The role of Vertical Gardens and Contribution in Mitigation of Sick Building Syndrome

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Abstract:

The concept of green spaces is considered to be lungs of cities, purifying the air while enhancing the quality of life. According to rapid urban growth and high density, the green areas have been limited in urban spaces which led to harm to the ecosystem and the emergence of sick buildings syndrome as a direct result of increased heat load, higher rates of energy consumption, and environmental pollution within the cities, thus creating a harmful environment resulting in negative effects on the human health.

The research aims to clarify the design considerations of vertical gardens as an environmental solution, mitigating the effect of sick buildings syndrome and the infrastructure. In addition, vertical gardens carry advantages that integrate the green spaces with the built areas such as; promoting urban sustainability due to its environmental, economic, psychological and social benefits. The aesthetics of vertical gardens help enhance the quality of life and positively affect the well-being and a higher life standard.

To achieve the research aims, the research was based on the analytical scientific method. The methodology of the study consists of two parts, the first part is a literature review that studies deteriorated buildings and addressing the vertical gardens concept, advantages, types, systems, and how to choose the type of plant to absorb pollutants and volatile organic compounds. The second part, is an analytical part that reviews applied examples of vertical gardens and analyse their design elements, types, systems, and the impact of these gardens in each application. Finally, the study is conclusive and recommended, which helps illustrates the importance of vertical gardens and the necessity of encouraging this concept of gardens, while supporting expertise in the field to implement them and make our cities more sustainable.

Keywords:

Sick building syndrome, Vertical gardens, Benefits, Green Facades, Living walls, The plants

Introduction.

Most Egyptian cities suffer from environmental, social and economic problems, such as poor air quality, noise, high density, traffic jams, increasing population and decreasing proportions of green areas, thus, environmental problems such as drought, pollution, the phenomenon of urban thermal islands and the syndrome of sick buildings are born. Vertical gardens play an important role in mitigating this by reducing the transferred heat between the building and the outer space where gardens provide protection from sunlight. [20]

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Sick Building Syndrome.

On average, a person spends 80% of his time in buildings, so the health risks when indoor air pollution occurs are greater than outdoor case.[3] The most important sources of indoor air pollution is the retention of pollutants inside buildings whose ventilation systems suffer from poor design, and its main causes are gases emitted from human activities such as VOCs, carbon monoxide, dust, bio-spray, external pollutants that enter the internal environment, physical factors, cigarette smoke, increased use of computers. [16]

Large amounts of these substances cause health problems for the users of the building such as eye infections, rashes, symptoms of allergic rhinitis and affects the nervous system, along with other symptoms such as fatigue, sensitivity to odors and difficulty to concentrate, thus affecting work and productivity, these buildings are called "sick buildings". [3]

The main characteristics of sick buildings are excessive energy use, depletion of natural resources, environmental pollution, and negative impact on human health. To overcome this problem (sick buildings), architects focused their attention towards using vegetation (gardens) in the vertical direction as an effort to reduce the negative effects of environmental pollution, and contribute to the reduction of the syndrome of sick buildings. [2]

Vertical Gardens.

This term is used to refer to all forms of plant-covered walls. [17]

The following is Figure 1, a conception of an integrated green sustainable building, in which vertical gardens play a major role in enhancing the sustainability of the building. [12]

FIGURE 1: AN EXAMPLE OF A SUSTAINABLE GREEN BUILDING. [12]

Benefits of vertical gardens.

Vertical gardens provide several benefits as shown in Table 1.

Table 1: Shows the Benefits of vertical gardens.

Benefits of vertical gardens	**Aesthetic Benefits**	Green walls are used to increase the aesthetic value of the building. [7]
	Economic Benefits	Its energy saving is an economic contribution, prolonging the life of the building, and increasing the value of the property. [23]
	Lowering the volume level	Vertical gardens have sound absorption [23] which significantly reduces noise and external vibrations. [19]
	Health and Psychological Benefits	The effect of vertical gardens can contribute positively to public health [30] reducing physiological and psychological pressures [19], also helping to focus, increase worker productivity by 12% and reduce stress [8], help absorb volatile organic compounds [21], in addition to preventing harmful dust and microorganisms. [19]
	LEED	When used with other sustainable building elements, green walls contribute directly to LEED credits. [24]
	Improving	Vertical gardens reduce atmospheric co2 levels, increase oxygen and

	air quality	improve air quality in the indoor and outdoor environment. [10]
	Improving the thermal efficiency of the building	It provides protection for buildings by reducing the temperature fluctuations of the building's envelope [27], and vertical gardens also act as a barrier against wind during the winter months. [24]
	Reducing the impact of urban thermal islands	Vertical gardens reduce the impact of urban thermal islands on the urban environment, enhancing natural cooling processes. [24]
	Manage vertical gardens of water efficiently.	
	Vertical gardens are less susceptible to pests and diseases.	

