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# Review of Green Walls on Building Energy Consumption

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## Abstract

Today, with the advancement of technology, industrialization, and scientific progress, life has moved toward mechanization. Attention to the environment, energy resources, and air pollution has become a significant concern of the present era. Creating interactive green roofs and walls is a way to make cities more sustainable, and one of the modern solutions to urban problems, reducing air pollution through the creation of green spaces. Green walls have tremendous potential in terms of energy savings and increasing the lifespan of buildings, which are among the side benefits of this approach. The use of vertical green systems, known by various names such as vertical gardens, green walls, energy storage, building facade beautification, and urban form enhancement, is gaining popularity. Green architecture is also one of the new trends and approaches in architecture that has attracted many contemporary designers and architects worldwide in recent years. This architecture, which originates from sustainable development concepts, seeks compatibility and harmony with the environment as one of humanity's essential needs in today's world. The research method in this article is descriptive-analytical. First, by reviewing the theoretical background, various types of green walls are named. Then, the type and extent of the effects of green walls on building cooling and heating are analyzed and explained based on the collected data. The goal of creating green buildings is to improve air quality, prevent energy loss used for cooling and heating, and reduce the negative impacts of construction on the environment. This results in the design and use of green walls in the building's exterior or interior spaces as one of the strategies toward implementing green architecture. In fact, a green fence goes beyond being just a plant-covered facade; it is a structure that, although having a relatively simple function, requires precise design of its components and the correct selection of plants to achieve the goals of reducing cooling and heating costs, mitigating the urban heat island effect, and increasing wind resistance.

**Keywords:** Green architecture, Sustainable development, Energy loss, Building cooling and heating, Green wall.

# 1 | Introduction

## 1.1 | Problem Statement

Green walls, also known as living walls, bio-walls, eco-walls, or vertical gardens, are walls that are partially or fully covered with green plants embedded in a growing medium similar to soil or substrate. These living walls

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are found worldwide and may be located inside or outside buildings; they can stand alone or be attached to other walls, and come in various sizes and shapes. Additionally, smart irrigation systems, special soil, and filtration must be considered in these walls to maintain an aesthetically pleasing green wall.

A green wall refers to a wall that is covered with vegetation either as a structure itself or as part of a building. In fact, the concept of a green wall applies to all systems capable of creating a vertical green surface (for example, wall facades, parapets, interior partitions, etc.) [1]. The questions raised in this study are:

I. How does a green wall affect the cooling and heating of a building?

II. What types of plants are used in this type of architecture?

III. How do plants influence the exterior walls of buildings?

IV. In which directions of the building is the impact of these plants noticeable?

The purpose of this study is to identify the type of impact green walls have on the cooling and heating of buildings. In fact, covering buildings with plants on a considerable urban scale can improve biodiversity, increase air quality, reduce air exchange between inside and outside to lower surrounding temperatures, and increase indoor temperature. The conclusion is that the variable "type of green wall" affects the variables of cooling and heating costs, energy efficiency, wind resistance, and urban heat island effect. These effects are respectively reduction, increase, and reduction.

# 3 | Research Background

## 3.1 | History of Green Walls

Green walls have been considered standard structures in many countries for hundreds of years, with their primary function being insulation on building walls using a combination of plants and soil layers. In cold regions, people used green walls or green buildings to retain heat inside, and in hot areas, to prevent heat from entering the building.

It seems that the initial idea for large modern green walls was introduced by a French botanist named Patrick Blanc, who is considered the inventor and promoter of today's green walls. Interestingly, the use of green walls is not new and dates back long before Christ. The sloped walls of the Ziggurat of Nana, built around 2100 BC, were covered with trees and shrubs. The following ancient example of green walls can be found in the Hanging Gardens of Babylon between the 8th and 10th centuries BC, built around 600 years BC. Later, from Scandinavia to Japan, various civilizations used climbing plants to cover buildings and construct what we today call green facades.

