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Techno-Economic Analysis and Cost Benefits of Green Walls for Building in Extreme Climate: Case Study Southwest of Algeria

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ABSTRACT

Green roofs such as green roofs (GRs) and green walls (GWs) have been one of the greatest attentions of architects and designers. In arid regions it is necessary to plant vertically, when urbanization continued due to the destruction of green spaces, it became very difficult to plant horizontally. In this regard, the methodology followed consists in evaluating the thermal effects of vegetation on the facade and the roof, covered with plants specific to the hot and arid climate. Then, using a dynamic simulation with Energy plus, we can measure the thermal impact of these green properties on the facade applied in an existing building. With a technical-economic analysis, we obtained a reduction of the various energy consumption values; cost benefits for green walls, and even reduce the effect of CO_2 emissions. Finally, we can effectively improve the exterior surface temperature, the thermal comfort inside the houses with low energy consumption thanks to the green facade.

1. Introduction

The use of green walls has developed since antiquity, one of the best-known examples being the Hanging Gardens of Babylon.

Over the past decade, the use of green facades and roofs has increased their presence in sustainable building design, providing several environmental and energy benefits. One of them is the energy saving potential in buildings, which plays an important role, especially in desert regions, where the climate is very hot and dry. Thus, the main objective of this work is to evaluate the thermal performance of constructions a single or collective house for the periods of cooling and heating. In addition, the green facades made it possible to decrease the hotness of buildings.

However, some research has paid particular attention to the characteristics of plants adapted to the climatic context. Nevertheless, there is no research done for extremely hot and dry regions. The arid climate of southern Algeria is the first reason that the building sector is responsible for 70% of electricity consumption, to maintain comfort in summer [1,2].

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For this, applying vertical greenery to the envelopes of buildings has certain drawbacks. In the study of Šuklje *et al.,* [3], the use of the bionic facade has positive effects to eliminates the disadvantages of green walls and allow the potential of cooling efficiency of the microclimatic. This type of layer presents a new photovoltaic cooling technique, demonstrate a good match of thermal performance between the bionic and green facade with lower surface temperatures of 20.8 K, which increases the daily electrical efficiency by 6.6% [3].

On the other hand, the modelling approach studies demonstrate that the vegetation presents as an identical layer by physical properties optimized using or investigational informations ± 1.3 °C of the VGS (Vertical Green Systems), while the heat flux on the inner face of the envelope deviates by less than ± 0.3W / m^2 measured values [2].

When it comes to the greening of buildings, there are a number of approaches used nowadays, such as facades covered with climbing plants or green-wall systems (built with prefabricated modular panels). These offer economic, environmental and social benefits, given the growing interest in restoring the environmental balance of urban areas; technological innovations have emerged in environmentally beneficial building practices [4].

2. Green Construction in Hot Arid Climate

2.1 Green Wall Systems

Various research papers have sought to determine the effectiveness of green-wall systems and their influence on the thermal transfer value, energy use, cooling effect, temperature variance, etc. These studies vary depending on the different climate conditions.

For Saharan area of Africa, the research of vegetation became important to the many of environmental benefits associated with green roofs and green walls. Tiny of the research has motivated for these areas, issues of design, and amount on energy conservation towards to remove of energy consumption and air conditioning during the summer with little thought to the potential of green roofs and walls in the summer by conserving energy.

However, Mazzali *et al.,* [2] studies a type of vertical greenery system in a Mediterranean context. They investigate potential of energy behaviour on building envelopes. These results indicate that the use of green architectural covering can contribute to cooling energy reduction and offer a valuable solution to retrofit existing construction [4].

Verticals greening systems (VGS) for buildings presents practically research, and it provides passive cooling. The renovation of green façade with double skin dropped can be create a distinction of microclimate in the cavity, with 0.4 °C in a daily circle, and maximally 5.5 °C for the Southern façade [5].

Another paper trait of GF optimizations strategies for thermal comfort in a hot-humid climate can be reduced average Temperature (PET) by 2.54 °C, but CFD simulations are operative in thermal environment in the summer [6].

For this, the green façades or Greenery systems are a solution to reduce energy and evaluated thermal comfort, in the hot dry climate. These systems are different kinds of greenery systems in cities, consistent vertical improving, and vertical garden used to grow plants on vertical surfaces [8-10]. These systems can be natural or artificial installed inside buildings as bio statues, interior walls, or outside, vertical greenery with form of fences, balconies or building covers [11].

