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Vertical Greening Systems by Integrated Design Approach in Residential Buildings Towards mitigating Urban Heat Island effect the case study of Tehran, Iran

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Abstract

As urbanization grows, the results become more visible. Heat islands are formed due to the loss of green spaces and the consequent disruptive effects of climate change, especially in densely populated urban areas. These phenomena threaten and endanger human health. One solution to compensate for the scarcity of urban green space today is to construct urban green space within the house's walls to provide a suitable and desirable space. Vertical greening systems have recently been recognized and tested by scholars as one of the most effective methods for reducing the harmful impact of heating on the environment. Due to the beauty of this solution, it has also been considered by architectural designers, and today we are witnessing a growing trend of green-covered buildings. In this regard, the number of manufacturing companies is expanding and considering that this solution is in its first steps of growth and there is a need for further study. So, the standard process makes it more functional. This research aims to study the actual process and design of green walls. As a result, at the outset of the journey, the market's current and *usable systems* should be defined and segmented, followed by analyzing the design and manufacturing process's strengths and limitations. Then, by examining the divisions produced among scientists and companies, the final classification has been presented and analyzed in this study in order to standardize the production process. It should be remembered that businesses from various European, Asian, Australian, and American countries were surveyed to ensure that gaps existed. Based on the current system's flaws, a new Vertical Greening Integrated Approach (VGIS) approach was introduced to make it more popular, economical, and functional. Developing countries like Iran have a significant share in increasing the earth's temperature. However, because of the high price of this nature-based, it is less welcomed and used more as a decorative component in luxury buildings. Therefore, Tehran's study sample, one of the leading centers of pollution and population density and buildings, has been selected. Finally, based on the new approach, the selected green wall simulated on residential building in Tehran. Results show that this strategy's effectiveness was to lower the surface temperature by direct green facade about 10.95 °C and via felt-based living wall 13.95°C.

Keywords: *Design strategy, surface temperature, plant-based solution*

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ABREVIATION

IPCC	Introgovenmental Panle on Climate Change
UNFCCC	United Nations Framework Convention on Climate Change
IEA	The International Energy Agency
GHG	Greenhouse Gas
VGS	Vertical Greening Systems
Lw	Livign wall
Gf	Green facade
Gw	Green wall
LAI	Leaf Area Index
rst	leaf stomatal resistance [s/m]
UHI	Urban Heat Island
ETTV	Envelope Thermal Transfer value
ECD	Economic Cooperation and Development Organization
MC	Moisture Content
T	Air temperature [°C]
Tmax	Maximum monthly air temperature [°C, K]
Tmin	Minimum monthly air temperature [°C, K]
U value	Thermal transmittance
R-Value	Thermal conductivity
LCCA	Life Cycle Cost Assesement
LCC	Life cycle cost
CBA	Cost Benefit Assesment
SG	Specific gravity
PM	Particulate matter
PAR	Photosynthetic active radiation
Mspec	Wet mass
Mdry	Dry mass
NO2	Nitrogen dioxide
O3	Ozone
Rs	Shortwave radiation [MJ/m2.day]

INTRODUCTION

Introcuction

Early in the twentieth century, cities held 15 percent of the world's population. Approximately half of the world's population lives in cities, which account for roughly 2.8 percent of our planet's total surface area (Millennium Ecosystem Assessment, 2005). However, its residents consume 75 percent of the world's energy resources (Gago et al., 2013). It is estimated that by 2030 urban land use could almost triple, rising by 1.2million km2 (Seto et al., 2012) and exposing much of the world's population to anthropogenic climate change in urban areas (Intergovernmental Panel on Climate Change, 2014). As cities grow in population, urban density will rise. It is acceptable that the fast-growing urban climatology reported by (Oke 1979b) has continued and sped up. The large and rising chunk of the population affected the atmospheric environments of cities. As a result, cities need vast amounts of energy to operate normally. Increased urban temperatures exacerbate energy usage for cooling purposes, raise peak electricity consumption, intensify pollution, increase urban footprints, and cause human discomfort and health issues (Santamouris et al., 2011). It is also related to the increase in urban temperatures (Bacci & Maugeri, 1992) and the so-called urban heat island (UHI). Hence, minimizing the adverse effects is becoming more critical (Haaland & van den Bosch, 2015).

The "Transition to Sustainable Buildings" studied by the International Energy Agency (IEA) stresses the need to incorporate urgent priorities in buildings such as high-performance building envelopes, high-efficiency appliances, and modern energy use approaches in this field (Wang et al., 2018). More than 40 percent of the savings anticipated in Europe (EU) by 2050 can be directly linked to enhancements in the building envelope (Cao et al., 2016). They provide the high-performance building envelope as one of the most promising means of reducing total building energy demand and efficiently lowering the urban temperature. Investments are required in the construction sector between 2020 and 2050 to reduce pollution and energy usage materialize. Although large expenditures will remain focused on gas for heat supply, isolation would be nearly half that number. Energy use in the built environment is the product of dynamic relationships between urban and building-scale design decisions related to energy networks, technology and materials, and how structures are used.

Many studies were conducted in order to fully understand the materials' optical and thermal characteristics, as well as their influence on the urban environment (Yap, 1975; Santamouris et al., 1999). A variety of structural features can affect indoor thermal comfort and, ultimately, a building's energy consumption, including orientation, form, and even the envelope's thermo-physical properties (Sadineni et al., 2011). Green buildings will also decrease energy demand and improve heatwave resistance and other climate threats (Slater, 2012). Vertical greening systems have an opportunity to reduce the thermal pressure on buildings, reduce the need for mechanized air conditioning and reduce urban heat islands (Jaafar et al., 2013; Sudimac et al., 2019). To enhance sustainable building capabilities, the building envelope also integrates modern materials and other technology (Köhler, 2008).

A green wall is a technique for greening the city by maximizing greater wall spaces accessible in urban canyons that decrease heat and energy usage and improve the cooling impact on all building areas (Peng et al., 2020). 100% greenery coverage effectively lowered the central radiant temperature of the glass façade building (Wong et al., 2009). It is a promising way to reduce cooling load, and their advantages do not end there. By decreasing heat transmission to and from the building envelope, a living wall and green facade improve thermal comfort in interior and outdoor building contexts (Stec et al., 2005). Green building envelopes are cost-effective in energy savings and sustainable design (Eumorfopoulou & Kontoleon, 2009). Also, VGS enhances comfort by lowering the structure's inner surface temperatures and the indoor air temperature in the summer and increasing them in the winter (Cheng et al., 2010; Eumorfopoulou & Kontoleon, 2009). It lowers urban temperatures by preventing the surface of buildings from warming up.

It is necessary to identify different vertical greening systems and their characteristics to choose an appropriate system to effectively and avoid adverse effects of greening systems while considering constraints and drawbacks and offering in-depth knowledge about plant species and climate factors. Optimal designs can reduce energy consumption and CO_2 emissions, which can counteract the heat island's adverse effects (Grosso, 1998). Vertical green systems have disadvantages that limit their productivity and, on the other hand, their generalization. One of the challenges ahead is choosing the proper system that works in terms of environmental advantages like energy saving, thermal comfort, air purification, urban habitat, noise barrier, water efficiency, and combat UHI effects.

Today, the decision to choose is made by manufacturing companies that have no control over the efficiency of the green wall. So, a deep analysis of the systems on the market is needed to select the most suitable one. After the green wall implementation, only periodic control is performed to ensure the green wall's survival. Besides, no controls are carried out to guarantee the efficiency for which it is designed. This issue becomes more vital with the green wall's life cycle and climate change, urban and minor changes in the green wall. Also, the main point that is ignored in the design process today is the lack of sufficient attention to the purpose of its implementation and expectations during the life of the vertical greening system, so this research was considered in the pre-design phase. This policy is not feasible and is not accepted because of its high cost, which is a significant barrier to adopting VGS, especially in developing countries that contribute significantly to global warming. Therefore, studying the green wall's physical, social, and economic context before starting the design can take this strategy out of luxury and make it a more implementable solution. The thesis examines and analyzes the design process in different countries and types of green systems, including living walls and green facades in Iran, Spain, the Netherlands, Germany, Australia, and the United States, which was done by visiting executive projects as much as possible and communicating with companies. This process can be divided into design, build-up, maintenance, and disposal phases, with the analysis done in general. Sometimes, the disposal phase and its influential factors are also ignored. Therefore, the research's design proposal is organized into six phases pre-design, design, build-up, maintenance, monitoring, and disposal, respectively, based on the life cycle approach. Practical factors and relationships between them have been identified. Inter-phases and intra-phases relationships are observable, indicating different factors and phases. An integrated approach by identifying the significant factors and their importance can increase the success rate of the green systems and, to some extent, decrease its costs. It seems that an integrated process can reduce green system weakness and, of course, increase efficiency. Practical design with management is fundamental to the efficiency and durability of planted walls as a sustainable strategy to mitigate climate change's adverse effects. This study focuses on existing residential buildings.

Research objectives

The general aim of this research is to provide effective and executable vertical greening systems in residential buildings to mitigate the adverse effect of Urban Heat Island, focusing on technology innovation by which decreasing energy consumption. The key research objectives are as follows.

- providing a set of indicators that influence the vertical greening (VGS) systems performances generally
- analyzing standard design process, as carried out in different companies producing VGS types
- proposal of an integrated design process

The specific aim of the research it to apply vertical greening systems to the Iranian context, deepening the most appropriate technologies and design strategies. The study pursues the following goals:

- Adapting VGS at the Iranian water supply constraints (especially in Tehran)
- Deepening the environmental, social, and economic aspects
- Depicting the construction requirements for a proper vertical greening system type by testing various types by which decrease energy consumption in typical residential buildings in Tehran climate (semi-arid)

Research methodology and thesis outline

The thesis is organized in three following parts:

Part 1 provides the Scientific background and major theoretical advances on the VGS. Include Chapter 1 and 2.

Chapter 1. The importance of analysis is articulated in this chapter based on previous studies and knowledge and comparative evidence derived from credible weather forecasts. In recent decades, increasing city temperatures have resulted in a rise in urbanization, which has led to increased destructive environmental influences caused by urban heat islands. It is essential to find a successful solution to mitigate the negative effects of this phenomenon. According to the evidence available, vertical green systems have a major impact on the temperature reduction of building surfaces and can be applied as an effective solution.

Chapter 2. Explain the definitions and relevant studies and analyze them in addressing the knowledge gap and present the critical literature review. In addition, the VGS classification survey explains the classification of requirements results from 1995 until now and suggests a new classification with the consideration of available products and current technologies. Also, describe their characteristics and thermal behavior in previous studies. Investigate Urban Heat Island Effects in buildings scale and Nature-based strategies that can combat adverse effects of this phenomenon.

Part 2 Defines the original integrated design approach carried by the research: consist of Chapter 3.

Chapter 3. the methodology applied in this study is based on qualitative and quantitative data extracted from experimental and simulation research and available in companies to evaluate various VGS types' thermal behavior. Also, using FUZZY TOPSIS to compare greening systems according to classification done in chapter 2.

Part 3 Aims to test the proposed methodology for the case study of Teheran, Iran, Chapter 4 and Chapter 5. Testing three selected greening systems on a real case study in Tehran and evaluate their environmental effects through simulation by ENVI-met. Finally, choosing the most proper one in the case study (Tehran).

Chapetr4. Analyzing design processes already apply in companies and finding gaps and errors. Extracting effective criteria in green walls success and proposing a new approach in the vertical greening systems design process.

Chapter 5. summarizes the research outcomes and discuss the latter critically

Main outcomes of the research

The thesis has three main outcomes

- A systematic review of the literature on VGS

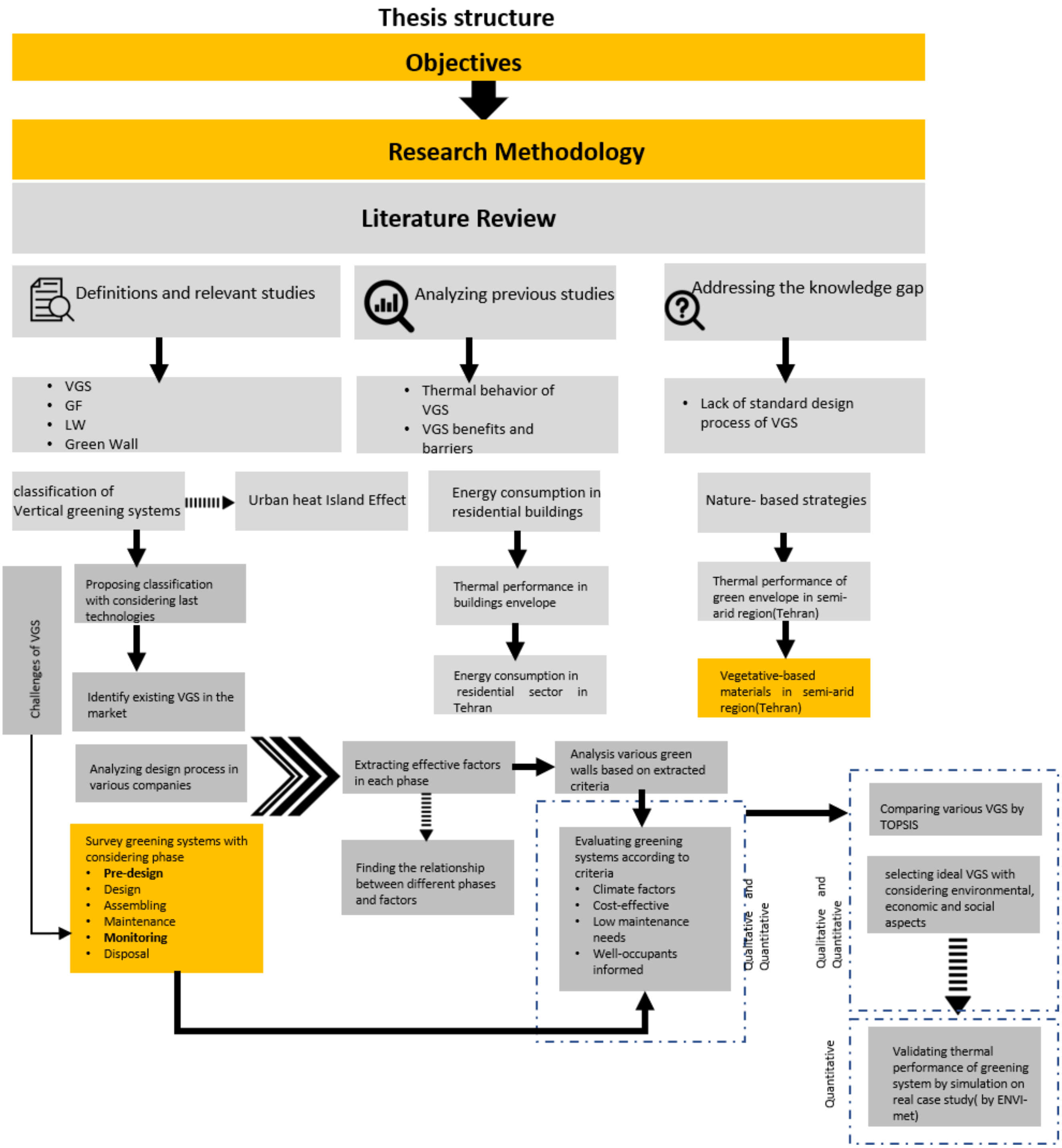
Previous studies from 1988 to the present have been reviewed, emphasizing VGS thermal behavior data gathered and analyzed.