Green facades have been important in art, handicrafts, and modern movements in Europe. For example, in the early 20th century (the Art Nouveau movement in Germany and Austria), climbing plants (decorative ivy) were used on buildings to create a seamless transition between house and garden. In England, the Garden City movement is a significant example of green facades [2].

## 3.2 | Theoretical Foundations

A green wall is defined as a wall that is either an independent structure or part of a building covered with vegetation. The vertical green garden system is a term used for all forms of green walls. In this system, the roots of climbing plants are located either in the ground (soil), within the wall, or in modular panels. Wang considers vertical green systems to include any method of placing plants on building facades.

Green walls are known by various names and abbreviations such as vertical green systems, green wall panels, living walls, vertical plant-covered walls, double-skin green facades, bio-walls, and oxygen-producing walls. Among these terms, the vertical green systems term is the most comprehensive and includes the others. Based on researchers' opinions, any wall covered by different plants using various methods is considered a vertical green wall, which provides many benefits through two main functions: shading and the evaporation-transpiration phenomenon [3].

## 3.3 | Types of Green Walls

Generally, green wall systems are divided into two categories: green facades and living walls.

### 3.3.1 | Green Façade

A green facade is a type of green wall where a simple structure, such as scaffolding, is attached to the building wall and acts as support for climbing plants like ivy, Virginia creeper, etc. Green facades can rely on the building facade, railings, and columns or be constructed as independent structures. The scaffolding for green facades can be made of various materials such as wood, metal, mesh, cables, etc.

In this type of green wall, climbers are planted at the base of the wall, in the ground, or in pots if ground planting is not possible, and are guided upwards by the scaffolding attached to the wall. In more complex cases, plants can be placed in flower boxes on balconies, rooftops, and repeated on the building facade [4], [5].

Perini et al. [6] investigated the difference between green walls attached directly to walls and green covers separated from the walls and found that the air temperature near the directly covered green wall decreased by about 1.2°C compared to a regular wall, and near the indirectly covered green wall decreased by about 2.7°C.

**Table 1. Results obtained by Parini [5].**

| Laboratory Results Obtained by Parini [5] | | |
|---|---|---|
| **Wind Speed Reduction (m/s)** | **Temperature Reduction (°C)** | **Vertical Green Wall** |
| 0.43 | 1.2 | Direct exterior green wall |
| 0.55 | 2.7 | Indirect exterior green wall |

Green facades can be divided into several different types:

**Traditional Green Façade**

Traditional green facades, or direct green facades, are those that are directly attached to the wall and consist of climbing plants that grow directly and without any barrier along the wall [6]. This method is associated with damage to materials, attracting animals, and high maintenance costs.

**Double-Skin or Green Envelope Façade**

In the double-skin or indirect green facade, which is attached to the wall using a supporting structure, the aim is to create a green covering that is independent of the wall itself [7]. The indirect green facade can itself be of the modular scaffold type. Modular scaffolds are very lightweight metal frameworks that are either placed on the building's wall or have an independent structure to support the climbing plants.

### 3.3.2 | Living Wall or Oxygen-Producing Wall

In this method, boxes are used that are attached to a vertical support system and sometimes to the wall structure itself. The vertical support system consists of a frame made of stainless steel profiles connected at specific intervals by stainless steel rods. The living wall features an automatic drip irrigation system, where a pump supplies water, and a filter is installed after the pump removes suspended particles from the water. A main pipe runs vertically from the pump, branching out into secondary pipes connected to each box. These pipes and nozzles are placed inside grooves provided in the boxes. A timer controls the watering intervals for the plants.

Living walls with modular panels have shown better capacity to reduce the surface temperature of the wall and maintain the lowest range of average surface temperature fluctuations. The maximum temperature reduction of the wall surface due to cooling by the living wall is 11.58 degrees Celsius. Olivieri and colleagues studied a residing wall on an experimental building. They found that during daytime hours, the indoor temperature with the living wall was 20% lower than a similar wall without plant cover.