Follow of the Table 1: Shows the Benefits of vertical gardens.		
Benefits of vertical gardens	**Energy saving for the building**	Vertical gardens reduce air conditioning requirements and energy consumption of buildings, and wall vegetation can help cool buildings in summer and isolate them in winter. [13] Built in Adelaide, Australia, as shown in 2, the average power consumption of the building is five floors without the vertical garden after measuring 395,000 kWh, and after the installation of the vertical garden of the same building the average power consumption of the building is 378,000 kWh. [11]

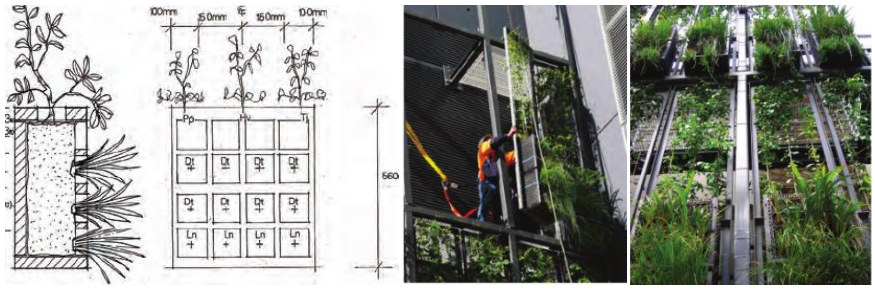


Figure 2: Shows the façade of the Adelaide Building in Australia. [10]

Vertical Gardening Systems.

Vertical garden systems are divided into green facades, living wall systems. [22]

The following Table 2 and Figure 3, which explain the difference between green facades and a living wall:

TABLE 2: EXPLAIN THE DIFFERENCE BETWEEN GREEN FACADES AND LIVING WALLS. [29]

Living Wall Systems	Green Facades
Living walls have a growth media (soil) that is vertically fixed to the building's wall or stand-alone and the living wall may be external to the façade of the building or internal to the interior spaces.	Green facades are raised only in the lower area of the vertical wall (either directly in the ground or in a soil container).

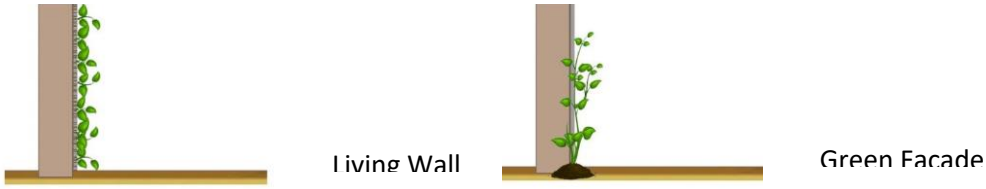


FIGURE 3: SHOWS THE DIFFERENCE BETWEEN GREEN FACADES AND LIVING WALL. [29]

Green Facades.

Green facades can be installed on existing walls, or built in the form of specially designed existing structures that allow for the installation of green spaces, inexpensive but used on the facades of low-rise buildings. [1] Support structures for green facades are made of plastic, wood, metal or stainless steel cables, as shown in the form. [27]

Single cables provide subtle screening and prevent people climbing | **Stand alone trellis systems provide intrinsic visual interest** | **Containerised mesh system for multilevel structures** | **Wall mounted cable grids can cover plain unsightly walls**

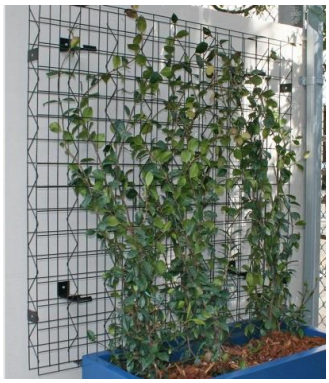
Figure 4: Forms of support structures for green facades. [27]

The modes of garden growth with green facade systems:

The following Table 3 shows the modes of garden growth with green facade systems:

Table 3: Shows the medias of garden growth with green facade systems

The garden growth medias with green facade systems	**Climbing plants**	It is a system that is a series of cables and wires installed on a dedicated structure, allowing plants to climb to be a wall of plants, these structures can be installed on the walls of the building and can be stand-alone. [13]  Figure 6: Shows the climbing of flowers. [33]  Figure 5: Climbing plants (wild berries) on a brick wall, give an attractive view. [41]
	Modular Trellis Systems	It is a system produced by the installation of standard trellises along the surface, these trellises contain plant rooting vessels and support structure to guide plant development[14], as shown in 7.

