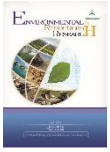

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Review Paper

A comparative study on details of green walls in different climates

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Abstract

Global warming has today turned to one of the most important environmental issues due to overuse of fossil fuels, and it needs serious attention. Since the mid-1970s, an urgent need was therefore felt around the world to reduce the use of energy for heating and cooling in buildings. Using green covers, especially green facades, in appropriate environmental conditions can be regarded as a method to achieve thermal comfort while maintaining the building energy consumption low as well as reducing greenhouse gases emission. The present paper investigates the features related to living walls in different climates. Based on results, due to reduced heat absorption, evaporative cooling and low thermal conductivity, the hotter and drier the climate, the higher the efficiency of the green wall as well as temperature reduction will be. On the other hand, using of green walls in temperate and hot and humid climates has a positive effect, but because of the humidity factor, open or closed air layers should also be considered. The green wall surface creates more stable relative humidity in the air layer near the wall surface without increasing the relative humidity of indoor air. At the urban scale in the warmer and drier climates, the green covers will have a dramatic effect on urban temperatures. Using green covers of buildings' walls, there will be a significant potential for reducing urban temperatures, while the highest efficiency will be achieved with simultaneous application of green surfaces for both roofs and walls.

***Keywords*:** Green façade, Living wall, Hot and humid, Temperate, Hot and dry

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Introduction

Green wall is a modern technology that is gradually finding its place in advanced contemporary cities in the world today. Green wall is referred to a wall, as an independent structure or part of a building, which is covered with greenery. Green systems such as green roofs and green walls are often used as aesthetic elements in buildings, even though the current technology employed in these systems can maximize the functional benefits of the plants with respect to the building performance (Lundholm, 2006). Green systems can also be regarded as part of a sustainable urban regeneration strategy and buildings retrofit (Sheweka *et al.,* 2011). In the study of climatic solutions and the use of green surfaces, green roofs have a much more important value than the green facade. In the studies, the definitions and general advantages of the green walls are further addressed and in some cases the climates are mentioned separately. Haggag *et al.* (2014) conducted studies on the variety of green walls and the direct and indirect green cover differences. Urban spaces and the influence of the living wall in reducing urban temperatures were studied by Johnston *et al.* (2004). Köhler (2008) performed the validation of the living wall function with respect to the still air layer and ventilated layer. Lundholm (2006) investigated an empirical study on monitoring the moisture content of the living wall, its dimensions and thickness in a hot and humid climate. The main factors affecting the living wall, of which climate is one of the most important ones were considered by Manso *et al.* (2015). The present paper deals with the prominence of the comparative investigation of thermal behavior of green walls in different climates.

Statement of the problem

Sustainable urbanization can bring many benefits that have been ignored in recent years in the wake of communities' haste for relentless development. The results of this short-sighted approach, including noise pollution, congestion and serious reduction in quality of life are visible to everybody. Sustainable development needs addressing the following factors: reducing energy and water consumption, minimizing waste and pollution, using environmentally friendly materials and having access to efficient public transport (Johnston *et al.,* 2004). Due to the lack of sufficient attention to ventilation and desired temperature and comfort in parking spaces and pilots in most buildings, residential complexes, etc., using a sustainable and economic method to create a pleasant atmosphere for residents and users is important. Green walls have their own benefits in different climates and adapting to local and climatic conditions is therefore necessary to benefit from their maximum efficiency.

The necessity and importance of the problem

Modern cities create a huge space of roofs and walls. Although all these spaces are not appropriate to grow plants, they are certainly more utilizable than what has been used in recent years (Dunnett *et al.,* 2008). Green walls provide a wide range of environmental and socioeconomic benefits. From the economic perspective, green walls add to the building value by increasing the green space, protecting the building structure and beautifying the environment. From the social perspective, green walls create and promote vitality and contribute to citizens' physical and mental health (Municipality of Tehran Parks & Green Spaces Organization, 2010). So, it is important to conduct studies on methods of green walls expansion as well as explanation, recognition and promotion of different aspects of green walls.

Methods

The present descriptive-analytical study was conducted using library information, photos, sketches and explanatory texts. To this end, after extracting, classifying and explaining the most important contents of journals, articles and reputable websites, the authors further developed the subject.

