2 year. When the results obtained in the study are evaluated together with the additional benefits of green walls in thermal insulation and gray water treatment, it can be said that it is an important parameter that can be used to reduce carbon footprint in architectural designs.

Keywords: Green wall, carbon footprint, architectural design, carbon dioxide removal

Yeşil Duvarların CO_2 Uzaklaştırma Kabiliyetinin Mimari Tasarım Parametresi Olarak Kullanılması

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Özet

Günümüz mimari tasarımlarında işlevsellik ve estetik unsurların yanında tasarımın doğal çevreye etkileri de önemli bir unsur haline gelmiştir. Tasarımın doğal çevreye olan etkilerinin belirlenmesinde kullanılabilecek en önemli parametrelerden biri karbon ayak izidir. Karbon izinin azaltılması konusunda küresel ölçekte koyulan hedeflerden sonra, mimarlar yaptıkları tasarımlarda, karbon ayak izini azaltıcı unsurları da kullanmaya başlamıştır. Bu çalışmada küresel ısınmaya

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neden olan emisyonların azaltılmasında kullanılabilecek dinamik bir yöntem olan yeşil duvarların, bir mimari tasarımın karbon ayak izini azaltmada ki etkileri incelenmiştir. Bu amaçla mesken olarak kullanılacak bir model bina tasarlanmış ve karbon ayak izi Tier 1 yaklaşımı ile belirlenmiştir. Model binanın yıllık karbon ayak izi 32521 kgCO_2-eq olarak hesaplanmıştır. Karbon ayak izi içerisinde en yüksek oran doğalgaz tüketimine aittir (16665 kgCO_2-eq/yıl). Bina tasarımında bulunan yeşil duvar sisteminin, farklı bitki türlerinin kullanılması durumunda tutacağı sera gazı emisyon miktarları (CO_2-eq) incelemesinde ise, en yüksek değer 1753 kg CO_2-eq /m^2 yıl ile *Z. matrella* bitkisinde elde edilmiştir. Tüm bitki türlerinin ortak kullanılması ile tutulabilecek CO_2-eq miktarı ise 1147 kg CO_2-eq / m^2 yıl bulunmuştur. Çalışmada ulaşılan sonuçlar, yeşil duvarların ısı yalıtımı ve gri su atımı konularındaki ilave faydaları ile birlikte değerlendirildiğinde, mimari tasarımlarda karbon ayak izini azaltmak için kullanılabilecek önemli bir paremetre olduğu söylenebilir.

Anahtar Kelimeler: Yeşil duvar, karbon ayakizi, mimari tasarım, karbon dioksit giderimi

1. Introduction

Green walls, which are an important part of today's architectural designs. They are complex systems established by fixing components such as plants, growing media, irrigation, fertilization, and spraying systems to the building surface with a solid construction element (Dede et al., 2021; Dede et al., 2019). In these systems, many plant species can be used depending on determining factors such as architectural design and climatic conditions of the region. The type of plant used influences the selection of all other components of the green wall (Dede et al., 2019). For example, climbing plants are planted in the ground and advance by clinging to the building surface or surface-mounted lattice reinforcements. In green wall systems where such plants are used, irrigation and fertilization equipment are on the ground. In green wall systems, where plants are planted in pots in the form of steps, the plant, the growing medium, and all necessary support equipment for the plants are attached to a platform firmly attached to the building surface (Dede et al., 2019). When the plants in the step-shaped pots reach a sufficient size, the pots, platform, and all other equipment are hidden behind the plants, and a wall of clumped plants appears.

Although green walls were initially used to add a different visual beauty to architectural design, today, it has been determined that it has many significant benefits, from improving the heat and sound insulation of buildings to preventing heat islands and air pollution in cities (Susca et al., 2011; Cheng et al., 2010). Studies conducted in recent years show that green wall applications will contribute to reducing global climate change by providing CO_2 removal from the atmosphere (Pan & Chu, 2016). Many different models and measurement methods have been proposed to determine the size of this contribution. In addition, the effects of plant species, growing media, irrigation, and fertilization regimes on CO_2 removal are examined, and optimum conditions for maximum CO_2 removal are tried to be determined.