The above studies show that green walls can provide a cooling potential on the surface of the building, which is very important during hot periods of the year, especially in warm climates[12]. Consequently, green-wall systems are a good way to create natural shading that reduces the temperature, they protect the facades of building against direct solar radiation and they provide shade. Moreover, the natural cooling effects. In addition, green-wall systems on buildings act as a barrier against the wind and thus block the effects of the wind on the building facade. This effect depends on the density and penetrability of the foliage, as well as the orientation of the facade and the direction and speed of the wind [19].

These green wall systems, called vertical gardens, created using modular panels, containing its own soil or other growing media, such as coir, rice husks, felt, perlite or rock wool. These technologies based on hydroponics, with balanced nutritional and water solutions of the plant [25].

As a study of Yeom *et al.,* [28], Psychological and physiological effects of green wall were measured using VR, using virtual reality, an experimental of green walls. Small green wall was effective in reducing the stress level of the residents, and large green wall increased the stress level of the residents [29].

Many studies have focused to mitigate urban air pollution, but have not dealt with different urban morphologies. This paper of Viecco *et al.,* [29] aims to investigate different GRs and GWs layouts and evaluate their efficacy for capturing particulate matter, by using ENVI-met model to simulate a metropolitan area with buildings, vegetation, paved surfaces, and traffic emissions to estimate air pollution abatement.

Living walls differ from green façades in being able to support vegetation that is rooted in an attached substrate to the wall itself, rather than being rooted at the base of the wall. Unlike green façades, living walls allow a rapid coverage of large surfaces and more uniform growth along the vertical surface reaching higher areas and adapting to different types of buildings. They also, allow the integration of a wider variety of plant species, with two main types: Continuous system and modular system [28].

2.2 Vegetation on Roofs of Buildings

The use of vegetation on envelope of buildings, particularly roofs practice in older buildings of countries like Iceland, Scandinavia, Switzerland, Germany and Tanzania, but not for Saharan area.

Historically, people in these countries applied vegetation, like a tree near buildings, to create a microclimate, to protect from the wind and insulation for winter warmth, cooling during hot summers, and to enhance the esthetical value of the construction.

Today, a green roof trade succeeds in many parts benefits associated with the technology. In Europe, particularly Germany, the last thirty years have expected research of green roof installations [13].

It is now to say that the vegetation could play an important role to ameliorate urban microclimates and have data on manage forest with sample urban areas. To help assess the urban arid context structure: number of trees, species composition, tree sizes, health and several functions, the Urban Forest Effects (UFORE) model should be developed in these areas.

Many studies have proved that vegetation can produce a cooling effect of 2 to 3°C on average, creating a microclimate [14,15].

Also, it is necessary to studying indoor environment with using different thermal insulation materials types. Like a study Morsy *et al.,* [23] studied the effect of and thicknesses on the thermal comfort for the building envelope, by using software Design Builder. It is paid attention to simulation of the thermal behavior of all accepted types of defined materials in the Egyptian energy code for the building envelope, conducting to get the most suitable insulation material [24].

Green roofs have classified depending on the soil layer thickness. The extensive structures are characterized by a soil depth < 15–20 cm, instead solutions with a thicker layer are called intensive. [27].

In this regard, the green walls make to look for an applied technique to capture and use the CO_2 gases and transform the gases into a different energy source. Adsorption technology to capture CO_2 gases has developed because of the minimal energy consumption and low costs required for sustainability [25].

A case study is adopted using mixed methodology combining qualitative and quantitative method. Findings indicate that external wall cladding made of composite aluminium provides many advantages to made of suitable material addressing ecology issues will not only provide a comfortable living environment to the users, but also established referential guideline for future designers and scholars whom interested in office design [26].

2.3 The Energy Consumption of Electricity in South West of Algeria "City of Bechar"

Electricity is one of the most factor of the domestic sector. It has figured that annual electricity consumption was 613.82 GWh /year in 2020, with 414 GWh of residential sector to maintain the occupants of the buildings in thermal comfort for the hot periods [17].