The research background

In studies of climatic solutions such as green walls, green roof has a stronger position compared to green wall. These studies have mostly investigated the definitions and general benefits of green façades and in some cases examined climates separately. It can be said in particular that few studies are conducted to compare the response rate of green walls in different climates. This paper conducts a comparative investigation of thermal behavior of green walls while presenting their executive details in different climates (Figure 1).

Types of green walls

Green walls are divided into two main categories; a) green façades and b) living walls, which are briefly presented in Figures 1 and 2 and described in the following text.

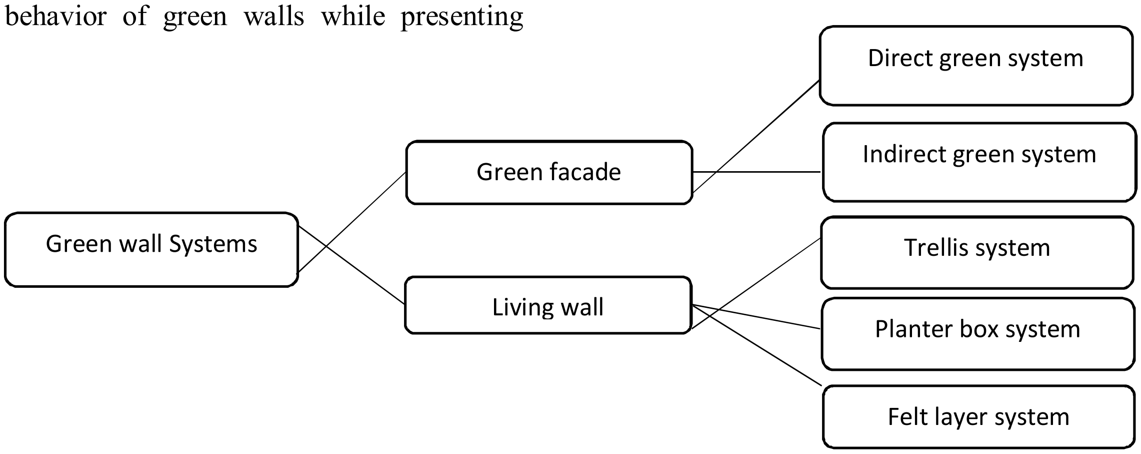


Figure 1. Types of green walls

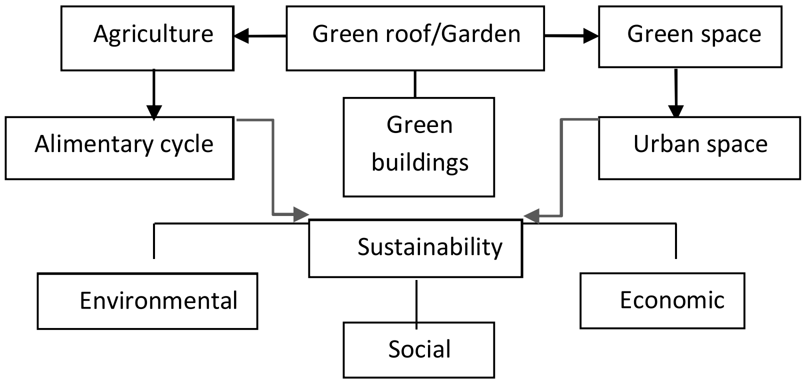


Figure 2. Different and diverse aspects of using green walls (source: Mahmoudi *et al.,* 2014)

Green façades

Green façades are based on using climbing plants, which cling directly to the wall or are reinforced by steel cables and scaffolds (Ottelé *et al*., 2011). Green façades consist of the following three methods and systems:

Modular trellis panel systems

These light modular panels are made of galvanized steel trellis and designed in a way that keeps the green façade at a distance from the wall surface. Modular trellis panels are placed side by side and cover a wide surface to create green façades (Figure 3).

Figure 3. Modular trellis panel systems (source: Greenroofs.org)

Cable systems and wire mesh trellis

Cable systems and mesh trellises are used alone or in combination to create green façades. Wire trellises are often used to support slow growing plants that need more support. The cable system consists of a series of balls, often made of stainless steel that pass the cables while allowing their traction to form the trellis intended and provide the necessary support for the plants (Figure 4).