This feature of green walls provides a significant opportunity for the success of programs with concrete targets to reduce CO_2 emissions, such as the Paris Agreement, international agreements, and the European Union Green Deal, in the fight on a global scale against the effects of climate change. Therefore, many governments and local governments encourage green wall applications and the number of buildings with green wall systems in cities is increasing rapidly (Susca et al., 2011).

The aim of this study is to design an architectural building and to calculate the amount of CO_2 that the green wall will uptake and the carbon footprint of the building by applying a green wall in this building. Although many techniques are used in the design phase to prevent greenhouse gas (GHG) emissions in buildings, systems with CO_2 holding capacity, such as green walls for carbon-neutral buildings, should be included in the designs. In this study, the contribution of the green wall application to the carbon-neutral target of the designed building will be examined.

2. Materials and Methods

In this study, a real-size building with a green wall system was designed to calculate the carbon footprint and the amount of CO_2 to be removed by green walls. The intended use of the designed building is residential. The building has five floors, and there are a total of 10 apartments, two on each floor (Figures 1 and 2). In the calculation of the carbon footprint, it is assumed that a total of four people live in each flat.

Green wall systems are on both sides and the front of the designed building. The dimensions of the green wall systems are 15x17.5 m, 13.5x17.5 m, and 3x17.5 m, respectively. The total area covered by the green wall system in the building, together with irrigation and fittings, is 551 m^2.

There are three approaches used to calculate the carbon footprint (Tier 1, Tier 2, and Tier 3). The ability to calculate calculations with a high accuracy rate depends on the ability to detail the data that needs to be collected (fuel type, fuel amount, characteristics of the process used, emission factor, etc.). However, as in this study, the details of the collected data may not be available in some cases. In such cases, the carbon footprint can be calculated with the Tier 1 approach.

In the calculation of the carbon footprint of the building designed in this study (Tier 1), IPCC, (Intergovernmental Panel on Climate Change, 2006), Greenhouse Gases (GHG) Protocol (World Business Council for Sustainable Development, 2004), Turkey's Informative Inventory Report (IIR 2021) and the methods and equations (Eq. 1-9) suggested in the studies in the literature were used (Intergovernmental Panel on Climate Change, 2006; World Resources Ins., & World Business Council for Sustainable Development, 2004; Lai, 2014; Haksevenler et al., 2020; Lapenangga and Satwiko, 2016; Turkey's Informative Inventory Report 2021).