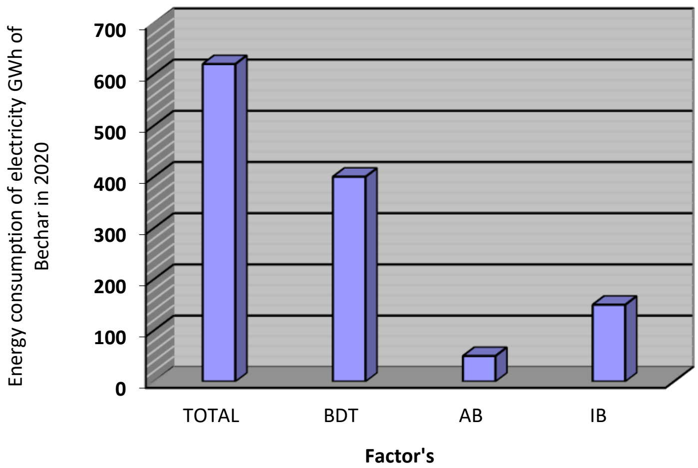

Fig. 1. Annual electric energy consumption GWh in Bechar 2020 [17]

3. Materials and Methods

3.1 Method and Case Study

We used three techniques of green walls (2 verticals (GWs) and 1 horizontal (GWr) to investigate the energy consumption, installing in existing building. This section discusses in detail the implementation of green walls on the case study located in southwest of Algeria. These techniques provide different tools to determine the different results of any phenomenon. This is a key step to understand the impact of the green wall or roof on total annual of electricity consumption and thermal comfort. To define the techno economic analysis, we employed simulation software. The method of this article is to:

Compare the thermal performance of three different greenery systems implemented from existing house located in Bechar, 75 m^2. Second, a simulation method used to investigate the thermal effect with Energy Plus and TRNSYS. Techno-economic analysis with multi criteria will be using to evaluate various criteria: environmental, economic and energetic of each of these scenarios.

3.2 Proposal of Different Component

Green façades: The green facades proposed in our case study, based on the behavior of climbing or hanging plants by a direct greening system, planted into the soil or planted into Box.

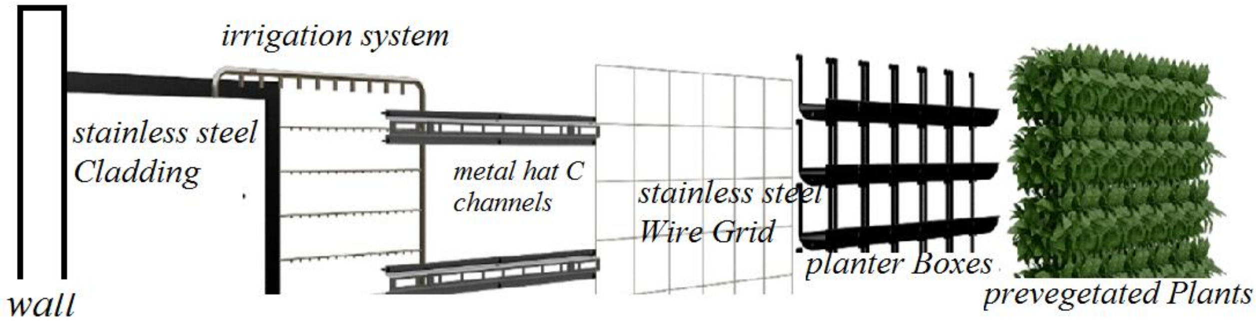

Fig. 2. Conceptual diagram of planter box-based system showing its main components [28]

Living walls:

In this study, we will choose modular living walls, different in composition, assembly and weight. They are composed of modular bins that can take the form of bins, flexible bags, planter slabs, or panels. We can be selected a south orientation for installing these type of vertical greenery systems. The planter boxes have made from Acrylonitrile-butadiene-styrene plastic, making them corrosion resistant and light in weight.

Green roofs:

However, the vegetal roof used in this study, presented the terrace of apartment had 30 cm side tent.