	  Figure 7: Shows the system of standard trellis panels. [43]
Cable and Rope Wire Systems	In this system cables or wires are used or both, as shown in figure 8,9. [19]  Figure 9: Shows how to install the cable network on the building wall. [42]  Figure 8: Shows the cable network system. [34]
Green wall systems with flower pots	It is a system installed in the wall of the building, the flower pots are installed by rods, as shown in 10. [13]  Figure 10: Green façade with flower pots. [40]

Living Wall Systems.

It is a "more advanced technique in which plant roots can grow"[13] ground plants can be planted perpendicularly to the walls of the building, consisting of plant or plant unit structures, which can be made of polypropylene, metal or other materials vertically connected to a structural frame. [19] The life cycle of living wall systems is described in form 11.

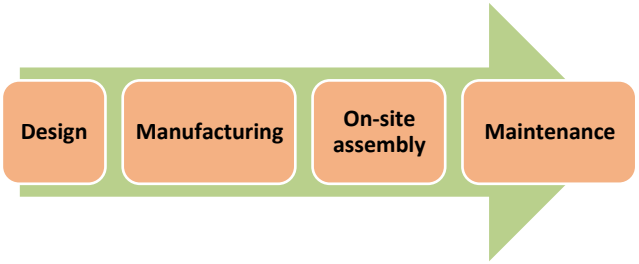


FIGURE 11: SHOWS THE LIFE CYCLE OF LIVING WALL SYSTEMS. [22]

The living walls belong to Patrick Blanc, a "French botanist", who presented his first report in 1994[14], a technological solution for Patrick Blanc, as shown in figure 12.

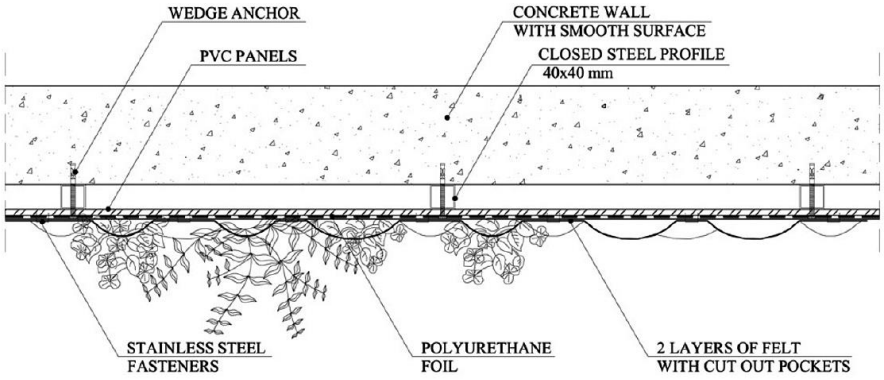


Figure 12: Patrick Blanc's green wall solution. [13]

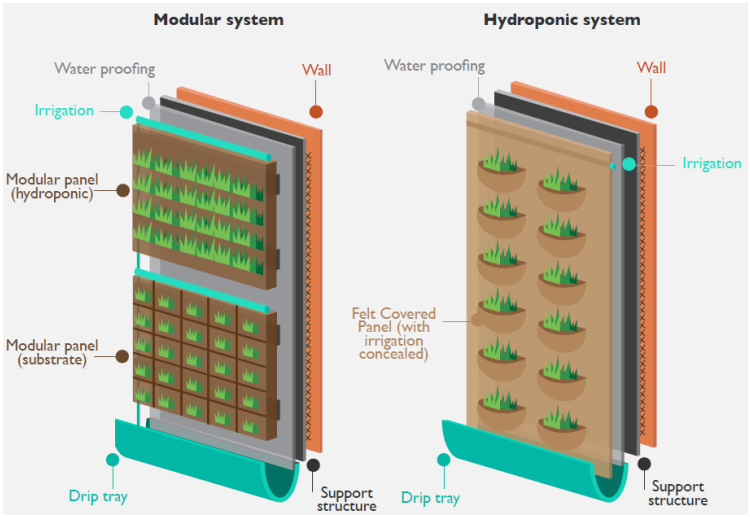


FIGURE 13: TYPES OF GREEN WALL CONFIGURATIONS . [27]