A proposed classification of the VGS

It is collecting and analyzing VGS categories that have been accepted in the scientific community, as well as determining classification parameters. After that, a new VGS classification is proposed.

- The original application of the VGS design method to a specific and less experimented with context

VGS's implementation methodology should be standardized to reduce mistakes, increase performance and increase the prevalence of this technique.



Thesis structure

References

Books

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., ... & van Ypserle, J. P. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change* (p. 151). Ipcc.

Reid, W. V. (2005). *Millennium ecosystem assessment*.

Rosenzweig, C., Solecki, W. D., Hammer, S. A., & Mehrotra, S. (Eds.). (2011). *Climate change and cities: First assessment report of the urban climate change research network*. Cambridge University Press.

Papers

Gago, E. J., Roldan, J., Pacheco-Torres, R., & Ordóñez, J. (2013). The city and urban heat islands: A review of strategies to mitigate adverse effects. Renewable and Sustainable Energy Reviews, 25, 749-758.

Jaafar, B., Said, I., Reba, M. N. M., & Rasidi, M. H. (2013). Impact of vertical greenery system on internal building corridors in the tropic. Procedia-Social and Behavioral Sciences, 105, 558-568.

Eumorfopoulou, E. A., & Kontoleon, K. J. (2009). Experimental approach to the contribution of plant-covered walls to the thermal behaviour of building envelopes. Building and Environment, 44(5), 1024-1038.

Stec, W. J., Van Paassen, A. H. C., & Maziarz, A. (2005). Modelling the double skin façade with plants. Energy and Buildings, 37(5), 419-427.

Santamouris, M., Papanikolaou, N., Koronakis, I., Livada, I., & Asimakopoulos, D. (1999). Thermal and air flow characteristics in a deep pedestrian canyon under hot weather conditions. Atmospheric Environment, 33(27), 4503-4521.

Oke, T. R., & TR, O. (1979). Review of urban climatology 1973-1976.

Wang, N., Phelan, P. E., Harris, C., Langevin, J., Nelson, B., & Sawyer, K. (2018). Past visions, current trends, and future context: A review of building energy, carbon, and sustainability. Renewable and Sustainable Energy Reviews, 82, 976-993

Chapter 1: THESIS BACKGROUND AND LITERATURE REVIEW

1. Thesis Background

Changing climate refers to a changing that can be detected (e.g., by statistical testing) that occurs for a prolonged period, usually for at least a few decades or longer (IPCC, 2013a). Growing the accumulation of greenhouse gases in the atmosphere is the primary way that humans affect the environment. It is the effect of emissions from fossil fuel burning (for the manufacture of electricity, transportation, industry, commercial and residential activities), deforestation, farming practices, land use, and forest conservation practices (EEA, 2016). The climate crisis became more prominent on scientific and political agendas in the early 1980s (Paterson, 1996). Following several science sessions and diplomatic summits, the (UNFCCC), the landmark international agreement on climate change, was accepted in 1992. The aim to maintain GHGs in the atmosphere to the degree that will "prevent harmful anthropogenic (human-induced) interaction with the climate system" is at the center of the UNFCCC—recognizing the necessity to prepare for future climate change effects (UNFCCC, 1992). It also reveals, though, that we should think differently about climate change, not as a common problem in the sense that it happens globally in the same manner, but as one with very diverse backgrounds and geographies, differing through time and space and in its impact on economies and cultures.

The international research community in climate change science has concluded that human activities alter the Earth's climate in ways that raise the risk to cities. This statement comprises many kinds of cases, including the history of the Earth's climate, observations of alterations in the past cultural climate record, new climate severe patterns emerging, and global climate models. The climate change effects have already begun to be witnessed by communities and their people. The United Nations adopted in September 2015 the latest Sustainable Development Target 11, "Make cities and human settlements inclusive, secure, robust and sustainable." Without explicitly acknowledging climate change as a central factor, this current sustainability target will not be reached (Rosenzweig et al., 2018). Two forms of approach are expected to combat climate change. First and foremost, we need to reduce our (GHG) emissions (i.e., mitigation), and, secondly, we need to take adaptation steps to cope with the future impacts (Pachauri, Rajendra K., 2014).

1.2 Environmental issues in urban areas

The IPCC AR5 reported that 'human activity is highly likely to have been the primary source of the warming since the mid-20th century (IPCC, 2013b). By 2030, nearly 5 billion of the world's population will live in urban areas Cohen, (2006). The (IEA 2009: 21) reported that cities and towns demand more than two-thirds of the annual electric power and generate more than 70% of the global carbon dioxide emissions associated with energy.

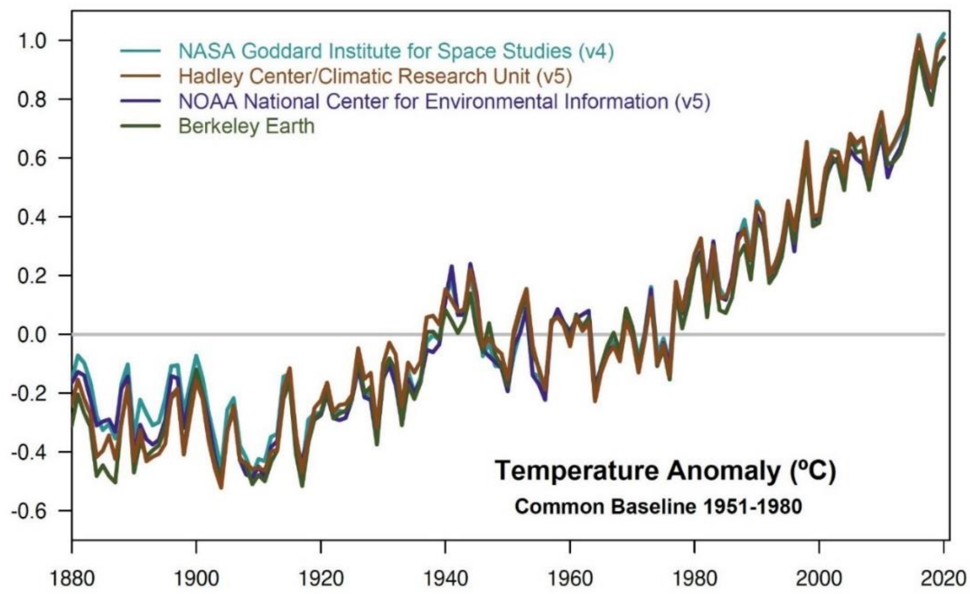


Fig 1.1 Temperature Anomaly from 1880 to 2020, NASA GISS/Gavin Schmidt

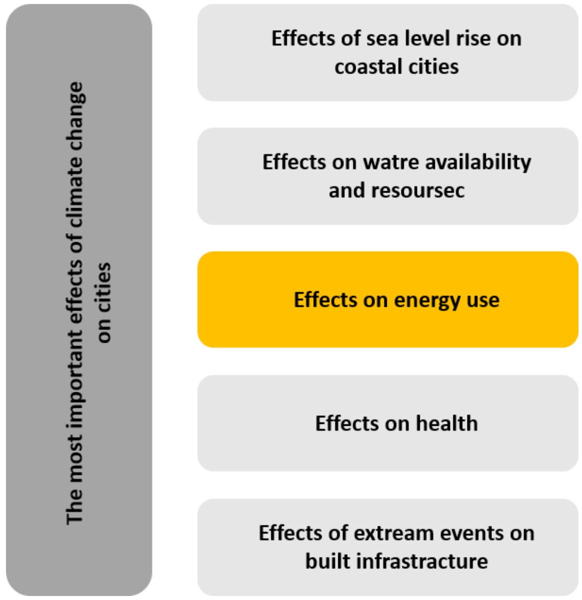
A globally temperature increasing has been confidently attributed to the influence of rising human-made (GHGs) (Hansen et al. 2007). Embracing creative green applications and strengthening the demand for renewable energy would also lead to ecosystem sustainability by reducing emissions at local and global levels (Omer, 2008). The impermeable surface of urbanization eliminates vegetated surfaces that have shade, evaporative cooling, rainwater interception, and infiltration functions (Whitford et al., 2001). Thus, it is possible to tackle climate change or reduce greenhouse gas pollution by using green infrastructure. Vegetation can minimize the benefit of excess radiation in buildings and reduce the need for air-conditioning mechanical ventilation, leading to both greenhouse gas pollution and urban heat island exacerbation by waste heat islands (Gill et al., 2007).

Climate adaptation is the process by which people reduce the harmful impacts of climate change on their health and well-being while still reaping the benefits of their ecosystem (Smit et al. 2000). Moreover, it involves any improvements in behavior or economic structure that decrease society's susceptibility to shifting in the climate system (Smit et al. 2000); "According to the Third Assessment Report of the IPCC, adaptation "does have the ability to minimize the adverse effects and improve the beneficial effects of climate change, but will incur costs and not eliminate all harm.

1.2.1 Energy issues

By 2030, the project that more than three-quarters of the world's energy consumption would be used by 60% of the world's population, cities, and towns. Moreover, over 80% of the expected growth in demand above 2006 levels would come from cities in non-OECD countries' (IEA2009: 21). In fact, the vast majority of potential growth in energy consumption would come from the least developed and emerging countries outside the (OECD). Cities are thus considered vital to the production of GHG emissions, which define, first and foremost, the consequences of climate change (Bulkeley and Betsill 2003; UN-Habitat 2011: 91). They are also considered both the victim and the culprit of climate change due to the increasing urban population and energy demand.

A variety of impacts of climate change on cities have been identified to date. Several recent reviews have described these (e.g., IPCC Third and Fourth Assessment Reports; Bigio 2003; Wilby, 2007). According to their estimates, the most major impacts of climate change on cities are expected to be:



0Fig 1.2 Effects of climate change on cities based on (Olmos, 2001)

Impacts of climate change developing country cities are perceived to be more significant, representing recognized regional vulnerabilities. A finding focused mainly on the reality that these cities' populations are often rising faster than their physical structures and that their vulnerability to climate change is higher than in developed countries. It has been shown that the concern of energy demand (especially in warmer cities) is potentially very critical, particularly in economic terms. As a helpful scale for mitigation measures, the city scale is gradually being recognized. The IPCC also states that specific adaptive steps associated with the built environment in cities, such as cooling houses, also have repercussions for mitigation strategies (McCarthy et al., 2001). Addressing climate change, therefore, required a solution that could be tackled. Encourage systemic change to mitigate GHG emissions while dealing with the economically developed and less economically developed responsibilities of varying developing nations (Swart et al., 2003).

1.2.2 Urban Heat Island effects

"Urban heat island effect" is a super climate created by the temperature difference between a urban area and the surrounding countryside (Taha et al., 1992; Nakayama and Fujita, 2010). This difference is primary because of the extent of hard and reflective surfaces (albedo) in cities that absorb incoming solar radiation and re-emit it as tangible heat (Takebayashi, 2007). Impermeable surfaces affect the urban microclimate by changing radiation components, thus increasing the air temperature in buildings and energy consumption (Priyadarsini, 2009). This phenomenon is mainly due to the high density of urban buildings and structures that absorb sunlight, the use of highly absorbent materials, lack of green space and the features of urban valleys, and the production of human heat it causes health, environmental and economic problems (Oke et al., 1991; Taha 1997).

Fig 1.3 Urban Heat Island effects in dense urban area

The UHIE Urban Heat Island effect occurs because the building and street materials absorb a high percentage of the sun's radiation. Hence, a considerable reflection occurs at the building and city level. There is a higher proportion of "green" surfaces in the surrounding areas that can absorb and convert this radiation into biomass and latent heat. Reheated, heat generated by waste generated from industry, vehicles, and mechanical equipment, and increased levels of air pollution (Taha et al., 1992). Preliminary studies by (Oke, 1982; Ruth et al., 1989; Taha, 1997) showed that the UHI effect could increase the air temperature in an urban city between 2 and 8 ° C. Recent studies show that the more accurate range is between 5 and 15 ° C (Santamouris, 2013a).