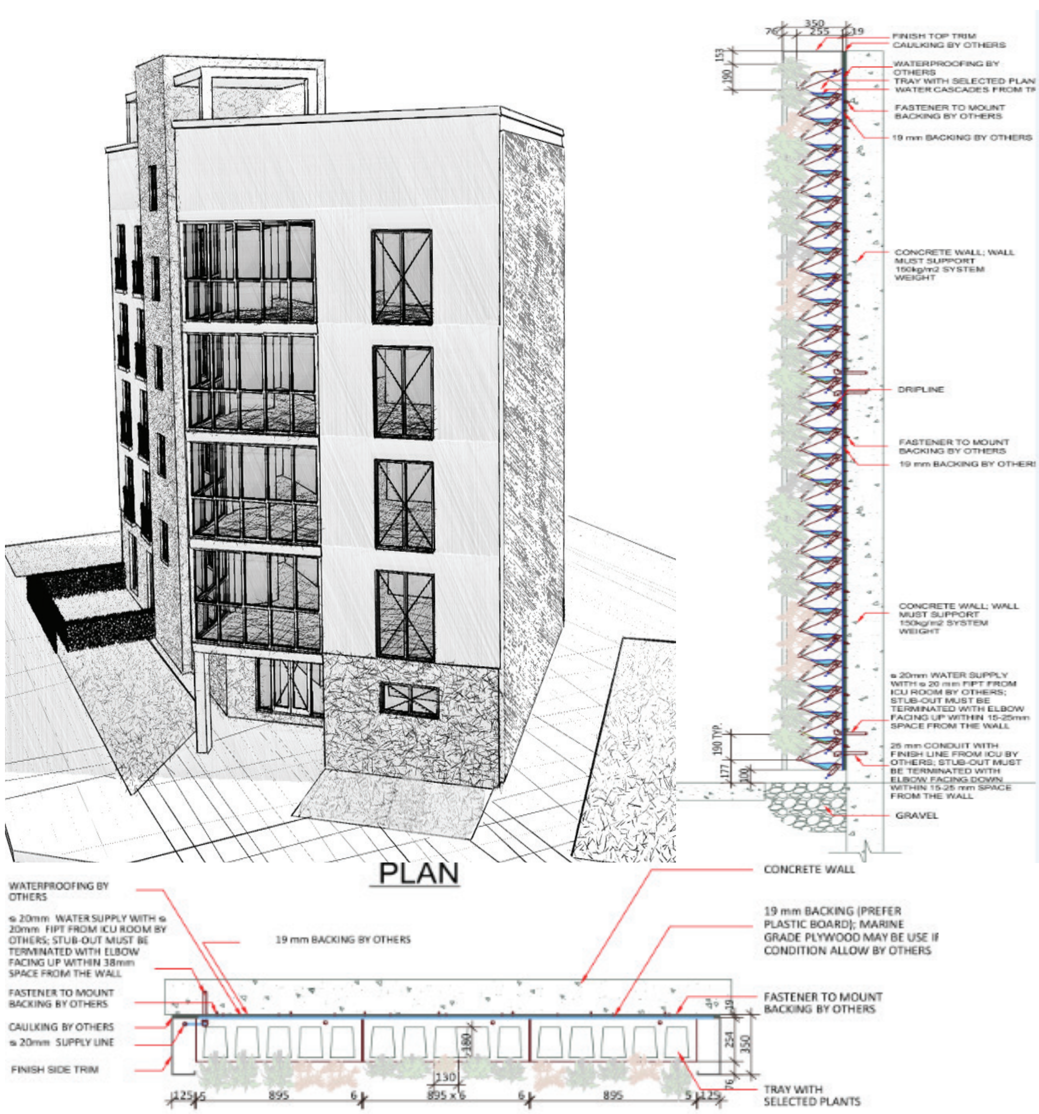

Figure 2. Green wall system

The activation data taken into account in the calculations are electricity consumption billed per household, natural gas consumption per household, water usage, and solid waste generation (for Istanbul/Turkey) (Turkey's Energy Market Regulatory Board, Electricity Market Development Report, 2021; Natural gas Distribution Industry Report, Turkish Natural Gas Distributors Association, 2021; Turkey Statistical Institute data, 2021a; Turkey Statistical Institute data, 2021b). These major parameters are heating, lighting, cleaning, food, personal care, entertainment/sports, etc. It covers the main activities that contribute to the production of CO_2 in the living space. Transportation, refrigerator usage, air conditioner usage, and some consumption parameters were not included in the calculations because they showed high variation or there was no official data on the usage amount.

Natural gas consumption is within the scope of direct emissions (scope 1), and the electricity consumption is indirect emissions (scope 2). Fresh water use, wastewater treatment, and solid waste disposal are scoped as other indirect emissions (scope 3). In the calculations, electricity consumption per household is 1797 kWh/year (Istanbul/Turkey), natural gas consumption per household is 884 m^3/year, water consumption per capita, and wastewater generation is 69.35 m^3/year (all of the water used is considered to cause wastewater), and The amount of solid waste per year was used as 449 kg/year.

Scope 1: Natural gas consumption (heating, hot water, cooking, etc.)

$$E_G = \sum AD_G \times EF_G \quad (1)$$

$$E_{G(CH4)} = \sum ADG \times EF_{G(CH4)} \times G_{(CH4)} \quad (2)$$

$$E_{G(NO2)} = \sum ADG \times EF_{G(NO2)} \times G_{(NO2)} \quad (3)$$

$$E_G\ [kgCO_{2\text{-}eq}] = E_{G(CO2)} + E_{G(CH4)} + E_{G(NO2} \quad (4)$$

Scope 2: Electricity consumption (lighting, electrical appliances, etc.)

$$E_E\ [kgCO_{2\text{-}eq}] = \sum AD_E \times EF_E \quad (5)$$

Scope 3: Water consumption, wastewater treatment and solid waste disposal (bathroom, toilet, cleaning, kitchen, etc.).