Types of living wall systems in terms of structure and configurations:

أ-Hydroponics Green Wall Systems: In this system, standard containers or panels are installed on a stand-alone structure outside the building wall to create an air gap between the wall and the wall supporting the living wall system, as shown in figure 13,14. A dormant growth medium is provided on which plants are physically grounded such as agricultural foam, mineral fibre or felt mat.

ب- Substrate- based Systems (Modular System): In the soil system uses containers made of metal or plastic or bags of synthetic fiber and those containers are water-accessible, packaged directly into the soil, the containers are attached to each other and are based directly on the wall of the building or on a holder or metal frame that is structurally secure, as shown in form 13. [27]

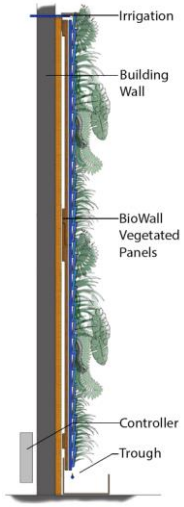
FIGURE 14: SHOWS A WALL THAT WAS IMPLEMENTED BEFORE AND AFTER THE INSTALLATION OF THE LIVING WALL IN THE HYDROPONICS GREEN WALL SYSTEMS. [28]

The modes of garden growth with living wall systems:

The following is table 4 showing the modes of garden growth with living wall.

Table 3: Shows the medias of garden growth with living wall systems.

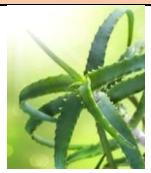
The garden growth medias with living wall systems	**Modular Living Walls**	Plants in this system are supported by square and rectangular modular units as shown in 15, each unit consists of a growth center containing a different composition of soil and nutrients. [14]   Figure 15: The shape of the living wall is illustrated by the Modular unit system. [38]
	Vegetated Mat Walls system	The plants in this system are supported by two layers of synthetic fabric (fabric) with pockets supporting growing plants and media, these layers of cloth are later connected to a larger frame located above the surface of the wall with a layer of waterproof membrane. [19] Figure 16 shows the shape of the living wall with a plant mat system, which also features easy maintenance and replacement [14], as shown in figure 17.  Figure 16: The shape of the living wall is illustrated by the Vegetated mat system. [5]  Figure 17: Shows the shape of the layers of the Vegetated mat system. [32]

Follow of the table 3: Shows the medias of garden growth with living wall systems.		
The garden growth medias with living wall systems	Bio- Filtration Walls	In this system the living wall is designed to integrate with the structure of the building, as shown in figures 18,19, it is designed for the purpose of purifying indoor air, thermal regulation of internal vacuum, filtering polluted air outside the building using the fan as a generator mechanism, and can obtain reductions in energy consumption of up to 30%. [15]  Figure 18: The shape of the living wall is illustrated by the bio filtration system. [35]  Figure 19: Shows the layers of the bio filtration system. [35]

Plants used in vertical gardens.

Plants must be selected in vertical gardens according to available resources and climatic factors [15], and according to geographical area, exposure to wind, light and building rigidity. [23] The right environment for plant growth must be chosen, and sustained. [15] Table 6 shows the top 10 plants approved by NASA to improve air quality and purification, with an explanation of the type of harmful compounds absorbed by each plant. [31]

TABLE 6: SHOWS THE BEST PLANTS IDENTIFIED BY NASA WHILE EXPLAINING THE TYPE OF HARMFUL COMPOUNDS ABSORBED BY EACH PLANT. [31], [26]

English Ivy		Aloe Vera	
 **FIGURE 20: ENGLISH IVY**	This plant absorbs formaldehyde and absorbs small amounts of gasoline.	 **FIGURE 21: ALOE VERA**	It is a great plant to improve air quality.
Boston Fern		**Peace Lily**	
 **FIGURE 22: BOSTON FERN**	This plant acts as a moisturizer that can restore moisture in the air, helps to get rid of the effects of formaldehyde, it should be kept in direct	 **FIGURE 23: PEACE LILY**	It can improve indoor air quality by up to 60%, helps reduce the levels of mould spores that grow in vacuum and absorb harmful fumes from alcohol and acetone. It is used outside the building.