Alexander and Jones, in their research, simulated the effect of green roofs and green walls on the urban environment. The simulation results show that green walls have a more substantial impact than green roofs within urban areas [8]. The combination of green roofs and walls leads to 32 to 100% energy savings in the building's cooling load and provides thermal comfort inside the building.

Overall, research on green walls and living walls indicates that both systems have great potential in reducing building temperature, saving energy, and mitigating the urban heat island effect. Therefore, this study aims to investigate the factors affecting building cooling and heating. Compared to green facades, these walls require much more maintenance. These walls are themselves divided into two categories:

**Active Systems**

These systems are the newest type of green walls. In this system, the air produced by plants is used in the building's HVAC (heating, ventilation, and air conditioning) system. This type of wall is designed to integrate with the building's heating, cooling, and ventilation systems to purify indoor air and act as a thermal regulator [9]. These walls are based on the science of biological air purification mediated by plants, according to research conducted at Waterloo Hospital in Canada. Green walls with biological filters increase air purification capacity. The natural coverings act as motors, purifiers, and cleaners, and the ventilation system operates by drawing air from the root system.

**Passive Systems**

In this system, no air movement occurs from the roots into the building's ventilation system. The effect of passive systems on indoor air quality raises many questions. In other words, green walls are protected behind glass to have more predictable airflow compared to what happens in passive green walls. Passive walls have no mechanism for air circulation; instead, they are kept open to create as much relative improvement in free air circulation as possible. Oxygen-producing walls have an independent structure separate from the main building façade and are placed at a close distance, stabilized by the building. Designing these walls involves various details, mostly related to how plants are maintained on the wall and the shape of the supporting system molds [10].

## 3.4 | Construction Methods of Green Walls

### 3.4.1 | Modular Green Wall

These walls consist of very lightweight metal scaffolds made of galvanized steel, either placed on the building wall or having independent structures to support climbing plants. These panels can also be shaped to form desired curves and shapes [11]. Due to the rigidity and strength of the panels, this modular system can bridge different parts of a building or serve as independent green walls.

### 3.4.2 | Cable Green Wall

The cable system is used to support leafy, fast-growing climbing plants [12]. It consists of a series of balls, usually made of stainless steel, which allow cables to pass through and stretch or contract to form the desired network, serving as support and carrier for the plants. The balls are attached to the wall surface by screws passing through their central holes. The placement and spacing of the balls on the wall are chosen according to a specific design.

### 3.4.3 | Mesh Green Wall

Mesh wall is a very lightweight structure that creates a barrier of steel meshes for climbing plants, connected either to the wall or the building's structure [13]. Mesh systems are often used to support slow-growing plants that need more support. Mesh systems are more flexible than cable systems and allow more diverse design options.

### 3.4.4 | Polymer Felt

This design involves a planting system where living plants grow on a vertical surface. It includes a polymer felt fabric with suitable drainage, folded in a specific way over the underlying frame so that one or more pots or vertical planting containers are created in rows with upward-facing pockets. Plants are placed in initial sleeves and cultivated in these containers [14].

This method is newer compared to other green wall installation systems and has more advantages. Compared to other methods, it offers a lighter wall structure, easy plant replacement and changes, better root ventilation, a stronger drainage system, freedom to select different plants, and more.

### 3.4.5 | Hydroponic Green Wall

In the hydroponic method, the green wall substrate is water-based, meaning there is no soil; water provides all nutrients for the living wall. This method allows greater plant variety, thinner and lighter structures, and the possibility of designing detailed patterns by first drawing the design and then installing flowers and plants. The hydroponic green wall is very attractive and equipped with a smart system that injects nutrients into the plants automatically [15]. Interestingly, the origins of hydroponic concepts date back to ancient Iran.

## 3.5 | Advantages of Green Walls in Cooling and Heating Buildings

### 3.5.1 | Increased Energy Efficiency–Reduction of Heating and Cooling Costs

An uninsulated wall causes warm air to escape from the building in winter and allows heat from outside to easily enter in summer. A green building can create thermal resistance along the wall, reducing energy consumption for heating and cooling the building [16].