$$E_{FW}\ [kgCO_{2\text{-}eq}] = \sum AD_{FW}\ x\ EF_{FW} \quad (6)$$

$$E_{WW}\ [kgCO_{2\text{-}eq}] = \sum AD_{WW}\ x\ EF_{WW} \quad (7)$$

$$E_{SW}\ [kgCO_{2\text{-}eq}] = \sum AD_{SW}\ x\ EF_{SW} \quad (8)$$

Total $CO_{2\text{-}eq}$: The total GHG emissions of the building designed in the study resulting from the activities examined.

$$E\ [kgCO_{2\text{-}eq}] = E_G + E_E + E_{FW} + E_{WW} + E_{SW} \quad (9)$$

Notations

E_G	: Total GHG emissions	AD_W	: wastewater generation
$E_{G(CO2)}$	: CO_2 emission from natural gas consumption	AD_{SW}	: solid waste generation
$E_{G(CH4)}$	: CH_4 emission from natural gas consumption	$EF_{G(CO2)}$	: CO_2 emission factor of natural gas consumption
$E_{G(N2O)}$	: N_2O emission from natural gas consumption	$EF_{G(CH4)}$	: CH_4 emission factor of natural gas consumption

E_G	: emissions from natural gas consumption	$EF_{G(N2O)}$	: N_2O emission factor of natural gas consumption
E_E	: emissions from electricity consumption	EF_E	: emission factor of electricity consumption
E_{FW}	: emissions from fresh water use	EF_{FW}	: emission factor of water used
E_{WW}	: GHG emission from wastewater treatment	EFWW	: emission factor of wastewater treatment
E_{SW}	: emissions from solid waste disposal	EFSW	: emission factor of solid waste
AD_G	: natural gas consumption	$G_{(CH4)}$	: global warming potential of CH_4
AD_E	: electricity consumption	$G_{(N2O)}$	: global warming potential of N_2O
AD_{FW}	: fresh water use		

The annual average of the amount of CO_2 that the plant species frequently used in green wall applications can uptake per square meter has been determined by the literature study (Table 1) (Marchi et al., 2015). Using these data, the amount of CO_2 the green wall system designed in the study can uptake in a year was calculated separately for each plant species. Using different plant species in green wall systems is a common practice. Therefore, the amount of CO_2 that all plant species can uptake in a year is calculated by taking the average amount of CO_2 they can uptake if used together in the green wall system in the study.

Table 1. The amount of carbon dioxide that can be uptaken per square meter per year in green wall systems with different plant species (Marchi et al., 2015).

Plant species	Annual active CO_2 uptake by plants ($kgCO_2eq/m^2$)
R. officinalis	2.91
Z. matrella	3.18
C. brunnea	2.65
S. nemorosa	3.04
S. spurium	0.44
F. japonica	1.33
G. sanguineum	1.07
Average for plant species	2.08

3. Results and Discussion

In calculating the carbon footprint of actively used buildings, annual data on all activities carried out in the building can be easily determined from bills and regular records. However, since these data are not available at the architectural design stage, the best way to calculate the carbon footprint with high accuracy is to use data from similar buildings or average values of the region where the building will be built. The activity data and emission factors used to calculate the carbon footprint of the designed building are presented in Table 2. The total natural gas consumption amount examined under Scope 1 is 8840 m^3/year, electricity consumption examined under scope 2 is 17970 kWh/year, fresh water 2774 m^3/year, wastewater 2774 m^3/year, and solid waste 17958 kg/year examined under scope 3.

Table 2. Activity data and emission factors used in calculations

Activities	Scope	Activity Data	Emission Factor (EF)
Natural gas consumption	scope 1	8840 m^3/year	1.88496 kg/m^3 CO_2 [18]
			0.000168 kg/m^3 CH_4 [18]
			0.00000336 kg/m^3 N_2O [18]
Electricity consumption	scope 2	17970 kWh/year	0.440 kg CO_2-eq/kWh [19]
Fresh water use	scope 3	2774 m^3/year	0.271 kg CO_2-eq/m^3 [20]
Wastewater treatment	scope 3	2774 m^3/year	0.646 kg CO_2-eq/m^3 [21]
Solid waste disposal	scope 3	17958 kg/year	0.301kg CO_2-eq/kg [21]

The highest share of the carbon footprint belongs to natural gas consumption with 16665 kgCO_2-eq emission value. The CO_2 emission value of other activities was calculated as 7907 kgCO_2-eq for electricity, 5405 kgCO_2-eq for solid waste disposal, 1792 kgCO_2-eq for wastewater treatment, and 752 kgCO_2-eq for water use, respectively (Table 3).