Figure 4. Cable system and wire mesh trellis (source: Greenroofs.org)

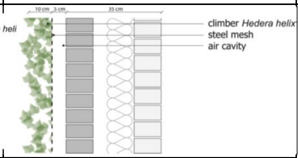
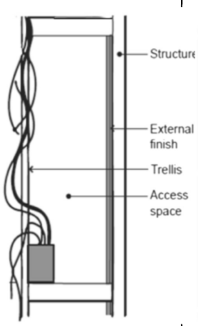
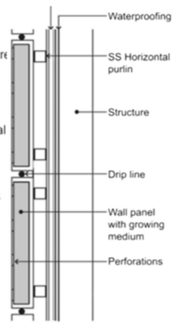
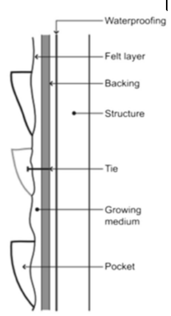
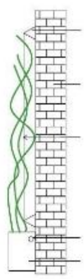
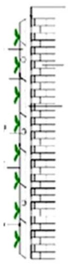
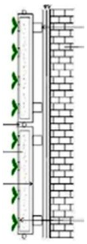
Living walls

The integration of greenery into buildings through green roofs and vertical green surfaces results in environmental and ecological benefits such as the improvement of air quality, saving energy consumption for heating and cooling and mitigation of the heat island effect (Ottelé *et al.,* 2011). Living wall systems and green façades have different features affecting their advantages. These features include cooling and insulation, aspects of foliage thickness, i.e. creating a still air layer and silhouette, amount of water, characteristics of materials and air cavities between different layers (Ottelé *et al.,* 2014). These walls include two types of inactive and active living walls (Table 1).

Inactive living walls

These walls consist of modular square or rectangular panels that provide a vertical medium for plant cultivation and their protection. These modular panels are connected, at a distance, to the building façade or structure with a light structure. Irrigation needs depend on the type of the system, plants and climatic conditions. Living green façade needs irrigation systems to supply the water needed to develop the plant. The irrigation water may be enriched with nutrients and minerals to develop and vitalize the greenery (Manso *et al.,* 2015). Inactive living walls are divided into three groups of scaffolds, modular panels system and felt systems (synthetic materials) (Feng, 2014).

Table 1. Details of the types of green façades and living walls (source: authors)

Green wall Systems				
Green facade		Living wall system (LWS)		
Direct green system	Indirect green system	Trellis system	Modular panel system	Felt layer system
				
Cable systems and wire mesh trellis	Modular trellis panel systems			
	 			

Active living walls

Active living walls, as one of the latest types of green walls, are designed such that they integrate the building heating-cooling and ventilation installations to filter indoor spaces air while acting as a heating regulator (Figure 5).

- This system uses the air generated by the plants in the building air conditioning system.
- The plants foliage absorbs carbon monoxide and carbon dioxide.
- The root microorganisms eliminate organic compounds and aerosols.
- The plants natural process generates fresh air, which is drawn and diffused through the building by a fan.

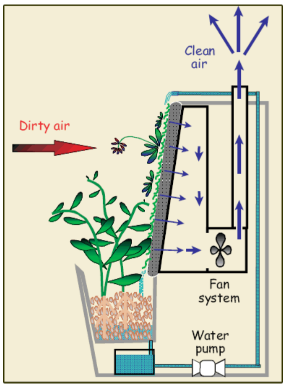


Figure 5. Active living walls (source: Greenroofs.org)

Effects of living walls in different climates

Hot and humid climate

The climatic indicator of a hot and humid climate is excessive heat and humidity. The purpose of using ideal green walls in this climate is therefore to reduce the thermal load while avoiding an increase in humidity. According to Chen, using living wall systems reduces the indoor temperature by a maximum of 1.1◦ C while the mean indoor temperature is 0.4◦ C less than spaces without LWS. A common concern about the factor of humidity is that the LWS may increase relative humidity due to its humid bed as well as the plants sweating. The relative humidity of the air layer, is higher than that in the environment during the day and lower at night (Chen *et al.,* 2013). The LWS creates therefore more stable relative humidity in the air layer near the wall surface without increasing the indoor relative humidity. The results indicate that the LWS has a high cooling effect on the wall surface and indoor space, and the exterior wall surface gives off heat to the environment instead of receiving heat. The LWS with still air has a better performance compared to the LWS with a naturally ventilated air layer. Results also show that the less the distance between the greenery and the wall, the better the cooling effect and the higher the relative humidity in the air layer (Table 2).