	sunlight.		
Heart Leaf Philodendron		Spider Plant "Chlorophytum"	
 **FIGURE 24: HEART LEAF PHILODENDRON**	It should be used away from animals and children because it is a poisonous plant, which is an excellent plant in the removal of formaldehyde. It can be used in and out of the building.	 **FIGURE 25: SPIDER PLANT**	It can remove up to 90% of gases and air-harmful substances such as mould and allergens, and helps absorb small traces of formaldehyde and carbon monoxide. It can be used in and out of the building.

TABLE 6: SHOWS THE BEST PLANTS IDENTIFIED BY NASA WHILE EXPLAINING THE TYPE OF HARMFUL COMPOUNDS ABSORBED BY EACH PLANT. [31], [26]

Eucalyptus		African Violets	
 **FIGURE 26: EUCALYPTUS**	Helps relieve colds.	 **FIGURE 27: AFRICAN VIOLETS**	It helps stimulate the secretion of adrenaline and can increase the flow of oxygen to the brain, helping to relax.
Chinese Evergreen		Chrysanthemum	
 **FIGURE 28: CHINESE EVERGREEN**	Helps detoxify the air. It is used outside the building.	 **FIGURE 29: CHRYSANTHEMUM**	Helps filter gasoline which is found in many detergents, paints, plastics and some gum products. Preferably grows in direct sunlight.

Application models for some buildings used vertical gardening systems.

Below are some of the buildings that have implemented vertical gardening systems.

8-10 Kavanagh Street, Southbank, Victorian, Melbourne, Australia.


Figure 30: The Green Wall of the Melbourne Apartment Building in Australia is illustrated. [18] ،[39[

Building Introduction: A luxury residential building in the South Bank Cultural District of Melbourne, Australia, completed in 2009, at a cost of $350,000, on a 206-square-metre space on a new building.

Type of green wall used: Using of the water green wall system (living wall system), on the south-east

exterior of the building, above the entrance to the building, as shown in 30. [18]

Chilean Consortia Building, Santiago, Chile

FIGURE 31: SHOWS THE SHAPE OF THE CHILEAN CONSORTIA BUILDING IN DIFFERENT SEASONS. [23[

Chilean Consortia Building. Location is in Las Condes. Santiago, Chile Santiago, Chile.
Architect: Henry Browne - Borja Huidobro
Owner: National Trust Insurance – Life**.**
Completed in 1993, it has an area of approximately 2293 m2, as shown in 31.
Green wall type used: Green Facade systems using cable system, as shown in 32, 33. [23]

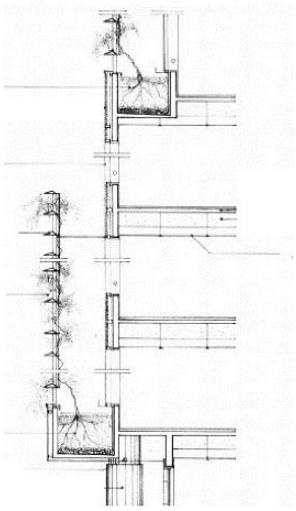


FIGURE 32: SHOWS THE DETAILS IN THE GREEN FAÇADE AND THE SHAPE OF THE AGRICULTURE FUND. [23]

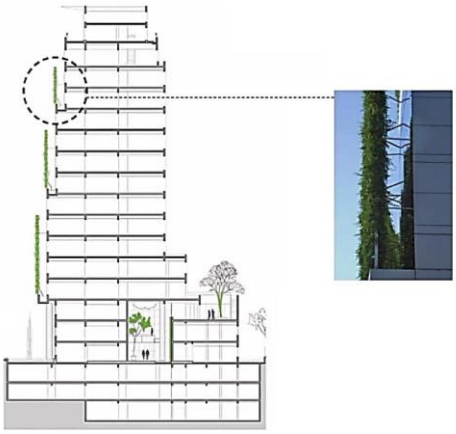


FIGURE 33: A STRIP SHOWING THE GREEN FAÇADE AND ITS LOCATION ON THE FAÇADE OF THE BUILDING. [26]

Taj Sultan in Cairo, Egypt.