Table 2. CO_2 Emissions of the investigated activities

Activities	CO_2 Emission [kgCO_2eq /year]
Natural gas consumption	16665
Electricity consumption	7907
Fresh water use	752
Wastewater treatment	1792
Solid waste disposal	5405
Total	32521

In similar studies in the literature, it is reported that the highest ratio of the carbon footprint of buildings used for residential purposes is caused by natural gas and electricity consumption (Ozen, 2022; Water UK, 2007; Republic of Turkey Ministry of Energy and Natural Resources, 2022; Istanbul climate change action plan, 2021; Atmaca and Atmaca, 2022). The data obtained from this study (natural gas: 51% and electricity: 24% are compatible with studies in the literature (Figure 3). However, the size of the carbon footprint of the buildings used for residential purposes and the ratio of emission sources in the carbon footprint are directly related to the size of the building and the climatic conditions of the place, seasons, and the type of fuel used (Lai, 2014). Depending on the type of fuel used in cold climate conditions, the amount of CO_2-eq from heating activities is high. On the other hand, in tropical regions, CO_2-eq from electricity and air conditioning gases is high due to the high need for cooling and the use of air conditioners.

The carbon dioxide uptake capacities of the plant species used in the green wall system are different from each other. Among the examined plant species, *Z. matrella* had the highest CO_2 uptaking with 1753 kg CO_2-eq/m^2.year. The lowest CO_2 uptake was calculated for the *S. spurium* plant (243 kg CO_2-eq/m^2.year). The CO_2 uptaking amount to be obtained as a result of using all plants in the green wall system is 1147 kg CO_2-eq/m^2.year. In case the *Z. matrella* plant, which has the highest CO_2 absorption, is used, the total carbon footprint can be reduced by 5.38% with the green wall system. In addition, CO_2 capture processes with plants are considered within scope 1. Considering that the greenhouse gas emission in Scope 1 is 16665 kg CO_2-eq/m^2.year, it can be said that emissions within scope 1 can be reduced by more than 10% with the green wall system.

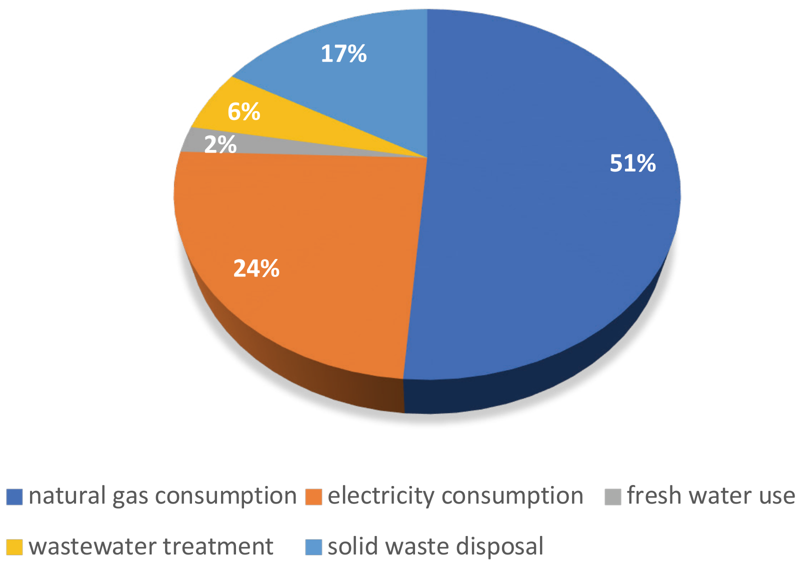

Figure 3. The proportions of the examined activities in the carbon footprint

However, although the rates are different according to the species, CO_2 uptaking occurs in all kinds of plants. CO_2 captured by plants increases over time as it represents plant biomass (Marchi et al., 2015). Therefore, when the results obtained are evaluated in the long term, the contributions of the green wall system in combating global climate change can be better understood.