Temperate climate

An important effect of living walls is shadowing, which greatly affects the cooling period. The shadow effect also causes a temperature reduction and a radiation reduction, and also a proper design of the green cover can result in a significant energy saving (Köhler, 2008). According to Scarpa *et al.* (2014), the temperature fluctuations in LWS with still air follows the temperature fluctuation rhythm of outdoor temperature in smaller intervals such that the wall temperature is less than the outdoor maximum temperature by about 5 °C. While the layer investigated in including living walls with still air chambers follows the air temperature fluctuations and does not exceed the hottest outdoor temperature, the layer investigated in living walls with ventilated air chambers reveals a temperature difference of about 10 °C compared to outdoor, i.e. it is hotter on average by 10 °C (Scarpa *et al* 2014).

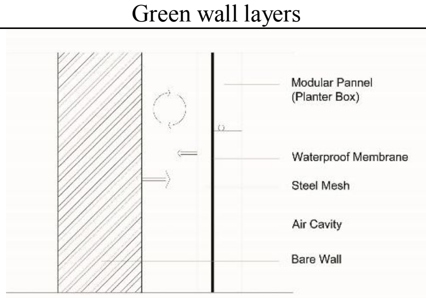
Hot and dry climate

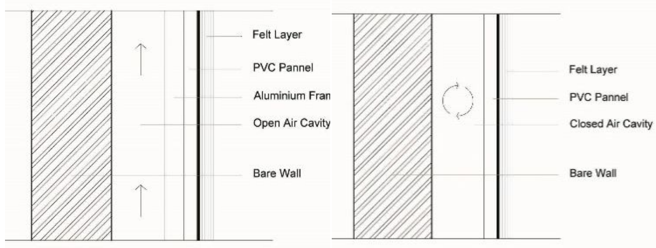
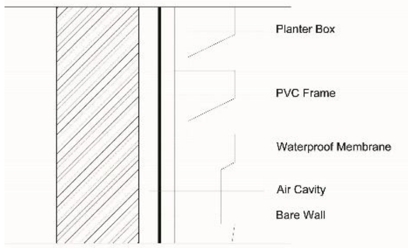
Excessive heat and very low air humidity are the two most significant climatic indicators in hot and dry climates. So, all efforts will therefore be made to control these two factors. Many studies confirm the thermal effects of vertical green surfaces on the building shell. There is credible evidence indicating that vertical green systems can reduce the air conditioning load by shadowing walls and windows, reducing the temperature, and a significant amount of annual savings can be considered. Results of investigations indicate that green façades in hot and dry climates can maintain a temperature which is lower than that of a simple wall at the peak daily heat of summer. This affects the building cooling load and improves the energy performance. According to Alexandri *et al*., (2008), using plants is more effective on the urban temperature in hotter and drier climates. Saving in energy consumption for the cooling of buildings will be 23%-100%.

The reasons why living walls cause temperature reductions are summarized as follows:

- -Reducing heat absorption caused by the plants
- -Evaporative cooling caused by irrigation
- -Heat resistance due to low thermal conductivity (Haggag *et al.,* 2014)

Table 2. Details of different types of living walls in different climates (source: authors)

Noteworthy points	Green wall layers		Climate
The LWS with still air layers has a better performance than the LWS with naturally ventilated air layers. The LWS creates more stable relative humidity in the air layer near the wall surface without increasing the relative humidity of indoor air			Hot and humid
In a temperate climate, green	a	b	Temperate

walls with open ventilable air layers have better performance than green walls with still air chambers		
Vertical green systems can reduce the cooling load by 23%. This figure is reduced by 20% using fans; an annual saving of 8% can therefore be achieved		Hot and dry

Different climates at urban scales

According to studies, when buildings sidewalls are covered with greenery, a significant potential will be created for urban temperature reduction. Regarding what has been emphasized before, according to Alexandri *et al.*, 2014, at roof levels, the daily temperature fluctuates at around 12.8 °C. There is a potential temperature reduction of up to 11.3 °C and 9.1 °C in urban areas in hot and dry climates (Alexandri *et al.*, 2008). It can be concluded that the hotter and drier the climate, the more significant the effects of the green coverage on the urban temperature. Although it has been proved that humid climates can also utilize green surfaces, especially when both walls and roofs are green. When surfaces are covered with greenery, more solar radiation is absorbed and temperature reduction will be higher.