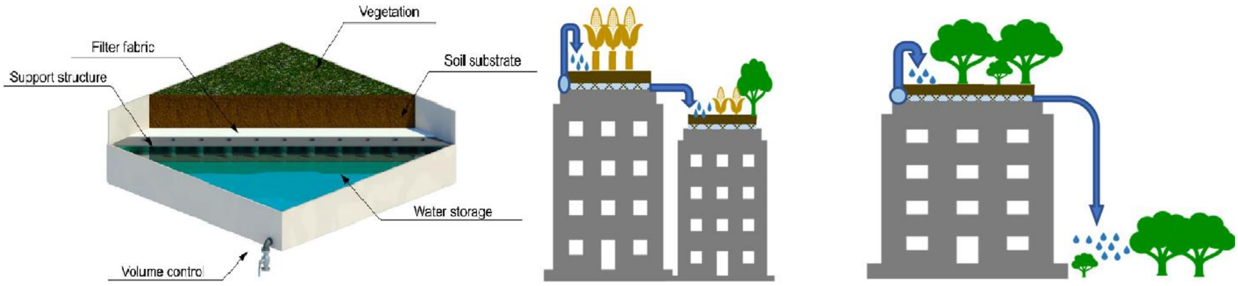

Fig. 3. Schematic representation of a multilayer green roof [27]

Table 1 defined the characteristics of different components of green façades, living wall and green roof proposed to studies in this research. Moreover, Table 2 presents a characteristics of green wall systems based by differences between green façades and living walls continued.

Table 1
Lists defined different scenarios studies [11,12]

	Compositions	Layer Thickness (m)	Total thickness e (m)	U ($W/m^2.K$)
Initial	Exterior plaster	0.015	0.25	0.89
	Concrete brick	0.10		
	Air blade	0.02		
	Concrete brick	0.10		
	Cement plaster	0.015		
A green façade	Cassette	0.015	0.25	0.41
	Green climber	0.02		
	Wall surface	0.25		
	polystyrene plate	0.05		
	Air vacuum	0.02		
	Growing media	0.05		
Living Wall	Treillis	0.015	0.32	0.53
Hydroponics	Green module	0.02		
	Wall surface	0.25		
	Air vacuum	0.05		
	Growing media	0.05		
Roof vegetal	Metal plate ceiling over	0.03	0.30	0.45
	Rocks in a water pool	0.06		
	Air gap	0.03		
	Aluminum plate	0.02		
	Dale concrete	0.16		

Table 2
Characteristics of green wall systems based by differences between green façades and living walls continued [28]

	Green Façades	Living walls
System continued	Planted into the soil or into Box	Modular system
Height (m)	30	Unlimited
System Weigh kg/m^3	5.5	150
Plants spices	Climbing plants	Shrubs
Irrigating	Irrigating System/ Rain Water	Irrigating System
Expectation (years)	50	10
Realization Time (years)	2.3	1
Estimated Cost euro/ m3	30-45	400-600
Maintenance	Pruning	Pruning/ replacement
Total Wall Area (m2) (m2)	36	36
Green Wall Coverage	24	24
Percentage of Green Coverage (%)	66.6%	66.6%
Elevation	South	North
Plant species	Outdoor	Indoor living walls
	Green climbing plants with leaves on grid and fence background (Mentha spicata, Selvia splendents)	Jasmine fast growing climbing plants for fences

4. Results and Discussions

4.1 A Calculate the Tai in the Summer

This study conducted to examine the thermal comfort of scenarios in the sample apartment between the green façade and living wall in the hot and dry climate of Algeria. To study will calculate the summer comfort index, with all systems have disconnected (the heating, ventilation and air conditioning system).

Based on the results of a calculate Tai, we observed that the type of living wall can be dropped temperatures superior to the green façade and vegetal roof.

Table 3 compares the temperature for three scenarios. The living wall can be reduced the air temperature of the apartment up to 8.0 °C, 6.32 °C for the green façade and 2° for vegetal roof.

Table 3
Comparison of Tai of three scenarios

Apartment	T initial	T ° green façade	T ° living wall	T ° roof vegetal
T max	37.82	31.50	30.00	35.99
AT Max	-	6.32	7.82	1.83
T Middle	33.94	29.85	27.6	31.50
AT middle	-	4,09	6.34	2.54

Figure 4 presented the evaluation of air temperature of three scenarios of reducing air temperature in buildings. The results show that the middle exterior temperature Tmax reduction of living wall is 8 °C and 6 °C of the green facade, respectively. Whereas the mean interior Tair reduction is 4 °C and maximally 6 °C, with similarity result with research and Field measurements carried out by another study by Wong *et al.,* [6] on buildings in Hortpark (Singapore) shows a maximum reduction of 11.6 °C.