Main causes of the Urban Heat Island

Surface

Continuous increase in hard and heat-absorbing surface, the density of our cities, and decrease of natural vegetation are the main factors influencing the heat island (Akbari et al., 2001; Dolus et al., 2004; Rossi et al., 2014) as a result of the acceleration of urbanization. The hydraulic, radiative, and thermal properties of materials used in modern construction are quite different from those of natural soils and rocks, vegetation, and water (Souch & Grimmond, 2006). The materials used in the envelopes of urban buildings and structures play a very important role in urban heat balance. To distribute the ambient temperature, they collect solar and infrared radiation and raise some of the stored heat through convective and radiative processes in the atmosphere. Therefore, the technical specifications of the materials mainly used determine the energy consumption and comfort conditions of individual buildings and open spaces (Santamouris et al., 2011). Besides, the use of materials capable of storing shortwave radiation in urban landscapes and the absence of evapotranspiration (e.g., lack of vegetation) also contribute to the appearance of UHI (Smith & Lormore, 2008). Increasing the use of human-made materials and increasing human heat production are the main causes of UHI, leading to increased energy needs, further contributing to the warming of our urban landscape health consequences (Mohajerani et al., 2017).

Human activity

In 1950, 30% of the world's population lived in urban areas, while by the end of 2014, that number had risen to 54%. Thus, the pattern of human habitation has undergone significant changes, leading to an intensification of urban economic activities and the production of distinct adverse environmental effects, namely CO2 emissions (Al-Molaali, Sab, & Fereidouni, 2012; Zhang, 2016). Due to the increasing use of air conditioners, a significant increase in atmospheric temperature and cooling demand in dense urban areas increases (Papadopoulos, 2001). Aerosols in the air, partly due to vehicles and industrial activities, reduce sunlight and increase its emission. Since many types of emissions change the toxic properties of the atmosphere, high levels of pollution in urban environments can also increase UHI (Oke, 1982). Rising urban temperatures increase energy consumption for cooling purposes; pollutants such as carbon monoxide, sulfur dioxide, nitrogen oxides, and particulate matter are released, particularly in cities with hot climates (Kalkstein & and Sheridan, 2003). increase electricity demand, exacerbate pollution issues, rise the urban footprint, and cause discomfort and human health concern (Hassid et al., 2000; Stathopoulou et al., 2008). High temperatures endanger human health and increase mortality and respiratory diseases (Ione Avila & others, 2018).

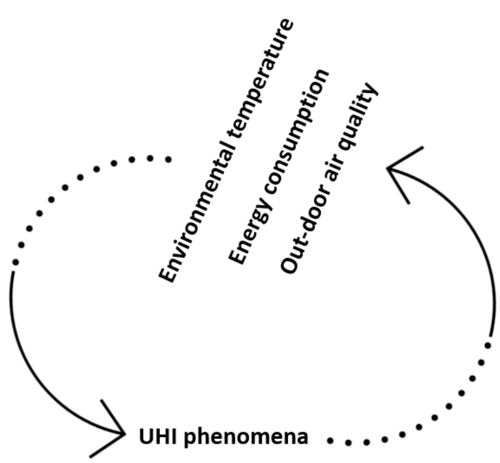


Fig 1.4 Key UHI Criteria based on (Aflaki et al., 2017)

Cities are connected to massive power plants and fossil fuel combustion as major energy users, which tend to be the primary source of air pollution Cohen et al., (2004). Moreover, estimated that for every 1 ° C increase in UHI intensity, energy demand increases by 2 to 4% (Shafaghat et al., 2014). Improving UHI increases the need for more energy for air conditioning and refrigeration in cities and increases living costs.

Lack of plants

Changes in the structure of cities cause heat islands, and as a result of decreased vegetation low evapotranspiration, there is a greater incidence of dark surfaces with low albedo (Stone et al., 2010). Lack of vegetation in urban areas reduces evaporation- transpiration, shade, and cooling effects of plants, which results in the city warmer (Taslim et al., 2015). As the temperature rises, the demand for air conditioning will increase, which leads to more energy consumption and a negative effect on ozone consistency. A study in Oregon found that non-vegetated areas can reach 50 degrees Celsius in summer, while plant areas can reach 25 degrees Celsius. Also, green can reduce indoor temperature depending on plants and green systems such as green roofs, green walls, or street trees. Studies have shown that using green walls can reduce energy consumption for air conditioning by up to 30% (Winmester, 2009).

Effects

UHI is related to the environmental and social challenges (Aflaki et al., 2017) and human health (Mohajerani et al., 2017). The negative impacts of UHI development are generally classified into people and (micro) climates (Dhalluin & Bozonnet, 2015; O'Malley et al., 2015). Extreme heatwaves, often with severe UHI, can increase the demand for air conditioning in buildings, especially in people who are more sensitive to heat (i.e., the elderly and children) (Dhalluin & Bozonnet, 2015). Heatwaves also increase electricity and water consumption (Hatwani-Kovacs et al., 2016). According to Santamouris (2013b), several studies have shown substantial changes in urban temperature due to the concurrent use of building cooling capacity.

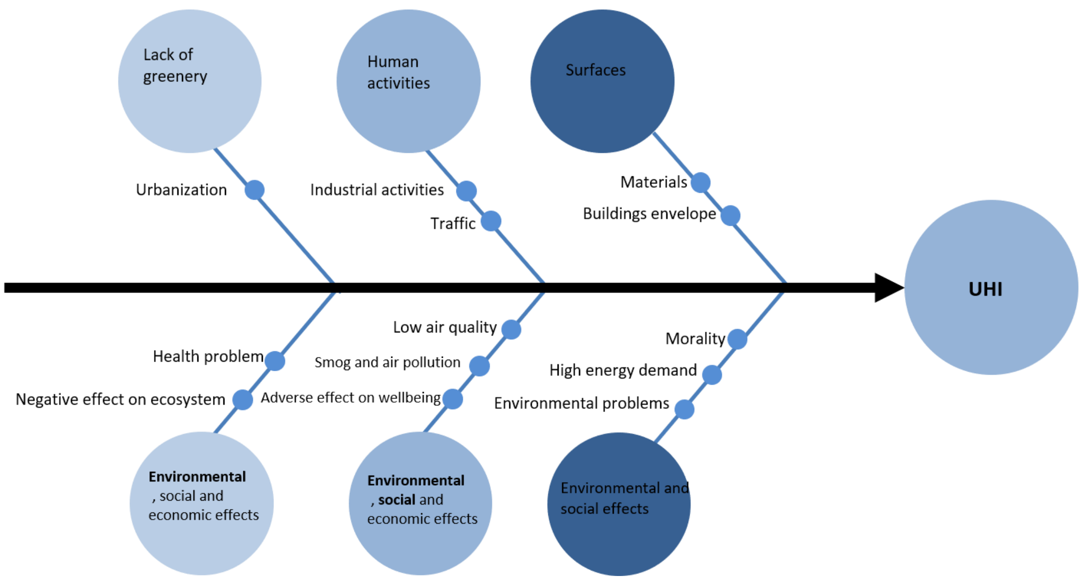


Fig 1.5 Causes and effects of UHI based on (Mohajerani et al., 2017)

Existing guidelines

Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau FLL (Germany)

Research Society for Landscape Development Landscaping (FLL) guidelines include Green facades, green roofs, and indoor greening started in 1995. It is one of Europe's first guidelines due to the prevalence of greening systems in Germany already. There are many examples of vertical greening systems, mainly traditional or direct Green Facades with climbing plants.

Basic focuses are:

- Link between science and practice
- FLL rules / technical reports as rules of technology for quality assurance
- Broad involvement and participation of affected specialist groups for a broad technical consensus in the definition of quality standards
- Dissemination of the content of regulations in specialist conferences and publications
- Neutral discussion forum for innovative or controversial specialist topics as a service for the entire green industry
- Initiation and support of quality assurance measures (certification)
- Promotion of comprehensible, fair competition through the most binding and specific guidelines possible

Facade greening (RWA)

the FLL "Guidelines for the Planning, Execution and Maintenance of Green Façades" from 1995 and 2000 established themselves in the profession and were implemented many times. In the course of the third revision, not only adjustments to the state of science and research in the field of ground-based facade greening were made, but also detailed descriptions of the material use and facade-related greening forms. In addition, the topics statics and fastening as well as requirements for building materials are presented. Since the plant plays a central role in all forms of building greening, the existing plant lists from the 2000 edition were expanded for ground-based greening and revised for wall-bound greening. The focus was on the following plant lists:

- Climbing plants and their selection criteria;
- Perennials for wall-bound greenery;
- Perennials for planters;
- Grasses for wall-bound greenery;
- Climbing plants for planters;
- self-supporting trees for plant vessels

A concise guide to safe practices for vertical greenery (Republic of Singapore): Structural consideration

In this guideline, consideration is divided into two parts: before VGS installation and after installation. Plant and material selection, drainage system, design for maintenance access, maintenance cost, and fire safety requirements are designer duties. Drainage and work safety are the responsibility of the landscape contractor. The maintenance team should be checking regular maintenance, ventilation, and work safety. Generally, Structural, design, and technical considerations are three parts of the greening process. This guideline emphasis on the role of buildings owner to the success of VGS.

Growing Green Guide (Australia, Melbourne and Victoria)

In these guidelines, Green roof, Green walls, and Green facades were analyzed.
the Technical Guide includes:

- Site Analysis (Climatic factors on-site, Weight loading, Drainage, Existing structure and size, Access, Nearby vegetation, Site assessment summary)
- Design & planning (Design objectives , drainage and irrigation, maintenance inputs, sourcing the right information and expertise, budget, relevant building industry codes and planning assessment tools, plant selection and establishment), Planning for drainage and

irrigation, designing for maintenance, cost considerations, regulations and local laws, building rating schemes and planning assessment tools, selecting plants.

- Building and installation (Occupational Health and Safety, Insurance and system warranties, project completion, Structures and components for green wall systems, waterproofing, irrigation and plant nutrition, wall protection and different facade treatments, soils and growing substrates.
- Maintenance (Maintenance planning, Maintenance tasks, Plant nutrition)

Overview and definition of Vertical greening systems

The World Green Building Council claims that, "a green building is a building that reduces or eliminates negative impacts in its design, construction or operation and can have a positive impact on our climate and natural environment." American architect Paula Soleri combined the words "ecology" and "building" and came up with the new idea of "ecological building". Green buildings have become a new building style that integrates energy saving, building design, and environmental protection from its simplest form over more than half a century. It is more compatible with the current situation of energy shortages, so it is a new building development model trend. Vertical green walls, also called vertical gardens, are a term that includes all forms of plant wall surfaces, regardless of whether they are directly rooted in the ground, in modular walls or panels attached to facade walls (Bartfelder and Kohler, 1987; Blomo, 2003).

Dunnet and Kingsbury (2004) describe landscaping as a way of life and thus a self-healing system of building reconstruction with the traditional use of climbing plants to cover the building surface. According to (Krusche et al., 1982), a green facade can be created using climbing plants directly on the facade or with the help of a support system (indirectly) to create a space between the facade and the plant structure. Several different terms have been used in the literature to discuss the vertical surfaces covered by plants. As the definition of the vertical greening system will be used in this document: Vertical green is the result of the emergence of vertical surfaces with plants, roots in the ground, rooftop and planter boxes, or to the organic or inorganic materials as a substrate directly or indirectly attached to the surface of the facade. Research in the literature suggests various definitions regarding the types of vertical green systems, sometimes leading to confusion and misunderstanding in determining systems and components. Therefore, most descriptions used in literature analysis clarify a better understanding of distinction and terms.

Table 1.1. Definitions of vertical greenery system according to researchers view

	Citation	Description
vertical greening system	(Francis and Lorimer, 2011)	Vertical greening systems (VGS) are different forms of vegetated wall surfaces, based on the spreading of plant species across the wall surface by using vertical structures, which may or may not be fixed to an indoor wall or to a building facade
	Citation	**Description**
vertical greenery system	(Wong et al., 2009), (Cheng et al., 2010), (Wong, Kwang Tan, Tan, et al., 2010)	It is referred to comprehensive term referring to any manner in which plants can be grown on, up, or against the façade of building or feature walls such as a vine, as part of a window shade, as a balcony garden, or in a vertical hydroponic system.
	(Bass & Baskaran, 2003) and (G. Pérez et al., 2011)	The way in that the plants can be grown on, above, or in the walls of the building
	(Stec et al., 2005)	Vertical greenery system is an excellent way of saving energy used in air conditioning, and their advantages do not end there. It occurred due to the existence of plants found in the VGS. Living wall and green facade enhance thermal comfort in building environment both indoor and outdoor by reducing heat transfer to and from building envelope
	(Chiang and Tan, 2009)	As greenery integrated into built forms in the city includes balcony gardens, sky terraces and green roofs.
	(Binabid, 2010)	Vertical greenery systems are described as growing each kind of plants on each kind of vertical surface
	Citation	**Description**
Green façade (Façade greening)	(Hermy, 2005)	Green façades are the green cover on vertical surfaces by plants rooted in soil. This can be rooted in the soil at ground level of the façade as well as in planter boxes possibly placed on the building
	(Dunnett and Kingsbury, 2008)	Green facades have historically been used mainly for ornamental or horticultura l purposes, and involve the establishment of climbing

		vegetation which is rooted in the ground or planters, and which is then trained to grow directly on wall surfaces or on an overlying wire or trellis framework
	(Köhler, 2008)	Typically covered with woody or herbaceous climbers either planted into the ground or in planter boxes in order to cover buildings with vegetation.
	(Dunnet and Kingsbury ,2004)	Describe as a living and therefore a self-regenerating cladding system for buildings, with the traditional use of climbing plants to cover the surface of a building.