### 3.5.2 | Temperature Regulation–Reduction of Urban Heat Island Effect

With population growth and the shortage of sufficient land for construction, building density has increased in large cities. This high density has caused many negative effects. One of these effects is the urban heat island effect, which causes the average temperature in the city to rise above normal levels. This temperature increase leads to higher energy consumption for cooling. Mineral surfaces such as concrete and standard building roofs increase urban air temperature, contributing to the heat island effect. The lack of plants and tall buildings prevents natural cooling of city air by wind, causing cities to reach higher temperatures than their surrounding environments. The increased city temperature also reacts with gases emitted by vehicles, leading to ozone formation in the city. This temperature rise increases energy demand. Covering walls with vegetation helps reduce city temperature and lowers energy consumption.

### 3.5.3 | Reduction of Wall Heat Transfer

Increasing the number of wall layers increases the thermal resistance of the wall. The added layers are: in traditional green facades, one layer including the plants; in indirect green facades, two layers including plants and air; and in living walls, three layers including plants, air, and soil-containing boxes. Heat transfer through these layers is both slower and reduced, thereby increasing the wall's thermal capacity and resistance, ultimately lowering heat transfer. Green walls create a microclimate between the building wall and the green facade with lower temperature and higher relative humidity, enhancing the green facade's capacity to reduce heat on the building surface. Simulations show that the temperature in the intermediate space between the green facade and wall in hot months is 1.36°C lower than outside, and conversely, in winter, 3.8°C higher than outside. In other words, this intermediate space is cooler in summer and warmer in winter than outside, indicating a milder microclimate between the exterior and interior of the building, which reduces heat transfer. Temperature reduction is more noticeable around noon, emphasizing the benefits of vertical greenery.

The most significant temperature reduction and the smallest temperature fluctuations occur where leaf density is highest; average surface wall temperature reductions up to 11.58°C and reductions in the underlying layer temperature up to 9°C have been reported. This significant wall temperature reduction leads to lower cooling loads and consequent energy cost savings. Temperature reduction patterns correspond to changes in leaf density over time, meaning that as leaf density decreases, temperature reduction also diminishes [14]. Temperature reduction highlights the importance of leaf density and healthy plant growth for more effective thermal performance of green walls. Accordingly, careful selection of plants compatible with specific climate conditions and green wall types is essential for project success. Factors affecting the thermal performance of green walls include various elements such as the type of green wall layers, substrate type, thermal resistance of the support structure, moisture content of the substrate, panel dimensions, leaf shading, plant insulation capacity, as well as leaf area, geometry, and color.

### 3.5.4 | Wind Resistance

In an experimental study by Perini and colleagues, wind speed reduction was measured. For this purpose, three walls with the following specifications were selected:

I. The first wall with a direct green facade covered by ivy, 20 cm thick

II. The second wall with an indirect green facade covered by evergreen ivy, 10 cm plant layer plus 20 cm air layer

III. The third wall is a living wall type, consisting of plastic modules filled with soil, 22 cm thick, and an air layer 4 cm thick.

Wind speed from September to October (cool season) was measured at the middle of the leaf layer, the middle of the air layer, 15 cm in front of the green wall, and 1 meter in front of the green wall using a hot-wire anemometer. The results are as follows:

I. In the direct green façade, the first wall wind speed decreases by 0.55 m/s. However, inside the 2 cm air layer, wind speed increases by 0.29 m/s.

II. In the living wall, the third wall wind speed reduces from 0.56 m/s to 0.1 m/s. No wind speed increase is observed in the 4 cm air layer, because the 20 cm air layer is not stagnant, but the 4 cm air layer is stagnant. This study states that for different green wall systems, the optimal air layer thickness is between 4 and 6 cm. It can also be concluded that the most tremendous impact on the thermal resistance of the envelope belongs to the living wall system, first due to the 4 cm air layer, and second due to the thermal resistance of the plastic modules and the soil inside them. Also, the presence of multiple layers (felt, plastic, soil, etc.) reduces wind penetration.