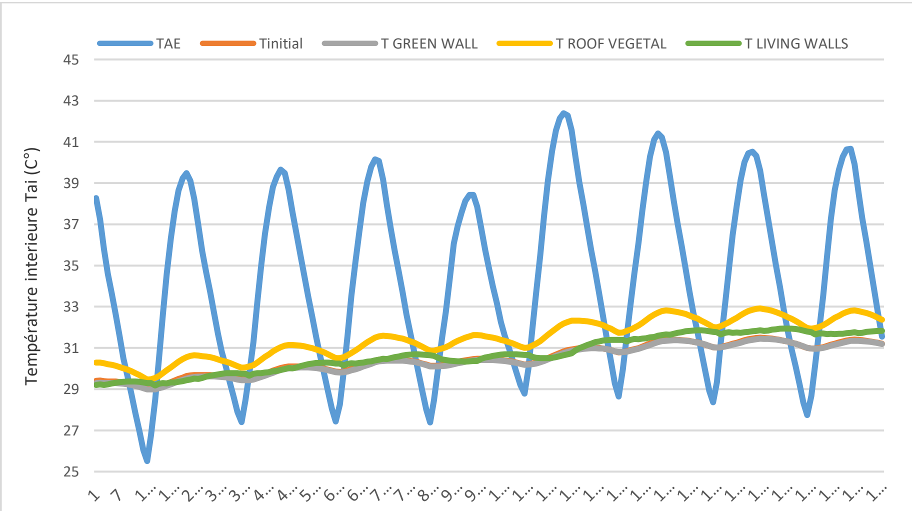

Fig. 4. Evaluation of air temperature of three scenarios of living room

The indoor thermal improvement by the green façade, evaluated by operative temperature (Top), is 2.5 °C averagely and 2.7 °C maximally of living wall on living room, and 1.6 °C averagely of green roof. This decrease can be lower if night natural ventilation functioned with free cooling.

4.2 A Calculate the Q Cooling and Q Heating

The performance of the green façade in terms of energy consumption of heating and cooling improving due to integrate system of plants in façade and roofs. Although a living wall is capable of allowing energy consumption to pass through the foliage and ventilating the air apartment, the shadow was more effectively reduce energy consumption than vegetal roof [13].

Table 4
Evaluation of indicators of the energy performance of strategies sustainable

Indices	Initial building	Green façade	Living wall	Vegetal Roof
Q heating (KWh /m^2)	353.42	150	200.11	250.16
Q cooling (KWh /m^2)	70.5	39.37	33.6	34.37
Q lighting (KWh /m^2)	5.25	5.25	3.05	2.25
Cep (KWh /m^2)	429.17	200.62	230.76	275.78

With:

-Cep= Cep heating + Cep -cooling+ Cep –lighting+ CepECS + Cep-auxs+ Cep-auxv (Cep auxs= cep auxv=0 et cep lighting= 4.5 KWh/m^2 et cep ECS= 4.5KWh/m^2

Green walls and green facades have different characteristics that can influence the abovementioned cooling potential, and can affect insulation properties. Among other aspects, it depends on the depth of the foliage (creating a layer of air and shade on the facade), water content, and properties of the material and possible air cavities between the different layers.

4.3 Techno-Economic Analysis and Cost Benefits of Different Components

On the other hand, this study does consider the Techno-economic analysis of different components representative for this building. Both of criteria such as:

- Economic benefits: Energy cost "L‟éco" and cost investment TR, water consumption
- Environmental and Social benefits: _ CO_2 emissions (kg CO_2/m^2 per year) and Water (m^3 and cost of water) and temperature Occupant: Thermal Comfort IPS or Tic[21]

Technical system:

Table 5 and Table 6 present a techno economic analysis, of each systems studied and under three aspects: the cost of investment, the savings made and the time of return on the investment. The initial findings suggest clear potential of green façade in thermal comfort improvement and cooling energy saving.

Table 5
Environmental benefits of different components

Benefits	Initial	Green façade	Living wall	Vegetal roof	Optimal
Temperature Tai	37.82	31.50	30.00	35.99	28.5
Energy Cep max KWh/m^2/ year	>350	150	200	250	85
Saving energy Eco	-	56%	54%	50%	75%

In recent years, growing attention has been focused on the economic benefits of green-wall systems. One way to use these systems is to set them on the windows of buildings so that the vegetation creates shade [18]. Table 6 shows economics benefits and investments for each component.