Wind direction in low velocity air flows does not have a major influence on the temperature. In relation to the geometry of urban spaces, the wider the spaces, the weaker the effects of green roofs and walls. For all the climates studied, green walls have higher effects than green roofs within urban spaces. Green roofs are more effective at an urban scale due to the increasing effects at the roof level. A combination of green walls and green roofs will be accompanied with the highest temperature reduction possible in urban streets (Alexandri *et al.*, 2008).

Conclusion

When studying green walls, the most influential factor to be considered is climate, as this determines the effective factors such as selection of wall layers, types of coverage and type of air layers (open or closed). Based on our results, due to the reduced heat absorption, evaporative cooling and low thermal conductivity, the hotter and drier the climate, the higher the efficiency of the green wall as well as temperature reduction. This degree of temperature reduction can result in a significant annual saving. Furthermore, green walls have positive effects in temperate as well as hot and humid climates, in that open or closed air layers are considered owing to the effects of the humidity factor. In temperate climates, green walls with open ventilated air layers have a better performance than green walls with still air chambers. So, the LWS creates more stable relative humidity in the air layer near the wall surface without increasing the relative humidity of indoor air.

At the urban scale, in the warmer and drier climate, the green cover will have a dramatic effect on urban temperatures. Using green covers of buildings' walls, provides a significant potential for reducing urban temperatures, while the highest efficiency will be achieved with simultaneous application of green surfaces for both roofs and walls. On the other hand, since the living wall has a highlighted role in reducing environmental pollution, the use of green cover for cities exposed to severe pollution is an effective solution. In this regard, to promote such schemes, the use of other countries' experiences and research, and the need for legal verdict, such as the obligation to use, especially in hot and dry climates is highly felt. To provide a more sustainable status of temperature and humidity, using green systems should be considered both at the building level and at the urban scale.

References

Alexandri, E., and Jones, P. 2008. Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. Building and Environment. 43(4), 480-493.

Chen, Q., Li, B., and Liu, X. 2013. An experimental evaluation of the living wall system in hot and humid climate. Energy and Buildings. 61, 298-307.

Dunnett, N., and Kingsbury, N. 2008. Planting green roofs and living walls. Portland, OR: Timber Press.

Feng, H., and Hewage, K. 2014. Lifecycle assessment of living walls: air purification and energy performance. Journal of Cleaner Production, 69, 91-99.

Green Roofs for Healthy Cities: introduction to Green Walls- Greenroofs.org

Haggag, M., Hassan, A., and Elmasry, S. 2014. Experimental study on reduced heat gain through green facades in a high heat load climate. Energy and Buildings. 82, 668-674.

Johnston, J., and Newton, J. 2004. Building green: a guide to using plants on roofs. London Ecology Unit. London. UK.

Köhler, M. 2008. Green facades—a view back and some visions. Urban Ecosystems. 11(4), 423.

Lundholm, J.T. 2006. Green roofs and facades: a habitat template approach. Urban habitats. 4(1), 87-101.

Mahmoudi, M., and Pakari, N. 2014. Green Roof. Iran. Tehran. Nashreshahr Press.

Manso, M., and Castro-Gomes, J. 2015. Green wall systems: A review of their characteristics. Renewable and Sustainable Energy Reviews. 41, 863-871.

Municipality of Tehran Parks and Green Spaces Organization. 2010. Vertical Development of Green Spaces, "Green Roofs", Green Space Vertical Development Council, Municipality of Tehran.

Ottelé, M., Perini, K., and Haas, E.M. 2014. Life cycle assessment (LCA) of green façades and living wall systems. Eco-efficient construction and building materials, Cambridge: Woodhead Publishing Series in Civil and Structural Engineering, Elsevier. 457- 483.

Ottelé, M., Perini, K., Fraaij, A.L.A., Haas, E.M., and Raiteri, R. 2011. Comparative life cycle analysis for green façades and living wall systems. Energy and Buildings. 43(12), 3419-3429.

Scarpa, M., Mazzali, U., and Peron, F. 2014. Modeling the energy performance of living walls: Validation against field measurements in temperate climate. Energy and Buildings. 79, 155-163.

Sheweka, S., and Magdy, A.N. 2011. The living walls as an approach for a healthy urban environment. Energy Procedia. 6, 592-599.