### 3.5.5 | Evaporative Cooling

Assuming full radiation exposure on the plant leaf, its reflection and heat absorption can be categorized as follows:

I. 5 to 30% is reflected.

II. 5 to 20% is absorbed and used for photosynthesis.

III. 10 to 50% is converted to heat.

IV. 20 to 40% is used to convert water to vapor.

V. 5 to 30% passes through the leaf.

Green roofs and walls cool the air by evaporating water. Through evaporative cooling, a large portion of solar radiation can be converted into latent heat. When 1 liter of water evaporates this way, 2260 kJ of energy is converted to latent heat, which can cool 1 ton of concrete by 2.56°C. Also, the latent heat from evaporative cooling reduces long-wave radiation emission to the outside at night, helping to retain indoor heat during nighttime.

Regarding the relative humidity of the interface space between the green wall and the main wall, it has been observed for all geographic orientations that during the leafy period, the relative humidity in the interface space is higher than outside. This difference increases with leaf growth, reaching up to 7% more in August on the southwest side. However, in the leafless period, the relative humidity in the interface space is lower than outside in all directions, with up to an 8% decrease in October on the southwest side. In other words, relative humidity is higher in the interface space during summer (leafy season) but higher outside during winter (leafless season). In windy months such as Ordibehesht (April-May), these differences are lessened. Thus, a microclimate forms in the interface space with higher temperature and lower relative humidity in winter, and lower temperature and higher relative humidity in summer. A microclimate shows the effect of evaporative cooling by plants in green walls.

### 3.5.6 | Reduction of Temperature Fluctuations

Evaporative cooling and increased relative humidity from plant cover, along with the creation of a microclimate in the interface space between the green curtain and the building wall, reduce temperature fluctuations; tests on plant-covered walls showed that the outside surface temperature fluctuated only within a narrow range of 27.9 to 29.5°C. Plants can reduce daily temperature fluctuations by up to 50%. Reducing daily temperature fluctuations on the wall surface decreases the formation of cracks due to thermal expansion and contraction. Daily temperature fluctuations lead to increased facade longevity by reducing wear, breakage, and maintenance or replacement costs of facade elements.

## 3.6 | Suitable Plants for Green Walls

When selecting plants for green walls, consideration of severe regional factors is of primary importance, such as severe dryness, poor water quality, soil conditions, etc. The following general points should also be taken into account:

### 3.6.1 | Climatic and Ecological Position of the Site, including Light, Temperature, Humidity, etc.

Factors such as light intensity, ambient humidity, temperature, quantity and quality of irrigation water, wind intensity, altitude, soil, and others affect the selection of appropriate species.

### 3.6.2 | Choosing Native Plants

If incompatible species are chosen, maintenance costs increase due to drought, high water demand, pests, and other issues. Native plants are more resistant to temperature fluctuations, soil type, and other environmental stresses than non-native species.

### 3.6.3 | Choosing Evergreen Plants

Evergreen plants depend on the climate. In cold and dry climates, using dense cover plants that reduce sunlight penetration between leaves is not recommended.

### 3.6.4 | Choosing Resistant Plants

**Visual and Aesthetic Evaluation of Plant Species**

Factors such as color diversity, scent richness, form, and deciduousness significantly affect the visual beauty of green walls.

**Plant Pests**

The environment is a shared habitat for many animals along with plants, and these animals are part of the life cycle. Many are harmless and considered beneficial insects. However, some plants naturally encourage the growth and spread of some animals; for example, sticky vine plants are suitable habitats for lizards. Therefore, this should also be considered in plant selection, especially in residential spaces.