Table 6
Economic benefits of different components [20]

Benefits	Initial	Green façade	Living wall	Vegetal roof	Optimal
Time of return TR	0	0-3 year	2 years	2 years	4-8 years
Cost of Electricity (DA)	>60000	2400-3000	4800	3600	2400
Emission CO_2 per/kg	1500	120-150	200-120	200-250	100
Water (m^3)	1200	1200-1350	1200-1350	1200-1350	1200-1000
Cost water	6000	6750	6750	6750	5000

We have shown the interest of the green facade and the adaptation with the construction, by a specific vegetation. In our study, the water requirement due to the scarcity of limited resources and the impact of humidity.

The evaluation of the energy performance of the Reference Building has made it possible to significantly reduce energy consumption and improve comfort in arid and semi-arid regions.

i. The use of the green wall must take into consideration the shading; orientation and direct wind speed were minor [22].
ii. The green roof did not have a big impact on reducing energy consumption. This could be partly due to how these factors were added to the simulation and partly due to the thickness of the growing medium. The reason for these factors may lie in extensive green roofs, which are more adaptable and require less maintenance. As the vegetation on these walls and roofs dies in the winter, the growing medium can freeze and / or covered with snow, offering very little additional benefit for energy conservation in the winter. However, the same cannot be said of the evergreen vegetation on green walls or intensive green roofs [16].
iii. Furthermore, green walls can act as permeable surfaces and control rainwater. The use of green-wall systems can reduce water consumption in the building given that they act like a filter for the rainwater and, when using certain materials, shown that they do not interfere with the physical or chemical properties of the water.
iv. The simulation used makes it possible to take into account the effects of heat transfer by radiation, convection and conduction and on natural lighting through the building envelope, for an overall evaluation of cooling, heating and developing recycling of water resources used [23].
v. The benefits of green walls can be categorised as aesthetic, environmental and economic, or a combination thereof. The greening of buildings improves visual, aesthetic and social aspects of urban areas, which in turn has a great effect on the financial value of a building and helps to improve human health. Urban greening is recognised as having a therapeutic effect, as demonstrated in a series of studies;
vi. The efficient use of daylight and the reduction of problematic glare are some of the benefits of green wall systems that provide enough shade (Yeom *et al.,* [28]), thus leading, over time, to lower electricity demand. Due to the capacity of green-wall systems to reduce temperature, they are an appropriate solution for reducing the energy demand for cooling buildings, improving their energy efficiency and subsequently cutting costs.

vii. On the other hand, this study will be investigated the effectiveness of green walls in relieving stress indoors.

5. Conclusion

The construction presents several problems related to thermal comfort and energy performance. To minimize these problems, researchers and architects are responsible for developing purely passive and natural techniques. The usefulness of living systems by integrating plants placed vertically on green facades. This study aims at a global understanding of the concept of thermal performance of the vertical green facade in the exterior walls of buildings. We have noticed a significant improvement in summer comfort.

In this paper, the techno economic analysis of green wall for external façade have discussed for existing residential buildings. It consists to taking into account both architectural and thermal aspects for new and old construction. Moreover, the green façade system has developed relying on a vernacular architecture and a new technology, which adapt in hot dry climate. The results shown that use of green façade was possible to reduce the heating/cooling demand of energy consumption.

Green walls and green facades have different characteristics that can influence the abovementioned cooling potential, and can affect insulation properties. Among other aspects, it depends on the depth of the foliage (creating a layer of air and shade on the facade), water content, and properties of the material and possible air cavities between the different layers.[20, 21]

In future research, it was necessary to study the types of species more specific for the desert region such as denser foliage with different plants that could fill all the recommended areas on the trellis. In addition, different types of substrates should be studies for living walls in order to compare their thermal performance and find the most efficient substrate for hot and dry climates. The only downside to the green facades examined was that they increased the humidity of the air.

However, in this study, the humidity of the green cavity of the facade was not significant compared to the normal wall, as the context is a hot and dry climate. The interior of the green wall should be ventilating, only if there are openings when using natural ventilation, which can reduce the effect of the green facade or green wall on temperatures and contributes to have a pleasant indoor environment. The potential of vertical green systems requires natural ventilation.

Green walls in construction, in our extreme climate and compact cities, should become an integral part of the energy-efficient approach and the sustainable built form and one of our essential strategies [28].

Ultimately, this article attempts to assess the energy performance and thermal comfort of these systems. We can conclude that the best and most economical solution achieved by the system of living walls, with a reduction of 56.08%, and 54% for the green facade.

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