	Citation	Description
Green walls	(Newton et al. 2007)	The concept of green walls refers to all systems which enable greening a vertical surface (e.g., facades, walls, blind walls, partition walls, etc.) with a selection of plant species, including all the solutions with the purpose of growing plants on, up or within the wall of a building

	Citation	Description
Vertical green (Vertical garden)	(Dunnet et al. 2004; Köhler, 2008)	Is the result of greening vertical surfaces with plants, either rooted into the ground, in the wall material itself or in modular panels attached to the façade and can be classified into façade greening and living walls systems according to their growing method
	(Perini et al. 2011)	Commonly referred to as a "vertical garden", is a descriptive term that is used to refer to all forms of vegetated wall surfaces
	(Peck et al. 1999; Bass et al. 2003)	Continuous LWS are also known as Vertical Gardens

	Citation	Description
Vertical Garden	(Peck et al. 1999; Alexandri & Jones 2008; Perini et al. 2011)	Growing of plants on, up, or against the facade of a building

	Citation	Description
Bio-walls	(Francis et al., 2011)	The application of green walls in indoor spaces in order to enhance the environment

1.3 Objectives of Literature review

The main aims of the literature review are following:

- Recognize various concepts and their variations in order to apply the most widely agreed definition by researchers in this field.
- Investigation of thermal performance of vertical greening systems in different climates zone
- It is defining the factors that influence the thermal activity of vertical green systems.
- Identify the gaps in previous research.
- Analysis of the connection between researches and factory-based green production systems

1.4 Method adopted for the literature review

- Describe key terms including vertical greening systems, green walls, green facades, living walls
- Looking for relevant scholarly materials through academic engine searches like google scholar and academic info.
- Searching based on key words to collect the studies have investigated the thermal behavior of VGS in different climate zone
- Focusing on the researches focused on the VGS impact in surface temperature reduction, energy-saving and UHI.

Findings

- There are many papers published in journals, conference papers, some books, and Ph.D. thesis related to the thermal behavior of VGS. The number of studies has increased in recent years. The thermal study is more common than other surveys and accounts for almost half of the publications (R. A. Bustami et al., 2018) focusing on plant species, the effect of climate factors, substrate characteristics and impact, orientation, and percent of coverage surface.
- Most studies were conducted in the summer, a small number throughout the year and only two surveys were done in the fall. the number of studies in the wintertime is limited. In the case of plant selection, it emphasizes climbing plant as Hedera helix investigated and the diversity of plant observed in living walls. Studies have been done concerning the types of green systems available in the market, which can be divided into green facades and living walls, which is sometimes done as a comparison between types and a reference wall. In terms of methodology, all researches were performed by experimental, simulation, or a combination of both together.
- Lack of study concerning thermal behavior of VGS in the whole year, regrading substrate feature, air gap impacts exist. Also apparent is the poor partnership between green wall manufacturers and researchers.

A summary of past studies on the VGS thermal behavior

The study by (Eumorfopoulou & Kontoleon, 2009) comprehensively analyzed the effect of orientation and ratio (percentage of coverage) of green walls on the thermal behavior of conventional buildings in Greece during the summertime. Regarding the impact of building parameters, the position of the masonry/insulation layer is also considered. The leaves of climbing plants (Parthenocissus triscupidata) are broad (25 cm) and dense (thick foliage that prevents direct sunlight from penetrating the surface of the outer wall). The coverage percentage of the leaf cover gradually varies from 0% (bare wall: no plant) to 100% (full cover). By increasing the percentage of plant leaf cover, their positive effect also increases more prominent for east or west surfaces. Adequate mixing of a plant wall in a building envelope is beneficial in terms of energy savings. While neutralizing the effects of the sun, it significantly improves and regulates the microclimate around the built environment (Kontoleon & Eumorfopoulou 2009).
A study by (Olivieri et al., 2009) set the goal of assessing the energy savings and environmental benefits of a plant façade compared to a traditional façade. This system consists of modular plant panels with the following components: evergreen vegetation, metal box, artificial structure, substrate, drip irrigation system, connection structure, and vertical structure. A similar façade without a vegetation layer has been installed in the same building to compare both façade models. In winter, the vegetation layer acts as a sun protection element, which means adverse effects for the optimal use of sunlight on the wall. As a result, the optimal use of these facade prototypes due to the climate of Colmenar Viejo (Madrid), whose climatic characteristics are hot summers and cold winters, brings essential advantages related to comfort conditions in buildings. During daylight hours, the indoor temperature of the vegetation module is 20% lower than the temperature data recorded by sensors in the vegetation-free module. By comparing the data of surface probes located in both the outer and inner layers of the metal box, the important effect performed due to

vegetation and substrate is significant. On days when the sun is higher, the difference can reach 15 degrees Celsius. In winter, during the day, due to sunlight, the facade without vegetation is warm. The outer layers can reach a difference of 15 degrees Celsius with vegetation sensors without vegetation.

Research in the Netherlands has shown that a green façade that attaches directly to a wall produces an average of 1.2 ° C cooling at a surface temperature from several studies in temperate climates. Another wall at a different location creates an air gap between the façade, and the wall cools 2.7 ° C compared to bare walls (Perini et al., 2011).

In a study by Mazzali and colleagues , he investigated the thermal effect of a living wall mounted on different external walls at different latitudes of the Mediterranean climate. The measurement campaign took root in the summer of 2011, especially between June and September 2011. By accurately measuring the field and preparing a mathematical model, it was possible to estimate the effect of the veneer on the interior behind the green wall. Interesting considerations are presented for reducing the cooling energy consumption of a typical three-sided office with a cut-to-wall ratio of 15%. The best results can be achieved with a massive south-facing wall where the cooling energy reduction for the latitude range of the northern regions of Italy is about 66%. More minor advantages were observed in walls with an insulation layer. In these cases, it decreases by about 2% in the case of external insulation walls and by about 5% in internal insulation walls. The most effective direction of cladding, regardless of the type of wall and latitude, was south.In this study, it was possible to perform a field measurement of a living wall installed in northern Italy. In the following sections, field measurements of green architecture and mathematical model validation will be described shortly. Then the limited volume mathematical model of the office room will be described. The measurements were made on a living wall, southwest, in a kindergarten in Lonigo, northeastern Italy. The main feature is the presence of a triple felt in which the first layer allows water to flow between the PVC panel and the felt, the second layer allows the roots to expand, and the third felt has a mechanical function as a support along with the plant.

The experimental method's three types of living walls are presented to investigate the possible effects of thermal conductivity of a building's façade by (Mazzali et al., 2013). Specifically, Living walls were studied in central and northern Italy in a temperate Mediterranean environment.

The most important plant species attached in LW are reported as foloowing: *Geranium sanguineum , Juniperus communis Sedum spurium, Johnson geranium, Anemone sp. , Viva minor, Parthenocissus tricuspidata, Oenothera missouriensis, Pitt Tubira, Heuchera micrantha Palace Purple, Salvia nemorosa, Loniceosporum pileata, Rosmarinus officinalis, Alchemilla mollis, Bergenia cordifolia, Plumbago capensis*. Case Study of Living Wall B. Measurements was made on a 3 m and 3 m southwest prototype for installation in Venice. The cover was made between June and September 2012 of an aluminum structure, a PVC plate mounted on it, and a vertical turf lawn. Another wall is supervised that is made of 126 recycled polypropylenes. covered by *Zoysia matrella 'Zeon', Zoysia tenuifolia, Zoysia japonica 'El Toro', Cynodon dactylon X Cynodon transvalensis 'Patriot' Stenotaphrum secondatum, Dicondra, Paspalum vaginatum, Cynodon*. The surface temperature difference between the covered and bare walls is significant and, in some cases, can reach values up to 20 C. On sunny days, The difference in external surface temperature between the bare wall and the covered wall varied from 12 degrees Celsius (case C) to 20 degrees Celsius (case A). During cloudy days, the temperature difference reduces their values to 1-2 ° C (Mazzali et al., 2013).

In 2013, Chen and colleagues conducted research on three examples of studies based on various layouts, in thermal laboratories with adjustable LW are installed on their western walls. In a hot and humid region, in Wuhan, China. LWS has a considerable cooling impact on the wall surface and internal space, according to the findings. When compared to a bare wall, the maximum external wall surface temperature is 20.8°C, the maximum interior wall surface temperature at 7.7°C, and the inside temperature drops by 1.1°C. The LW-created microclimate resides in a cool layer of air with the same average relative humidity as surrounding air. The results demonstrate that shorter distances have a better cooling impact, although the air layer has a higher relative humidity (Chen et al., 2013).

Comparing the thermal performance of eight types of VGS (one type of green facade and seven types of living walls) using the same method of measuring VGS analysis under the same conditions and comparing their performance has been done by (Wong et al., 2012). In terms of maximum reduction of average wall surface temperature compared to control wall, VGSs 4 (living wall - modular plate, vertical interface, inorganic substrate) and 3 (living wall - lattice and modular, vertical interface, mixed substrate) best maximum thermal performance A decrease of 11.58 ° C in wall surface temperature is observed on clear days. It is a considerable decrease in wall temperature, which will result in a decrease in energy cooling load and hence energy savings. These findings indicate to the thermal benefits of vertical green systems in lowering building surface temperatures in tropical regions, resulting in lower cooling loads and energy expenditures (Wong et al., 2012).

In another study conducted by (Coma et al., 2017), The main goal was to evaluate the thermal performance of two different vertical green systems compared in laboratory chambers such as homes for both cooling and heating. The first room has a two-tone green façade with deciduous plants, another façade covered with evergreen species. Finally, an identical third room without any green cover is used as a reference. High potential for energy savings in the cooling season for green walls 58.9% and two-color green facades 33.8% compared to the reference system. On the other hand, no additional energy consumption has been observed for the evergreen system for heating periods.

In 2017, Bianco and colleagues did an experimental study of a vertical green modular system (VGMS) applied to a lightweight insulation wall. The use of a substrate with standard pot compost mixed with insulation materials from industrial waste (felt obtained from the production of seat felt pads) has been investigated, *L. nitida* and *B. cordifolia* were tested. Therefore the passage through the wall is reduced in the range of 37-44% reducing. During the summer, the potential of green modules in reducing the effect of urban heat islands was demonstrated by observing a noticeable decrease in the external surface peak temperature. To describe the effect of thermal insulation in winter and heat reduction in summer. The thermal transfer values equivalent to the modular green system show a 40% reduction compering to a plastered wall, significantly affecting the energy demand in the heating season. In summer, up to 23 degrees Celsius. A pilot monitoring campaign was conducted on an experimental cell located in Turin (northern Italy) to evaluate biometric parameters and energy issues. These results show that green samples positively affect the system's winter behavior by reducing heat loss by 63% compared to conventional plastering walls. During the night and in the early morning, the temperature difference between the surface and the middle layer was maximum up to 3 ° C. the air layer behind the green modules gets warmer, thus creating an extra layer of insulation. As expected, heat flux profiles during urban-scale transfer and considering the real effects of vegetation on overall outdoor energy performance and air quality, scenery, sound, and other related benefits, facade price increase, estimation about 70% (comprehensive structure, modules, plants, and irrigation system). Compared to the same non-

green system, it can certainly be balanced. Therefore, a multidisciplinary approach should be followed, and comprehensive research should be conducted (Binaco et al., 2017).
In a study in Genoa, Italy, a building that let the air out of its room showed that consuming fresh air behind the VGS could cool the air to 10 degrees Celsius with a monthly difference of 5 degrees Celsius in summer and allows the building to save an average of 26% in the summer to reduce the energy required for cooling (Perini et al., 2017).
A green facade optimization (GFO) approach has also been developed to simulate the thermal behavior of green facades with different insulation thicknesses (Olivieri et al., 2017). A new method has been proposed to evaluate the benefits of direct green facade cooling from thermal and three-dimensional infrared point cloud data in Nanjing, China (Yin et al., 2017).
A study with an experimental method has been done to investigate the role of urban green areas in reducing temperature and overcoming global warming in Tehran. In this study, data collected by the data logger includes air temperature and relative humidity. Two urban green walls were tested and measured at specified intervals of 0.5, 1, 2 meters. According to the obtained measurements, the green walls in the warm season reduce the temperature of the surrounding space by 0.63 and 1 degree Celsius. In the cold season, the temperature is 2.43 and 1.76, respectively, at the points attached to the wall. The results show that the temperature around the green wall is up to 1 degree Celsius cooler in summer, and in cold seasons, it is 3 degrees warmer. In this study, the type of plants used and their LAI were not mentioned. This study confirms the effect of green walls in overcoming the heat island in Tehran (Azmodeh et al., 2017).