Introducing the building: Taj Sultan in Cairo is the first stage of Tegan Development Vision, includes residential and commercial units, swimming pools, playgrounds, a medical center and a club spread over 300,000 square meters. Taj Sultan is located along The Revolution Street overlooking the Cairo Ring Road, owned by Nasr City Housing and Development (MNHD), which began construction in 2013, and the first phase of The Taj Sultan was delivered in 2015.

Type of green wall used: Use the living green wall system, as shown in 34, 35. [28] , [36]

FIGURE 34: SHOWS THE PUBLIC GARDEN WITH GENERATOR ROOMS COVERED WITH LIVING WALLS.

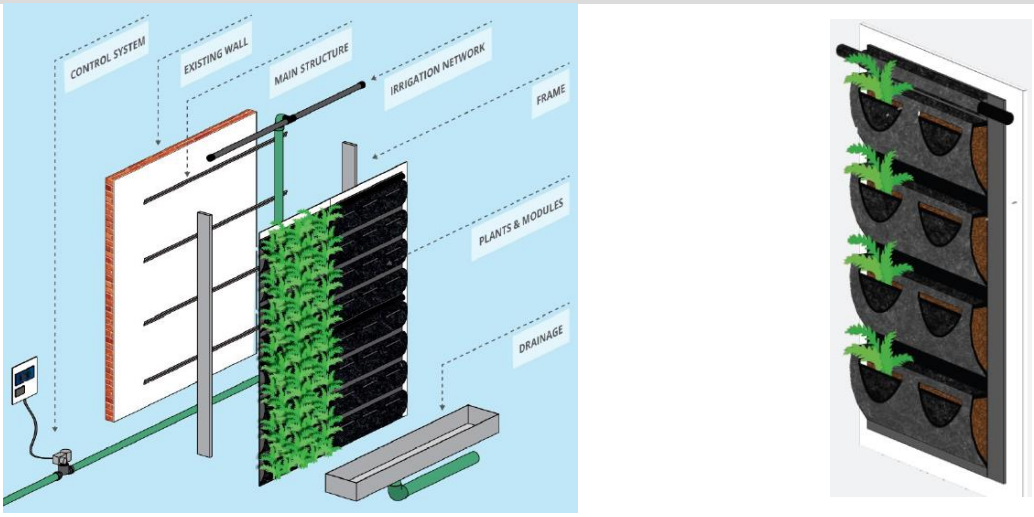


FIGURE 35: SHOWS THE LAYERS OF THE GREEN WALLS USED IN THE TAJ SULTAN. [28]

Results and recommendations.

The research reached a set of findings and recommendations, the most important of which are:

- Vertical gardening systems contribute significantly to air pollution reduction and improving air quality around the building and inside the building, thereby reducing the syndrome of diseased buildings, protecting humans from air pollution diseases, reducing energy consumption and improving the thermal efficiency of the building.
- Vertical gardens should be applied widely and carefully on the facades of buildings in crowded urban areas that lack green areas, and thus return to communicate with nature, which aims significantly to enhance human health and productivity, and vertical gardens contribute to environmental sustainability.
- Vertical gardens contribute to the aesthetic form of the building, which provides psychological comfort to individuals, increases the value of the building, prolongs its life and improves the urban image.
- The building must be studied thoroughly, climatic conditions, environmental and cost considerations should be analyzed before implementing and determining its purpose, to determine the type of green system most suitable for use and suitable for the purpose of vertical garden implementation, also plant type and irrigation system.
- The selection of healthy plant species that improve air quality and help its purification and can adapt to the environment should be selected.

- To ensure the safety of the building, it is preferable to use vertical gardening systems on a structure separate from the building wall, leaving an air gap between it and the building wall.
- The plant must be located according to the receiving of sunlight, as well as the façade of the building should be implemented with this respect.
- The use of vertical gardens to solve environmental problems should be encouraged rather than the trend of energy waste.
- The system of recycling rainwater and grey water should be used to irrigate vertical gardens to rationalize water use.
- Encourage many green building designers to integrate vertical gardens as part of a sustainable building design strategy.
- Although vertical gardening systems are expensive, their benefits will pay off for the health of individuals, but research recommends several studies in vertical gardening systems and the search for less expensive solutions.
- Governments should support vertical gardening systems, support their spread in Egypt, and raise awareness of their use among designers.

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