## 3.7 | Characteristics of Suitable Plants for Green Walls in Shady or Sunny Spaces

### 3.7.1 | Parthenocissus (Boston IVY)

A climbing and twining shrub that can grow up to 10 meters high, with very fragrant flowers. It prefers light, alkaline soil with good drainage and abundant water. The minimum tolerable temperature is -15°C.

### 3.7.2 | Pothos (Epipremnum aureum)

Has permanent woody, climbing, and adhesive stems, suitable for covering walls and fences. It is a groundcover and evergreen plant that grows well in shade, is highly adaptable to various environmental conditions, tolerates high and low temperatures, low and high light, and grows well on northern and eastern walls. Suitable for semi-shaded or shaded environments with rich, organic soils.

### 3.7.3 | Lysimachia

Has golden leaves in sunlight and green leaves in shade. Requires partial shade, is a groundcover, resistant or semi-resistant to cold, and prefers soil rich in organic matter with good drainage.

### 3.7.4 | French Rose (Succulent type)

Grows up to 30 cm. Leaves are thick and fleshy, and require sufficient sunlight (summer in shade, winter in adequate light). Minimum tolerable temperature is -10°C, needs little water, and prefers light soil with good drainage.

### 3.7.5 | Alcea (Hollyhock)

A perennial plant 3 to 8 meters tall. Newly planted bushes require regular watering; established bushes are drought-resistant. Tolerates partial shade during parts of the day.

## 3.8 | Benefits of Using Plants on the Exterior Walls of Buildings

Plant cover, such as climbing vines, is a good climatic tool, especially when growing on the exterior surface of walls, bringing many advantages. The most apparent benefit is shading in summer. Dense plant cover acts as a barrier between direct solar radiation and the outer surface of the wall, reducing the outer surface temperature and lowering heat transfer from outside to inside the building.

The only downside of having vegetation near the exterior wall in summer is that the plant layer traps air close to the building surface, reducing the effectiveness of wind to remove these warm air layers. However, any wind strong enough to pass through the foliage will solve this issue, and the cooling effect of water vapor on the leaves also helps cool the surroundings.

One benefit of green walls is improving energy efficiency. These walls increase thermal insulation capacity by regulating outside temperature. The amount of energy saved depends on various factors such as climate, distance from the building sides, and type of vegetation. Green walls affect both cooling and heating by:

I. Trapping an air mass within dense vegetation.

II. Limiting heat transfer through the thickness of the vegetation.

III. Reducing ambient temperature by shading and releasing moisture from leaf surfaces.

IV. Creating a windbreak during cold winter months.

V. Reducing the internal energy required for heating and cooling from outdoor air.

The impact of sunlight in urban areas is undeniable, given city structures and layouts. Urban temperatures rise due to replacing natural vegetation with pavements, buildings, and other necessary infrastructure for growing populations. This phenomenon, known as the urban heat island effect, converts sunlight to heat. Using plants in urban environments cools buildings and surroundings, provides shade, reduces reflective heat, and produces moisture. The benefits of plants in this context include:

I. Enhancing the natural cooling process.

II. Lowering the ambient temperature in urban areas.

III. Breaking vertical air flow and cooling air as its movement slows down.

IV. The increase in temperature in modern urban environments, along with the growing number of vehicles, ventilation systems, and industrial pollution, leads to an increase in nitrogen oxides, sulfur oxides, organic compounds, carbon monoxide, and fine particles.

V. Green walls also create thermal insulation, resulting in energy savings for heating in winter and cooling in summer, ultimately reducing energy-related costs. It has been observed that the exterior surface of a wall covered by a green wall is 10 degrees Celsius cooler than an exposed wall. With rising costs and energy shortages, this characteristic of green walls helps reduce energy consumption for cooling or heating. These structures have the potential to reduce your electricity bill by up to 20%.