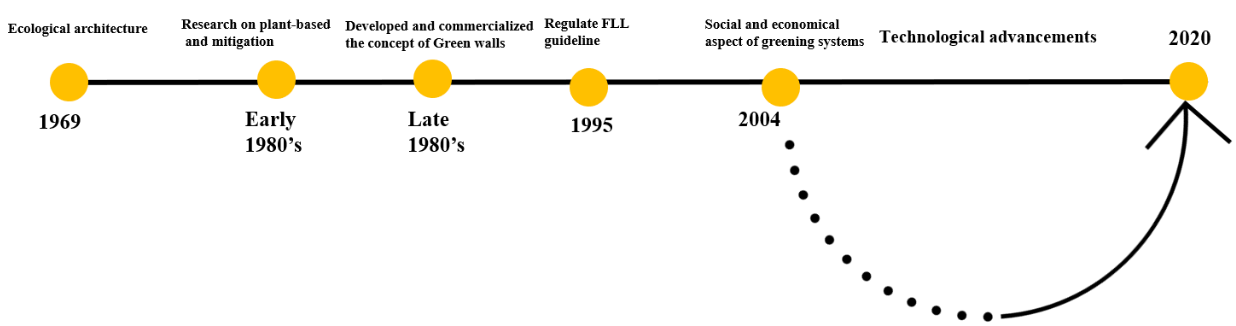


Fig 1.6 The progression of VGS over time depending on significant incidents

Table 1.2. Previous studies on vertical greening systems based on effective factors

Authors	PUBLICATION YEAR	COUNTRY LOCATION	CLIMATE REGIONS	PERIOD OF STUDY	PLANT SPECIES	ORIENTATION	TYPE OF GREENING SYSTEM	METHODOLOGY	SUBSTRATE	AIRE CAVITY	RESULT EXTERIOR SURFACE TEMPERATURE ENERGY CONSUMPTION
Wong	2009	Singapore	Af	whole year	Nephrolepis exaltat,Urechites lutea,Ophiopogon japonicus, Tradescantia spathacea	S/W/N/E	Green Wall panels based	Simulation			Maximum 11.58 ◦C surface temperature reduction
Wong et al	2010	Singapore	Af	February/ April/June	Hemigraphis epanda Phyllanthusmyrtifolius, Tradescantia spathacea; Mosses	S	Living wall	Test on real case	Soil and inorganic substrate	❖	Temperature reduction Day: 1 - 10.94 ◦C Night 2- 9 (depending on the system) ◦C
Cheng et al	2010	Hong Kong	Cwa	Summer	Grass	W/ SW	Living wall Panel-based	Experimental	hydroponic medium	30-600 mm	1.2-1.3 ◦C between surface temperature of LW and ambient air
Jim	2011	(Hong Kong)	Cwa	February/ November	Perennial plant	S/N	Grid panel (PVC) LW	Experiment Simulation			0.3-3 ◦C
Perini et al.	2011	Netherlands / Zuid-Holland	Cfb	Autumn	Hedera helix/ H. helix, Vitis, Clematis, Jasmine and Pyracantha	NW/NE	Indirect GF	Experimental	20 cm		2.7 ◦C
Perini et al.	2011a	Netherlands / Zuid-Holland	Cfb	Autumn		W	Modular LW	Experimental	40 mm	potting soil	5 °C
Mazzali et al.	2013	Lonigo Venezia Pisa	Cfa	Summer Autumn	Several, shrub, herbaceous and climber species	SW/E	Living wall Pocket typed, felt and grid panel (polyprop. Panel)	Experimental	50 mm 30 mm	Felt - soil	12-20 °C
Chen et al.	2013	Wuhan, China	Cfa	Summer	Six different plant species	W	living wall	Experimental	Adjustable 3– 60 mm	hydroponic medium	20.8 °C. the smaller distance has better cooling effect but higher relative humidity in the air layer

Safikhani et al.	2014	Malaysia	Af	April, May and June	Thunbergia grandiflora Perennial plant		Felt living wall	Experimental			8 °C between air temperature and air cavity (max) 4 °C between air temperature and indoor temperature (max)
Olivieri et al	2014	Colmenar Viejo- Spain	Csa	Summer	Sedum sp	S	Living wall metal box modular	Experimental	❖	❖	
Tan et al	2014	Singapore	Af	March to November	Several species of perennial plants	N/A	Living walls Vertical panel	Experimental			6.7 °C
Coma et al	2014-2015	Spain /Lleida	Csa	summer and winter seasons	deciduous creeper plants- evergreen species	E/ S /W	double-skin GF and LW	Experimental			Cooling energy reduction by LW (58.9%) and double-skin green facade (33.8%)
Pan and Chu	2016	Hong Kong	Cwa	Jun - September			Green Wall	Experimental			16% reduction of electricity consumed for air-conditioning
Razzaghmanesh and Razzaghmanesh	2017	Australia	Csa	February - August	evergreen perennial	W	Living wall polyprop. Trays modular	Experimental	❖	scoria, clay	
Carlos	2014	Portugal	Csa	winter	Evergreen perennial plants (e.g. Campsis, Cucurbita, Hedera, Ficus)	N/SE/W	Living wall Planter boxes (ceramic)	Simulation			6-33.5% of heating load reduction for the use of LWs on the north, east, and west walls but not the south wall

Authors	Publication year	Country Location	Climate Regions	Period of study	Plant species	Orientation	Methodology	Type of VGS	Substrate	Aire cavity	Result
Hoyano	1988	Tokyo, Japan	Cfa	Summer	Hedera helix	SW	Observation	Direct GF	soil	❖	13 ◦C
Bartfelder and Köhler,	1987	Berlin	Cfb							❖	temperature reduction 2-6 ◦C
Hoyano	1988	Japan	Cfa	summer	Luffa cylindrica	W	Observation & simulation	Indirect GF Frame	❖	840 mm	1–3◦C
Holm	1989	(Pretoria, SA)	Hot, arid continental	Summer-Winter	English ivy (Hedera helix) as well as Boston ivy (Parthenocissus tricuspidata), Virginia creeper (Parthenocissus quinquefolia) and grape (Vitis vinifera)	N	Simulation	Direct GF		❖	an ambient temperature range of 21°C – 31°C
Di and Wang	1999	Beijing, China	Dwa	Jun	ivy	W	Experimental	Direct GF	soil	❖	In winter, , for an outdoor range of 7°C – 18°C.
Di and Wang	1999	Beijing, China	Dwa	summer	ivy	W/ S	Observation & simulation	Direct GF	soil	❖	
Stec et al.	2005		❖	❖	Climbing plant	❖	Experimental Laboratory condition and simulation	Indirect GF	❖	❖	8.2 ◦C
Köhler	2008	Berlin	Cfb	Summer/Winter	Parthenocissus tricuspidata	W		Direct GF	soil	❖	Reduction of the peak-cooling load 28% on a clear summer day
Eumorfopoulou & Kontoleon	2009	Thessaloniki – Greece	Af	Summer	Parthenocissus-tricuspidata climbing plants	E	Experimental test Obs -model	Direct GF	soil	❖	4-4.58 ◦C lower during night and daytime respectivly
Wong	2010	Singapore	Af	February/April/ June	Climber plants	❖	Experimental	Indirec GF	❖	<8	reductions of 28% for peak-cooling loads
Price	2010	MD, USA	Cfa	Summer	Nine spp. deciduous & evergreen, LAI 3	S/ W	Experimental and simulation	double-skin GF Trellis × 3 types	Pot mix + sand	❖	about 20 °C reduction of the cooling capacity by almost 20%.

Perez et al,	2011b	Lleida-Spian	Bsk	Spring & summer	Wisteria sinensis	S/E	Experimental	Inderct-GF modular trellises	Vary between 0.8-1.5 in different orientation		
Sternberg et al.	2011	UK	Dfa	Whole year	Hedera helix	W/S	Test on real case study	Dirct GF	Soil	❖	5.7 ◦C
Perini et al.	2011	Netherlands	Cfb	Autumn	Hedera helix	N/W	Observation	Direct GF	soil	❖	1.2 ◦C
Koyama et al.,	2013	Japan	Cfa	summer	Momordica charantia, Ipomoea tricolor, Canavia gladiata, Pueraria lobata, Apios americana ‘Medikus	S	Experiment	Indirect GF Plastic mesh	Soil	❖	
Susorova	2013	USA Chicago	Dfa	summer	Parthenocissus tricuspidata	S	Simulation Mathematical model	Direct GF		❖	Energy reduction 6.2% Annual cooling energy reduction of 34.6%
Jim	2015	China HongKong	Cwa	Summer	Ficus pumila, Campsisgrandiflora, Bauhiniacorymbosa, Pyrostegia venusta	E/S/W/N		Indirect GF	Soil		10 ◦C
Hoelscher	2015	Berlin, Germany	Cfb	summer	climbing plants: Parthenocissus tricuspidata, Hedera helix and Fallopia baldschuanica	S/SW/W/E	Experimental test	Direct GF	Soil	❖	
Vox et al.	2018	Bari, Italy	Csa	2 years June 2014 to December 2016,	Rhyncospermum jasminoides Pandorea jasminoides variegated	❖	Experimental	Direct GF	Soil	❖	

Jaffar	2013	Malaysia	Af		❖	N/W	Experimental	LW& GF	Soil	❖	Maximum 17.62 ◦C on the North West side
Susorova	2014	USA Chicago	Dfa	Summer	Parthenocissus Tricuspidata	E/ S/W / N	Experiment	Direct GF	Soil	❖	daily maximum temperature was 36% higher and the average
Shafiee et al.,	2020	Shiraz	Bsh	summer	Gazania, Petunia Sprawling, Liriope and scrollable Cactus.	E/W	Experiment and Simulation	Living wall		❖	8.7 ◦C maximum ambient air temprature reduction by panel-based LW
Farrokhirad	2020	Tehran	Bsk	summer	Hedera helix	S /E	Simulation	Direct GF	Soil	❖	1.2-3 ◦C

❖ No data available

Af:Tropical, **Cwa**:Subtropical, **Cfa**: warm temperate; fully humid; hot, **Csa** :warm temperate; hot summer
Dfb: Warm-summer humid continental , **Cfb**: Temperate oceanic, **Bsk**: Hot semi-arid , **Dfa**: Hot-summer humid continental, **Cwa**: Monsoon-influenced humid subtropical
S:South N:North E:East W:West

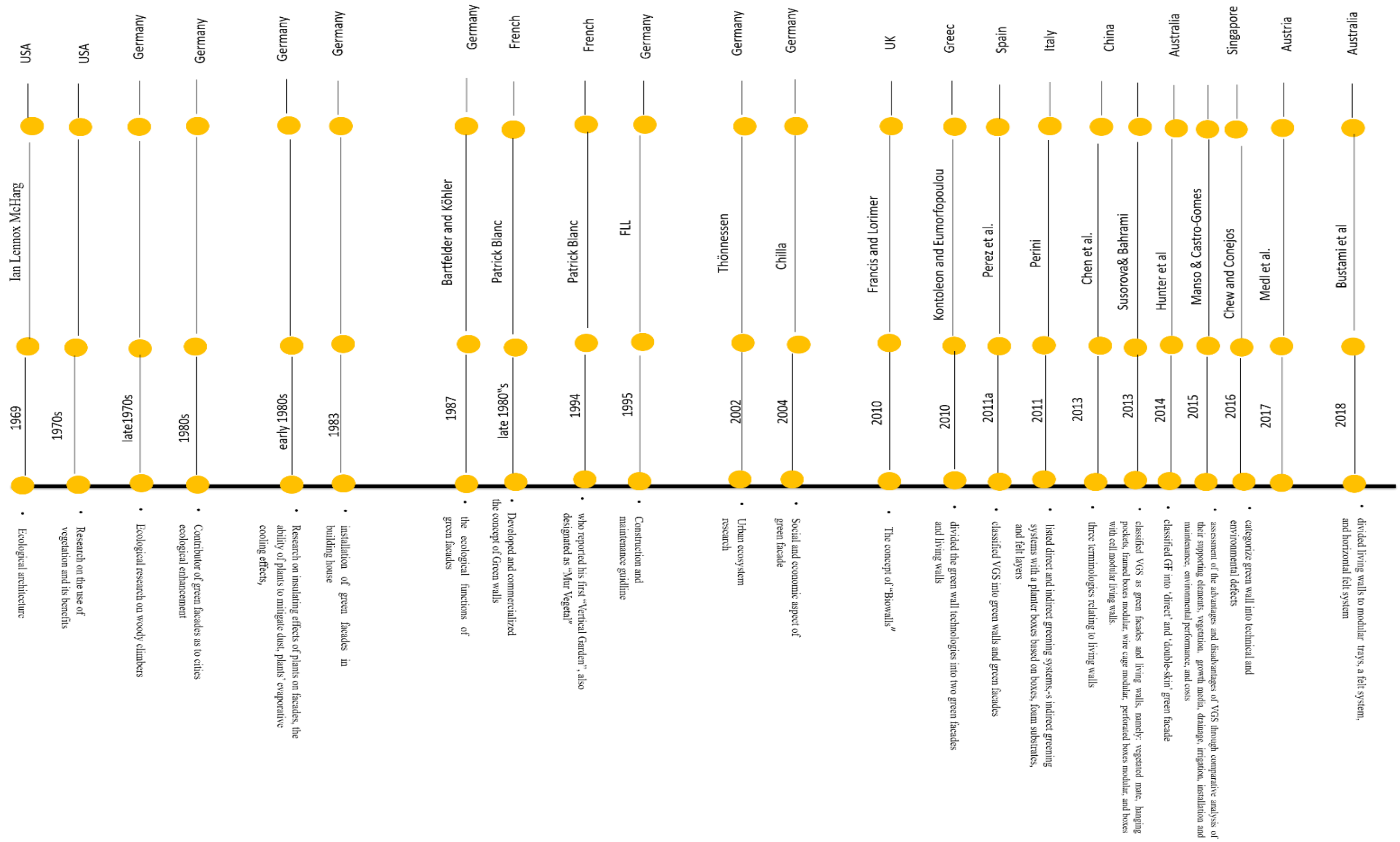


Fig 1.7 The timeline of VGS

1.5 Outline of Literature review

Overally, the researches mothodology are experimental, simulation, and tested on real case studies. In imperical models, the green wall's thermal behavior is usually compared to that of the bare wall. In reviewing the studies, according to the indicators affecting the thermal performance of the VGS, including climatic factors of the study site (Mazzali et al., 2013), plants used (Hoelscher,2015; Mårtensson et al., 2015; Perini et al., 2017), season and time of the research (Holm, 1989), orientation (Carlos, 2015), type of green wall (Wong et al.,2010), methodology and air cavity (Perez et al., 2014), which is essential in double-skin green facades and the characteristics of the substrate (Price, 2010) data collected. Finally, the results have been analyzed by emphasizing the reduction of the building's surface temperature and reducing energy consumption.

Traditional green facade, which is the oldest type of VGS, was studied in 1987 in Japan by Hoyano, with a humid subtropical climate and show in 1988 by the same researcher. The results indicate a significant yield of *Hedera helix* with a decrease of 13 ° C in the direct green facade and a decrease of 1-3 ° C in the double-skin green facade. Although no information is available on plant thickness in these two studies, direct ones can be used as a sustainable tool to reduce surface temperature. Then in 1988, a study on direct GF was conducted by Kohler in Germany, which shows a decrease of 2-6 ° C.

Although no information was provided on the research season, plant thickness, or climatic parameters of the study site, Stec et al. reported a 20 ° C reduction in surface temperature in 2005. In 2011, Perez reviewed the performance of traditional and double-skin green facades and recorded a 17.62 ° C decrease by the trellis panel. Chan in 2013 confirmed the highest rate of surface temperature reduction by the living wall in Wuhan with the climate with a decrease of 20.8 ° C per year and (Mazzelli et al., 2013) in the north of Italy with a decrease of 12-20 ° C by the pocket based living wall.