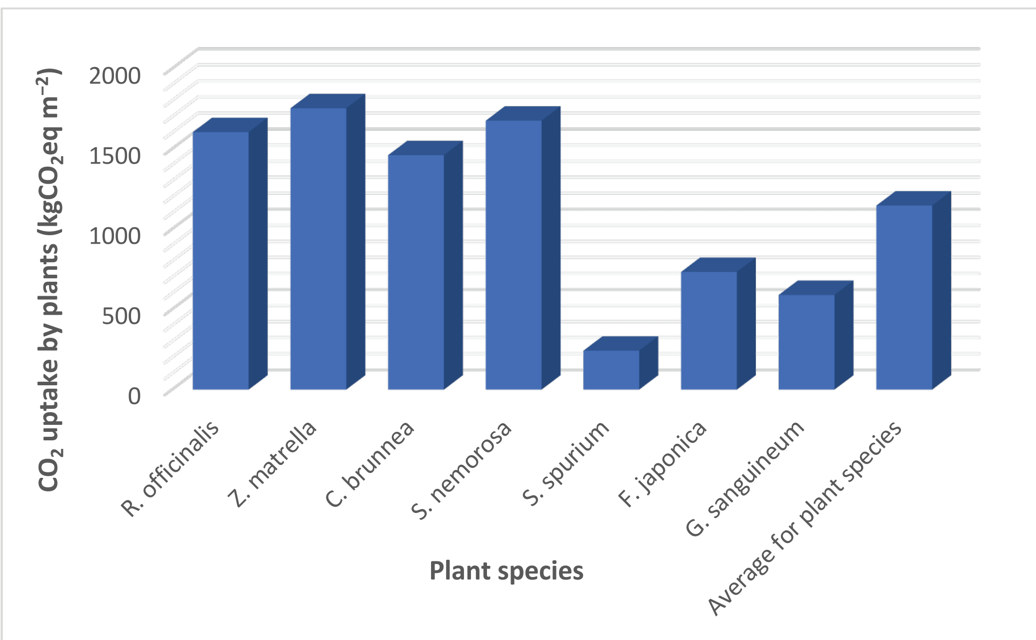

Figure 4. Annual active CO_2 uptake by plants ($kgCO_2$-eq/m^2)

4. Conclusion

The CO_2 uptake process of green walls depends on many factors such as plants, plant residues, growing media, microorganism activities. Literature studies have generally focused on the effects of these factors on CO_2 uptaking separately. In this study, in order to clearly reveal the potential of green walls, the CO_2 uptake process carried out by plants is considered as a whole.

The most important source of CO_2 emission in buildings used as residential buildings is energy consumption. Energy consumption in residences varies depending on environmental and socio-demographic characteristics. Therefore, in determining the size and characteristics of green wall systems to be added to buildings for carbon reduction, it is necessary to obtain reliable information about the type and amount of energy consumed by examining the environmental and socio-demographic characteristics of the building's location. In addition, a more comprehensive carbon footprint can be found by taking into account all daily life activities such as transportation, etc. which are not used in the calculations in this study.

The amount of CO_2 that can be uptaken in the green wall system is directly related to the plant species. However, plants with high CO_2 uptake capacity cannot be used in all green wall applications. In plant selection, the climatic conditions of the place where the building will be built should be considered first. The compatibility of the plants to be used with the climatic conditions and the provision of ideal conditions for healthy and rapid growth will be decisive in the amount of CO_2 captured. Otherwise, it becomes difficult to care for the plants in the green wall system. Applications such as irrigation, fertilization, spraying, and replacement of dead plants can become an additional source of CO_2 emissions.

In this study, in line with the studies in the literature, it has been concluded that green wall systems will contribute to the carbon-neutral building target with CO_2 uptaking and is an important parameter to be considered in architectural designs. Considering their additional contributions to heat and sound insulation and gray water treatment, the importance of green wall systems increases even more. However, in determining the exact amount of CO_2 that can be captured by plants, other design elements such as green roofs and paysage applications should also be taken into account.

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