# 4 | Analysis

One of the main concerns of modern life relates to air pollution, environmental importance, energy resources, and so on. Using green roofs and walls is one of the contemporary solutions for urban problems and reducing air pollution. A notable side benefit of this approach is that green walls have great potential in energy efficiency and increasing the lifespan of buildings. In fact, vertical green systems known by various terms such as green walls, vertical gardens, green facades, living walls, biowalls, and oxygen producers are all based on the concept of sustainable development. A green wall is a wall that is partially or fully covered with green plants growing in a growing medium such as soil or substrate. These walls can be installed inside or outside buildings, either freestanding or attached to another wall, and come in various sizes and shapes.

The initial idea of these walls was first proposed by a French botanist named Patrick Blanc. Also, ancient examples of vertical green systems include the sloped walls of the Zigurat Nana and the Hanging Gardens of Babylon.

Green walls can be generally classified into green facades and living or oxygen-producing walls. Within green facades, there are traditional green facades and double-skin green facades, which themselves include active and passive systems. The difference between green facades and living walls is that in green facades, part or all of the building is covered by plants rooted in the ground or growing on a cable structure. In contrast, living walls use boxes that are connected to a vertical support system and sometimes attached to the wall structure itself. Living walls require more maintenance compared to green facades. Another classification of green walls, based on type and construction method, divides them into modular walls, cable green walls, mesh green walls, polymer felt, and hydroponic green walls.

**Advantages of Green Walls**

Green walls create thermal resistance, increasing energy efficiency and reducing cooling and heating costs. They also reduce the urban heat island effect, which generally causes city temperatures to be higher than those in surrounding areas. By reducing this effect, green walls lower energy demand.

Another advantage is reducing heat transfer through walls. Increasing the number of wall layers increases thermal resistance, which slows down and reduces heat transfer. The wall increases the wall's thermal capacity and resistance, thereby decreasing heat transmission. This reduction in wall temperature leads to reduced cooling loads and energy savings. Wind resistance, evaporative cooling, and reduction of temperature fluctuations are other benefits of green walls. Evaporative cooling converts large amounts of solar radiation into latent heat, which reduces long-wave radiation emission to the outside at night, helping retain indoor heat overnight. Additionally, evaporative cooling and the higher relative humidity caused by the vegetation cover create a microclimate in the space between the green facade and the building wall, reducing temperature fluctuations. This temperature reduction decreases cracks caused by thermal expansion and contraction, thereby increasing the building's lifespan.

Finally, plants should be selected based on geographic location, preferring evergreen and native species adapted to regional conditions such as heat and water needs, to minimize maintenance and consumption costs. Plants such as Parthenocissus (Boston Ivy), Pothos, French Rose, and others are suitable choices for green walls in sunny or shaded spaces.

# 5 | Conclusion

The conducted research leads to the conclusion that green walls and roofs have numerous advantages, including: increasing energy efficiency (reducing heating and cooling costs of buildings), temperature regulation, reduction of the urban heat island effect, improving the mental well-being of city residents, protecting buildings, increasing property value, managing stormwater, reducing greenhouse gas emissions, building protection, creating local jobs, and reducing noise pollution.

However, this technique has one disadvantage: maintaining green walls during the winter season. In winter, due to the cold, the green vegetation tends to dry out. Iran is a hot and dry country, and in the southern regions, summer temperatures can exceed 40°C. In these areas, sunlight in summer is extremely intense, and this strong radiation produces significant heat on rooftops. Therefore, the importance of green walls in reducing energy consumption becomes clear.

Consequently, green walls contribute to lowering regional temperatures, thereby reducing cooling loads. Considering the lack of space for planting greenery in many urban areas, green walls are among the best solutions for increasing green space. It is important to note that to evaluate the average annual energy use of a building, the lighting levels and required electrical energy, considering the shading effect of the green façade, must be fully simulated. The total annual energy consumption, including heating, cooling, and lighting, must be analyzed, which requires a comprehensive, separate study.

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# Data Availability

All data supporting the findings of this study are derived from previously published literature and are cited accordingly. No new data were generated or analyzed during this research.

# Conflicts of Interest

The author declares that there are no known financial or non-financial conflicts of interest related to the content or publication of this article.

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