Reduction of annual cooling energy consumption about 34% with green facade, 58.9% reduction of energy consumption in a hot season by a living wall, and 33.8% by double-skin facade shows the high potential of a VGS in reducing cold weather confirmed by Sosurova. In the cold season, a study in Spain did not show excess energy consumption, while Stec et al. in 2005 acknowledged that the plant in the cold season might justify an increase in heat demand.

(Wong et al., 2010) proved the dependency of ambient temperature affected by VGS to the type of greening system. A review of green wall performance studies confirms the reduction of energy consumption in summer, especially in warm regions, and the decrease of heat in winter. although due to the lack of studies in winter days and nights, it is not possible to ensure proper green wall performance in all climates. Because most of the studies were conducted in the warm temperature region and then the equatorial region, sufficient information is not available, especially in hot and dry regions facing a water crisis. Research conducted by (Farrokhirad, 2020) on the direct green facade covered with *Hedera Helix* in Tehran confirms a decrease of 2.8-3° C in the surface temperature.

Reviewing the studies conducted since 1997 on the direct GF covered by climbing plants, it can be found that researchers have welcomed this field of research, and the number of studies is increasing. Even though many researchers from around the world are interested in studying green wall efficiency, there is still a shortage of studies in the following fields:

- Since several researchers have demonstrated the VGS's effectiveness in minimizing cooling load in the summer, its insulating properties in the winter have also been considered. But most studies are done in the summer, and there is a lack of information about the performance of the green wall in the winter. For example, they have confirmed the reduction of heat load in winter, while the study conducted by (Carlos) has also showed the heat load increasing.
- The impact of VGS features, including materials and executive details, has been repeatedly emphasized by researchers, while many studies have not provided information on the configuration, plant thickness, and location of the supporter frame.
- The role of selected plants has been proven as the most important factor in the thermal behavior of the green wall. Plant characteristics that include morphological and physiological parameters can cause changes in system performance. A small number of studies provide readers with sufficient information about the characteristics of the plant, the most important of which is the Leaf Area Index. Only (Price 2010) compares the average LAI leaf area of 9 different plant species, considering the shade structure design and cooling provided by the green facade.
- Seasonal variations and shifts in habit growth during the year, as well as their effect on thermal behavior, require year-round research.
- Due to the importance of building use in determining energy consumption patterns, it is necessary to achieve more practical information by considering using and changing the pattern of energy consumption according to seasonal fluctuations. Also, the pattern of energy used in the building is one factor that should be take into account when choosing a green system. For example, residential use involves more economical and social constraints for users. Also, the amount and rhythm of energy consumption in housing require more attention compared to other uses.
- The importance of studying the wind pattern and selecting the appropriate system, followed by the primarily selected plants, has not been mentioned in any study.
- Substrate and physical characteristics included, and soil chemical feature have been ignored in the studies. One of the factors is overlooked the importance role of the soil specialist in the green wall design process. The insulation capacity of VGS also depends on the thickness of the substrate, foliage density, and the air cavity (Perez et al., 2014; Jim, 2015).
- The air gap offers an additional but important cooling service. Trapped air depends on the density and coverage of the climber in exchange for the open air in front of the VGS (Eumorfopoulou and Kontoleon, 2009; Cameron et al., 2014). The air cavity between the green wall and the wall surface plays an essential role in insulation. It can affect the cooling property by changing the wind speed. It is, therefore, a factor that is often neglected (Ottelé et al., 2011; Hunter et al., 2014).
- The number of studies performed by the experimental method is more than simulation and observation. In the case of the traditional green facade, the studies are on a real case study, but in the case of the living wall and the double-skin green facade, the number of analyzes performed on the case of real sample has more realistic and accurate results in terms of geometric conditions and climatic factors.

References

Books

Bigio, A. G. (2003). Cities and climate change. *Building Safer Cities: The Future of Disaster Risk, World Bank, Washington DC*, 91-99
Betsill, M., & Bulkeley, H. (2003). *Cities and climate change* (Vol. 4). Routledge.

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., & White, K. S. (Eds.). (2001). *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change* (Vol. 2). Cambridge University Press.

Metz, H. (2000). *The geometry of ecological interactions: simplifying spatial complexity*. Cambridge University Press

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., ... & van Ypserle, J. P. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change* (p. 151). Ipcc.

Paterson, M. (2013). *Global warming and global politics*. Routledge.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., ... & van Ypserle, J. P. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change* (p. 151). Ipcc.

Rosenzweig, C., Solecki, W. D., Romero-Lankao, P., Mehrotra, S., Dhakal, S., & Ibrahim, S. A. (Eds.). (2018). *Climate change and cities: Second assessment report of the urban climate change research network*. Cambridge University Press.

Santamouris, M. (Ed.). (2013). *Energy and climate in the urban built environment*. Routledge.

Papers

Hansen, J., Sato, M., Ruedy, R., Kharecha, P., Lacis, A., Miller, R., ... & Zhang, S. (2007). Dangerous human-made interference with climate: a GISS modelE study. *Atmospheric chemistry and physics*, *7*(9), 2287-2312.

Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*, *108*(455), 1-24.

Oke, T. R., & Cleugh, H. A. (1987). Urban heat storage derived as energy balance residuals. *Boundary-Layer Meteorology*, *39*(3), 233-245.

Oke, T. R., Johnson, G. T., Steyn, D. G., & Watson, I. D. (1991). Simulation of surface urban heat islands under 'ideal'conditions at night part 2: Diagnosis of causation. *Boundary-layer meteorology*, *56*(4), 339-358.

Santamouris, M., Papanikolaou, N., Livada, I., Koronakis, I., Georgakis, C., Argiriou, A., & Assimakopoulos, D. N. (2001). On the impact of urban climate on the energy consumption of buildings. *Solar energy*, *70*(3), 201-216.

Stone, B., Hess, J. J., & Frumkin, H. (2010). Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities?. *Environmental health perspectives*, *118*(10), 1425-1428.

Taha, H. (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. *Energy and buildings*, *25*(2), 99-103.

Cheng, C. Y., Cheung, K. K., & Chu, L. M. (2010). Thermal performance of a vegetated cladding system on facade walls. *Building and environment*, *45*(8), 1779-1787.

Bass, B., & Baskaran, B. (2003). Evaluating rooftop and vertical gardens as an adaptation strategy for urban areas.

Smit, B., Burton, I., Klein, R. J., & Wandel, J. (2000). An anatomy of adaptation to climate change and variability. In *Societal adaptation to climate variability and change* (pp. 223-251). Springer, Dordrecht.

Reports

-EEA, R. (2012). Climate change, impacts and vulnerability in Europe 2016. An indicator-based report. *EEA Report No. 12/2012*.
-UN-Habitat (2011) *Global Report on Human Settlements: Cities and Climate Change*. UN-Habitat, Nairobi, Kenya.
-Principles Governing IPCC Work, Intergovernmental Panel on Climate Change, Geneva, Switzerland (2013)
-Principles Governing IPCC Work: Procedures for the Preparation, Review, Acceptance, Adoption, pproval and Publication of IPCC Reports (Appendix A), Intergovernmental Panel on Climate Change, Geneva (2013)

Websites

https://data.giss.nasa.gov/gistemp/

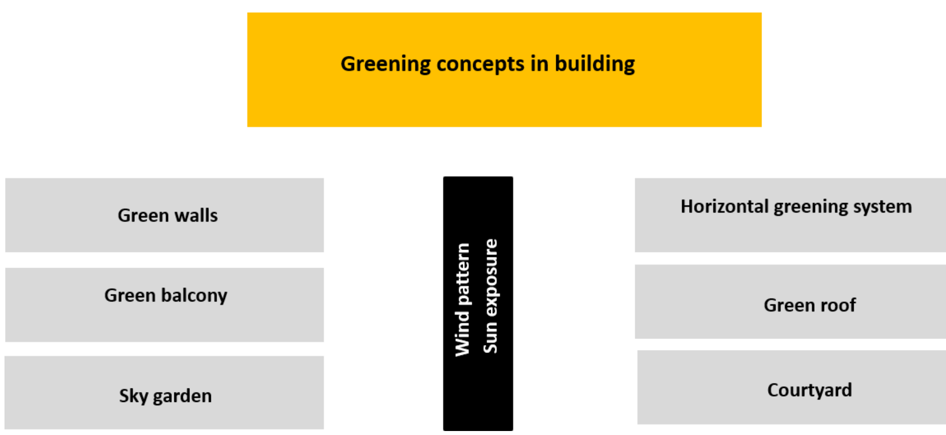
CHAPTER 2: CHARACTERISTICS AND CLASSIFICATION OF VERTICAL GREENING SYSTEMS

2. Vertical Greening classification

Plant-covering of building surfaces has been adopted as a technique to minimize the Urban Heat Island impact in recent decades (Gago et al., 2013) due to the full range of environmental and ecological benefits, especially those influence temperature (Hunter et al., 2014b), cooling effect (Kontoleon & Eumorfopoulou, 2010a) and carbon emissions reduction within the buildings. Green building systems are becoming more widespread, and architects and academics are becoming more interested in them. The research would show producers looking to develop and supply goods in order to implement cost-effective and easier-to-maintain productions as a result of the increasing movement toward these systems. This chapter aims to review the studies conducted in the field of vertical green systems to collect information on the types of existing classifications and extract the main principles. In addition, a new classification focusing on the most current systems on the market was proposed. Because of the innovation and value of this industry, the rate of new product development is increasing. As a result, new classification standards based on the most recent technology in green wall development are beneficial. Since climatic conditions play such a large role in the positive outcome of green systems, classification based on climatic characteristics is also taken into account.Any living walls have different names depending on the type of materials and construction companies due to the wide variety of products and production companies. Designers face a significant challenge in determining which green system is best suited to a given project. However, it depends on the building characteristics (e.g., orientation, accessibility, height) and climatic conditions (e.g., sun, shade and wind exposure, rainfall). Moreover, understanding their differences in composition and the main character is essential (Manso & Castro-Gomes, 2015). Nevertheless, it should be taking into account the needs of the users, the appropriate budget, and, most importantly, the purpose of installing (e.g., air purification, noise barrier, reduce the cooling load or aesthetic) the green wall. The study on VGS classification includes the following steps:

-Classification of Gf and LW

-Classification of subgroups



0Fig 2.1 Classification of green buildings envelop

The thermal performance of the greening systems in horizontal and vertical forms varies depending on sun exposure and wind pattern in this classification. To begin, recognize the systems' characteristics and potentials before deciding on a green facade or a living wall is necessary.

Second, within each type, subgroups are formed based on the knowledge of each specification. One cannot anticipate proper success in this phase without understanding the characteristics of green wall forms since choosing the most appropriate structures considers the criteria in terms of ecological, environmental, social, and aesthetic aspects.

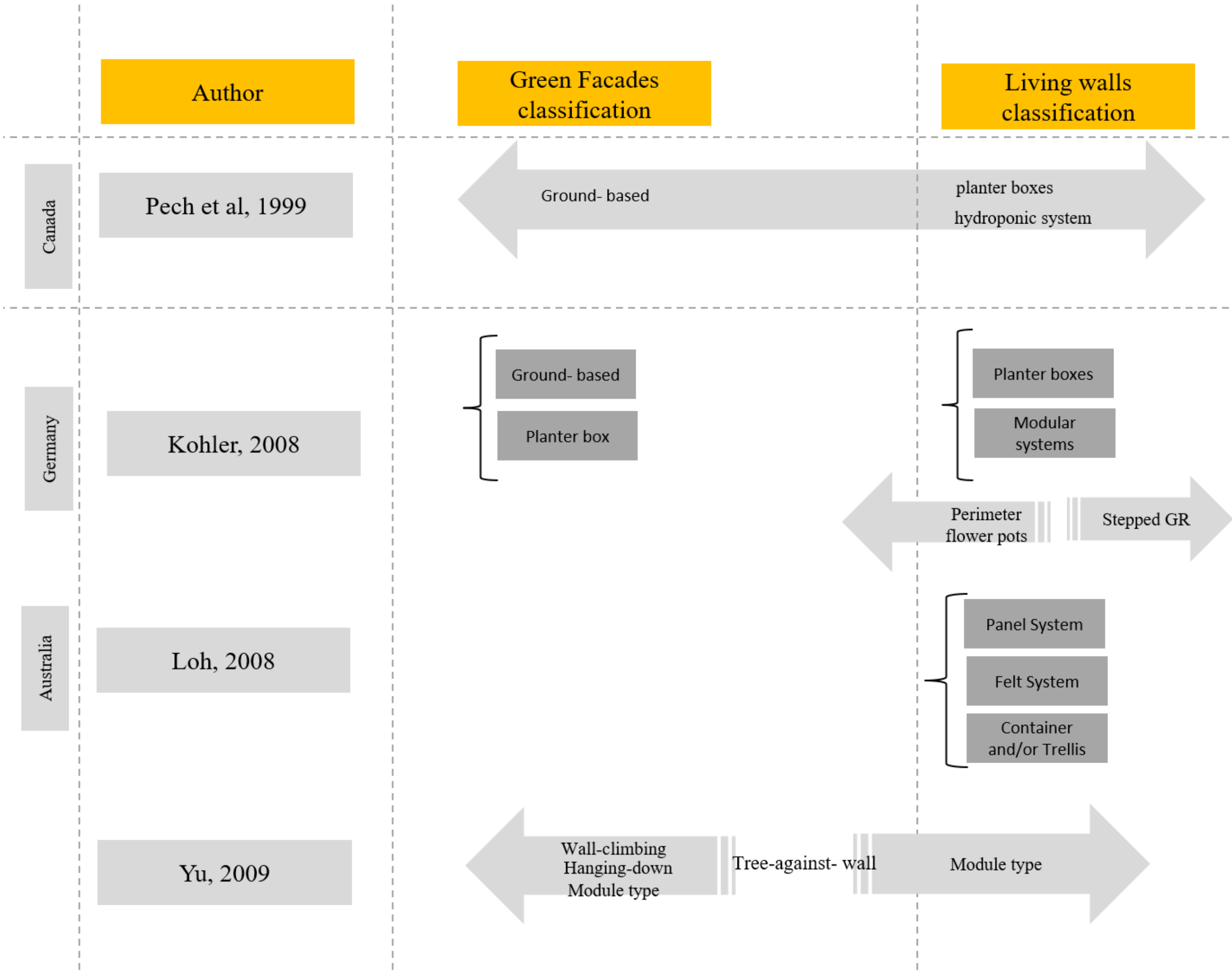
Systematic classification, in which the desired subtype is decided and designed and clarifies the designers of green walls (Jim, 2015). all green systems in the model must be systematically classified based on design requirements, technological features, varieties of growing plants, and weather constraints. Professionals can best appreciate and select a more effective method by identifying the capabilities, incentives, and drawbacks of VGS. Sustainable architecture and maintainability, also known as green maintainability, should be incorporated into the planning and design processes, according to (Asmone & Chew, 2016). Systems performance includes effective environmental performance, cost-effectiveness, and high-durability systems that meet the need for maintenance. It is also described as having an active role in reducing maintenance costs. Reviewing the existing classifications, as this technology advancement depends on time, and its noticeable impact on products have been compared based on chronological order. Definitely, due to the importance of climatic and geographical factors, they have been considered. By reviewing the classifications made by researchers since 1999, which was first done by Pech et al., it can be stated that at the beginning of the emergence of green building systems and the use of these systems as an active environmental strategy, the classification was initially based on the plant growing method. Due to technical shortcomings and the challenges of developing greening in buildings, the number of VGS was not substantial during this period of expansion.

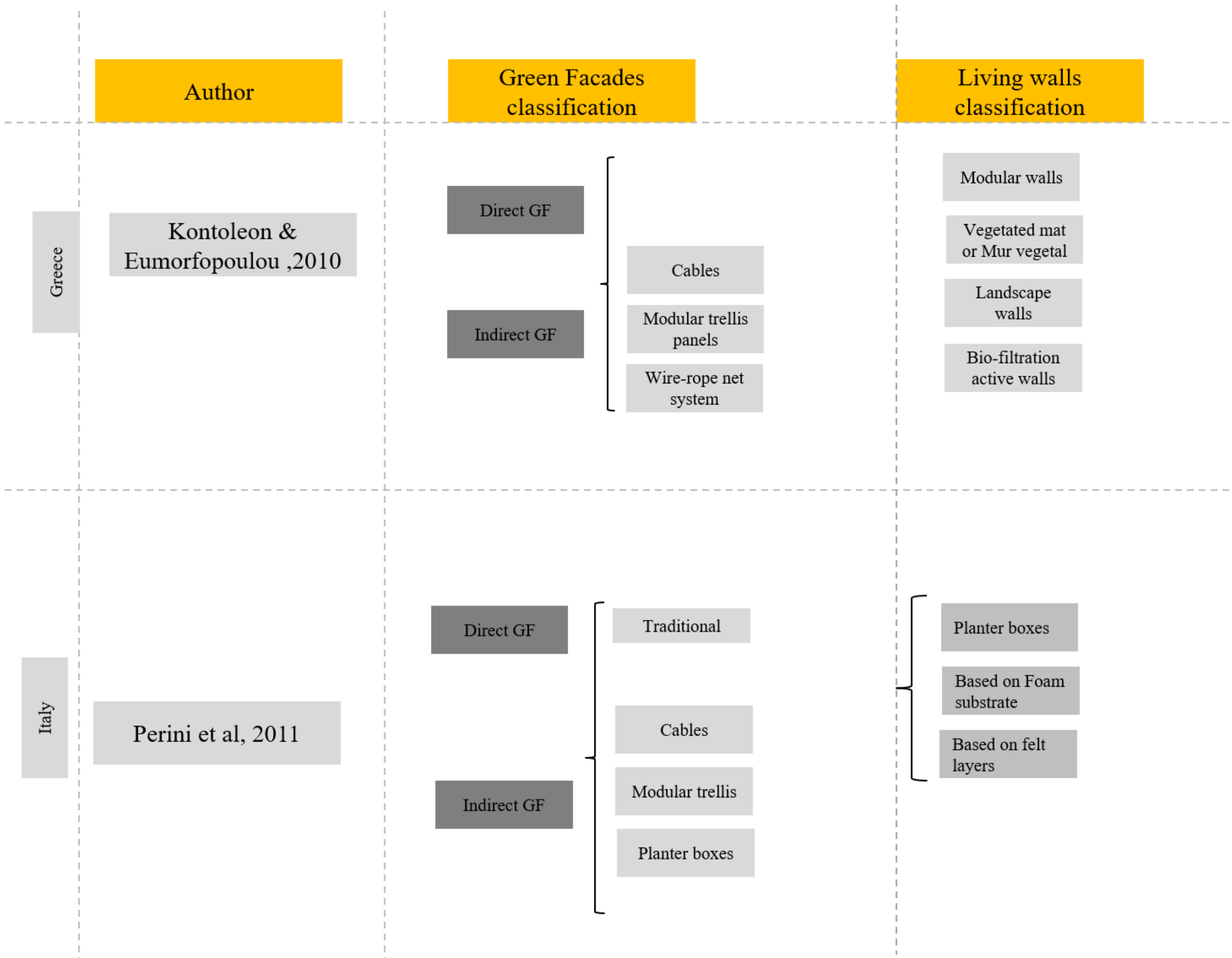
The classification by (Peck et al., 1999) includes a ground-based type of plant that works like a traditional green facade or a direct green facade. Planter boxes and hydroponics are also known to belong to the living wall group. Also, The green system is classified into green facades and walls based on the growth method by (Köhler, 2008). The classification of green walls into two types of green facades and living walls begins in this period, widely accepted by researchers today. He describes the green façade as two mains types (the same as the long-standing green façade) and another type that requires additional structures to support plants in the growth pathway, called the Planter Box. The difference between these two types of green facades is the plant's roots' location and nutrition. Also, in the living wall's classification, two types of modular and planter boxes have been introduced, and a kind of step between the stepped green roof and the green facade of the flowerpots. Although this kind is more common today, especially in residential complexes, it is not included in the classifications. In 2008, the vegetated walls were classified into the living wall and green facade, divided the living wall into different system panels, felt, and containers. In 2009, it was classified by (Yu,2009) separation based on a modular system, wall-climbing plants, and hanging-down plants, modular and against the wall. Based on today's classification, perhaps the first three categories can be considered in the green and modular facades in the living wall group. The tree would not blend into this division like other green walls because of its maintenance and structure. After that (Eumorfopoulou & Kontoleon, 2009) followed Koehler's classification in 2008 into two main categories: green facades and living walls. The green facades are a direct or traditional type in which plants grow upward without any additional structures. Usually, the plants are self-clinging that find their way to grow and attached to the wall without intermediaries. Indirect green facades or double skin include additional structures attached to support the plants to the building envelope. These structures vary, each with its limitations and advantages. This classification includes wire-rope net systems, modular trellis panels, and cables. The living wall is also divided into different groups, including modular, Vegetated mat or Mur vegetal, landscape walls, and the type of biofilter in the indoor space. The point to consider in this classification is the internal green system and making it a part of the division. Researchers have also considered the performance of indoor greenery, and studies have been conducted on its effectiveness. The classification of the green facades into two categories, direct and indirect, is based on the previous classification of the living wall into three types of the planter box, based on felt layers proposed by (Perini et al., 2011). In 2018, she presented a new classification based on the amount of maintenance needed considering plant species and average price. Then (Susorova et al., 2013) offered a classification of the green walls into two-dimensional and three-dimensional green facades. The three-dimensional requires more maintenance than the two-dimensional one, it reduces the cooling load. Each of these two types can be divided into different types, such as cable and ropes. Another proposed classification by (Susorova, 2015) divided living walls into continuous and modular. Also (Manso & Castro-Gomes, 2015) presented similar classification with minor differences in subgroups. The living wall consists of two modular and continuous groups, with the difference that in the continuous type, it accommodates lightweight structures, while in the classification performed by Sosurova vegetated mat and hanging pockets, it is in this group.

(Perez et al., 2014) proposed a comprehensive classification with a different perspective. Along with the growth of technology, green systems need to be, maintained and, consequently, affect the whole system cost. More complicated maintenance systems have been designed by producing new types of living walls due to variety of plants. For example, plant nutrition and irrigation system were developed that could cover all plant's needs. It also requires pruning and pinching, removes waste foliage, and pests' control at a higher cost than green facades. Therefore, they categorized the system into two parts, intensive and extensive, based on the amount of maintenance required. Due to its less complexity and less need for maintenance in the extension's category, all green facade types consider the extensive group, and all types of living walls, including geotextile, perimeter flowerpots, and panels, fit into the intensive category.

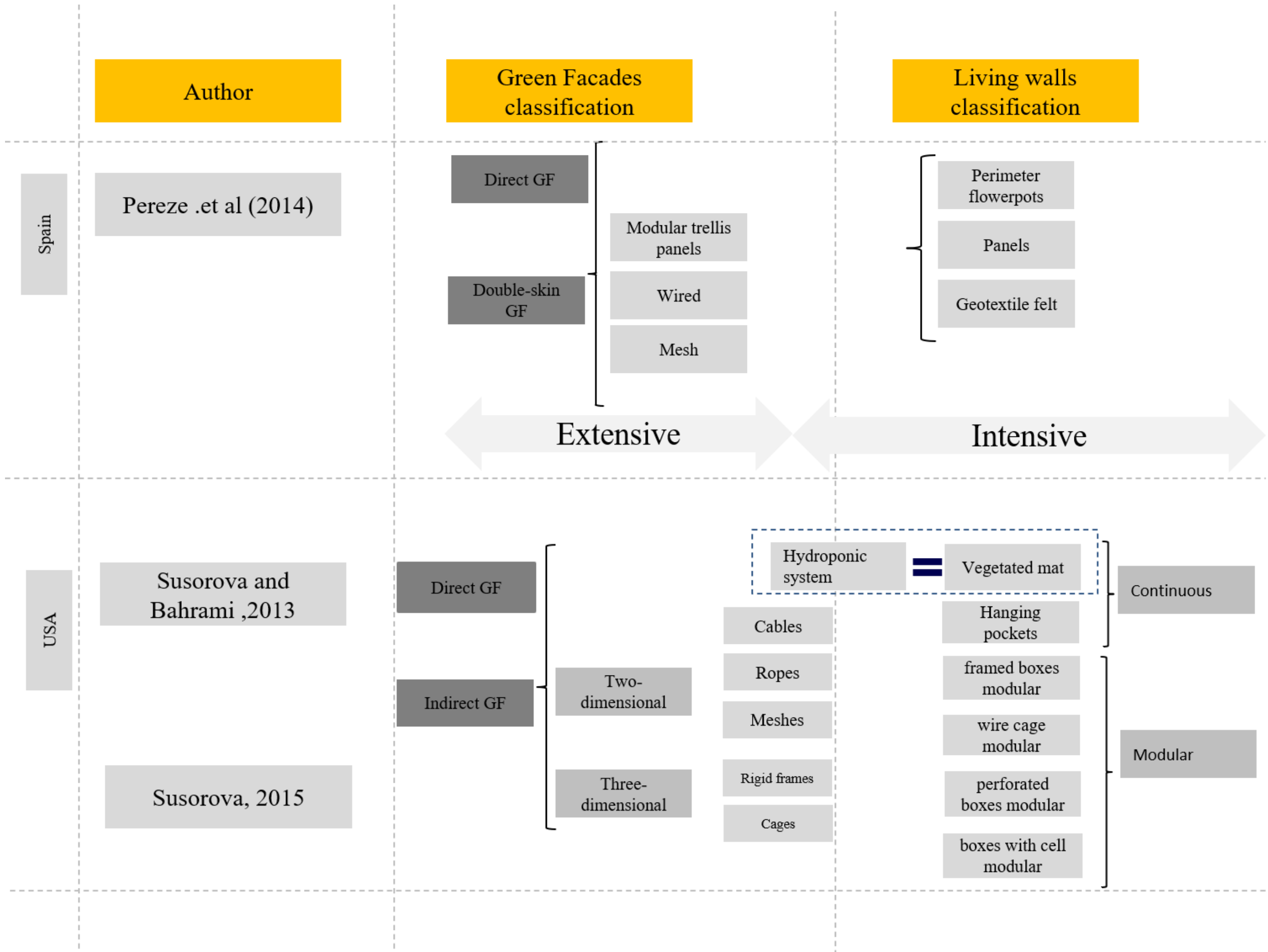
The classification made by (Jim, 2015) is analytical and systematic. It is based on the type of plants used in two categories, like dependent climber (CGW) and mechanically independent herb-shrub (HGW). CGW is made up of climbing, air gap, substrate, and vegetation, while HGW consists of extra water-nutrient factors. Triple criteria are proposed in this classification. Main criteria training- system and wall-toe substrate CG divided into 16 subgroups. For HGW with regarding the substrate-system and elevated substrate criteria, eight subtypes identified. It can be noted that the CGW group is equivalent to today's green facades, and HGW is in the category of living walls. There is no simple demarcation between the internal and external green walls in this form of view, owing to the complexities of the architecture as well as the maintenance needs. Besides, the point to consider in this division is plant-based, consequently water demand, maintenance requirements, and nutrition.

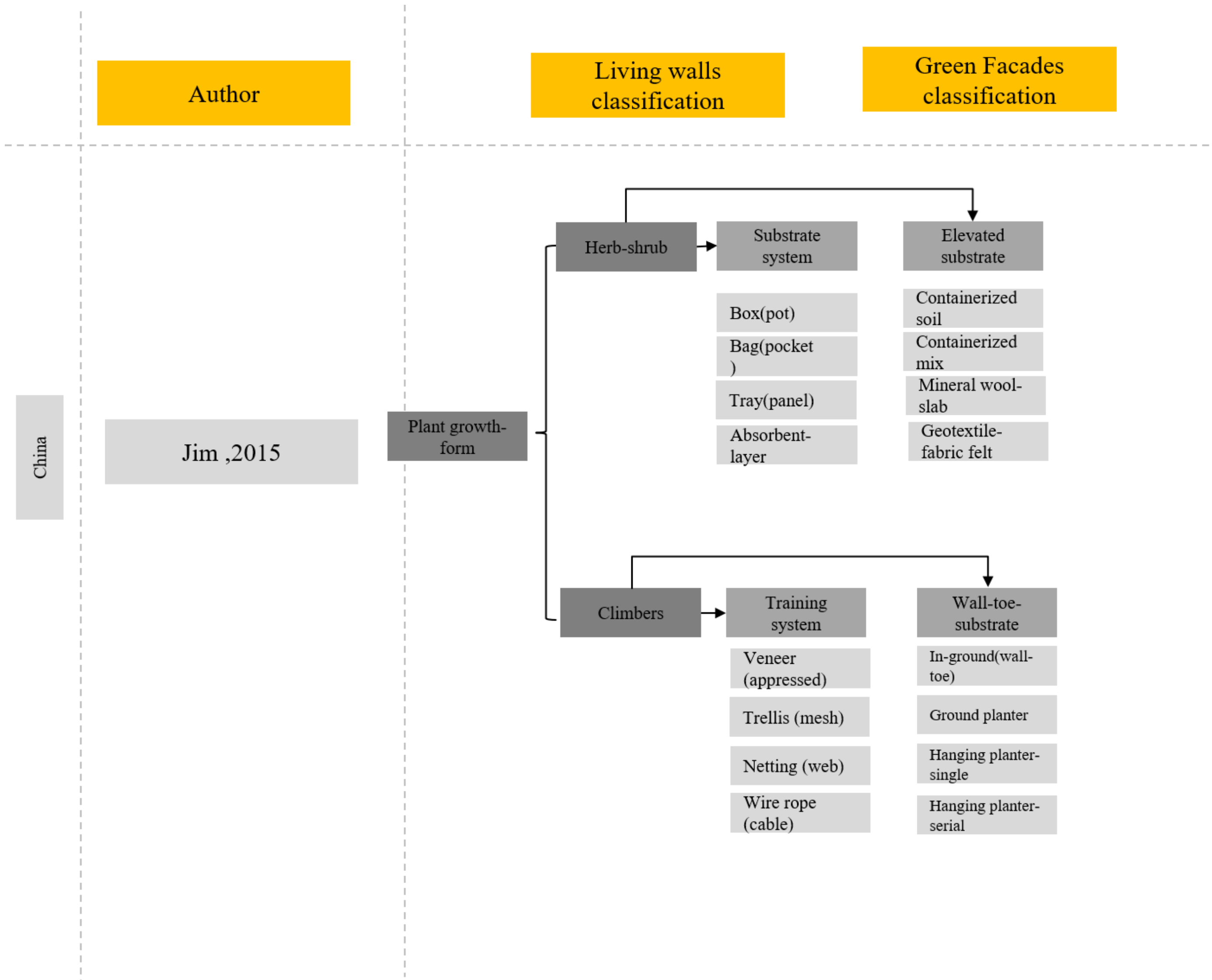
The critical question is whether this division can be applied to all climatic regions. The discussion mentioned a few levels ago regarding the localization of classification based on different climates concluded that this classification could be cited in China's tropical climate. However, it may take a different form in hot and dry areas and undergo fundamental changes due to plant maintenance and nutrition needs. Besides, according to the previous routine, the green facades is divided into direct and indirect. The last division (Beecham et al., 2019) is in the indirect GF, which includes mesh, trellis, and cable, and the living wall is divided into two main groups, modular and vegetated mat. The modular group includes modular boxes, felt pockets, planter boxes. Felt-based and hydroponics systems fall into the vegetated mats subgroup.


Author
Green Facades classification
Living walls classification
Canada
Pech et al, 1999
Ground- based
planter boxes
hydroponic system
Germany
Kohler, 2008
Ground- based
Planter box
Planter boxes
Modular systems
Perimeter flower pots
Stepped GR
Australia
Loh, 2008
Panel System
Felt System
Container and/or Trellis
Yu, 2009
Wall-climbing
Hanging-down
Module type
Tree-against- wall
Module type



Author
Green Facades classification
Living walls classification
Greece
Kontoleon & Eumorfopoulou ,2010
Direct GF
Indirect GF
Cables
Modular trellis panels
Wire-rope net system
Modular walls
Vegetated mat or Mur vegetal
Landscape walls
Bio-filtration active walls
Italy
Perini et al, 2011
Direct GF
Indirect GF
Traditional
Cables
Modular trellis
Planter boxes
Planter boxes
Based on Foam substrate
Based on felt layers

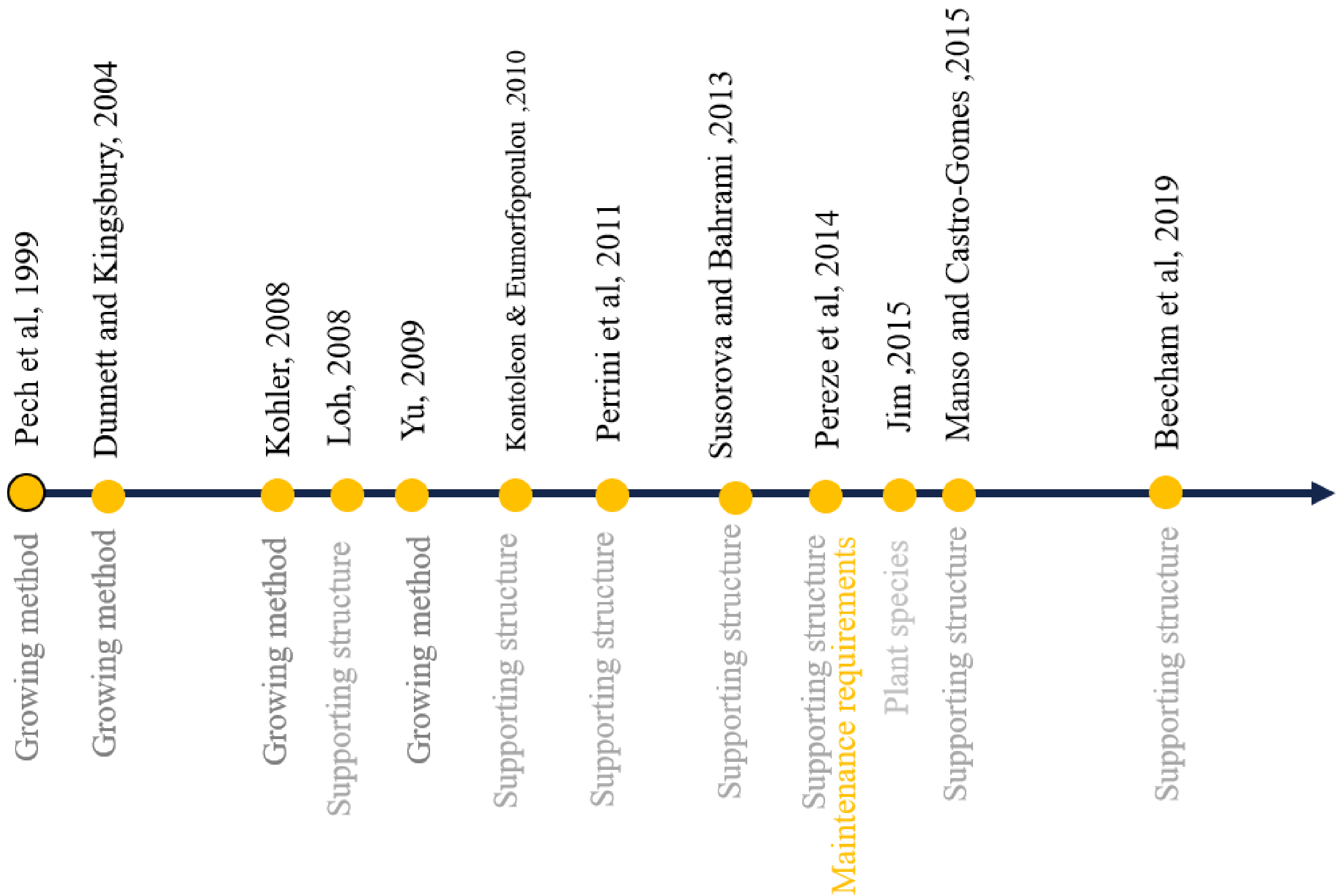

Author
Green Facades classification
Living walls classification
Spain
Pereze .et al (2014)
Direct GF
Double-skin GF
Modular trellis panels
Wired
Mesh
Perimeter flowerpots
Panels
Geotextile felt
Extensive
Intensive
USA
Susorova and Bahrami ,2013
Susorova, 2015
Direct GF
Indirect GF
Two-dimensional
Three-dimensional
Cables
Ropes
Meshes
Rigid frames
Cages
Hydroponic system
Vegetated mat
Hanging pockets
framed boxes modular
wire cage modular
perforated boxes modular
boxes with cell modular
Continuous
Modular



0Fig. 2.2 Comparison of VGS Classifications from 1999 up to now

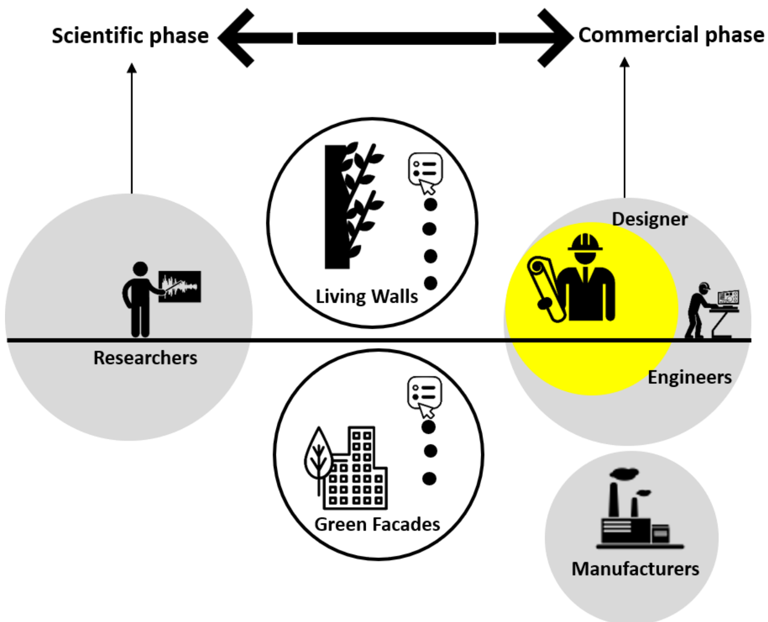
The results of reviewing the divisions show that generally, VGS can be classified into two major groups: green façades and living walls according to the plant species and growing methods (Dunnett and Kingsbury, 2004; Köhler, 2008;Hunter et al., 2014), supporting structure employed (Fernández-Cañero et al., 2018; Kontoleon & Eumorfopoulou, 2010a; Maria Manso & Castro-Gomes, 2015a; Pérez-Urrestarazu et al., 2015) maintenance needs (Perez et al., 2014) and based on the key components and factors (Jim, 2015).

Greening systems mainly depend on plant species, but it is debatable that the number of plants that can be grown in these systems has been identified and tested regarding on climates. Manufacturers listed the most proper spices, and they try harder to produce the new support systems to apply this plant. It means that the types of plants used are known. Usually, the effort is to produce and introduce new structures that can support plants based on predicting growth behavior, water demand, feeding, and, most importantly, maintenance needs; since 2008, most divisions have been defined based on structural systems.



0Fig 2.3 Timeline of VGS classification from 1999 up to now

By reviewing the recent technology development, it can be found that by expanding the variety of products in the interior and the building's envelope and offering new types, it is challenging researchers. Because of the manufacturers' commercial view, they try to introduce their products as the best products. They also play an essential role in providing practical and ultimately researched products to researchers. In other words, different goals and priorities of researchers and manufacturers cause a gap in research. Researchers' priority is to study the performance of the green systems and environmental effects without bias, while for manufacturers, the priority is to sell products and economic benefits. Besides, the priority of users is sometimes reduced to the aesthetic aspect of the green wall. Along with emphasizing the critical role of construction and design in providing systems that researchers can study and analyze. Because of the discrepancies between manufacturers' ideas on economic desire and academics' ideas on environmental performance, this topic is complicated.



0Fig. 2.4 Schematic diagram of relation between researcher and designer

It appears that the classifications developed so far have been connected to the study areas and accessibility to a variety of items. The influence of geographical factors on the classification by researchers cannot be ignored. Since a system is designed and produced according to the climatic factors and its limitations and based on plant species' growth in that geographical area, they are subconsciously introduced as standard systems. It can be called the localization of VGS classification. A beneficial system may be produced in a geographic area not included in the classification in another area. For example, systems introduced in Europe may not be considered more popular in the classification of Asian researchers. Thus, the prevalence of techniques within the classification is dependent on several factors, such as geography, climate, costs, expertise, and management. This study argues that climatic factors play a critical role in the design and manufacturing and the other performance that many researchers have discussed. Furthermore, the key role of plant species and substrate features is distinct. It means that it is possible to produce an economically viable and functional system in one area that imposes many restrictions on the use of the same system in another area. For instance, an efficient system in the Mediterranean region that can be used in Tehran's hot and semi-arid region has high costs for the irrigation and maintenance system, especially in the living walls. As a result, the research's shortcomings is the inability to generalize these investigations, despite the need to standardize systems based on specific criteria.

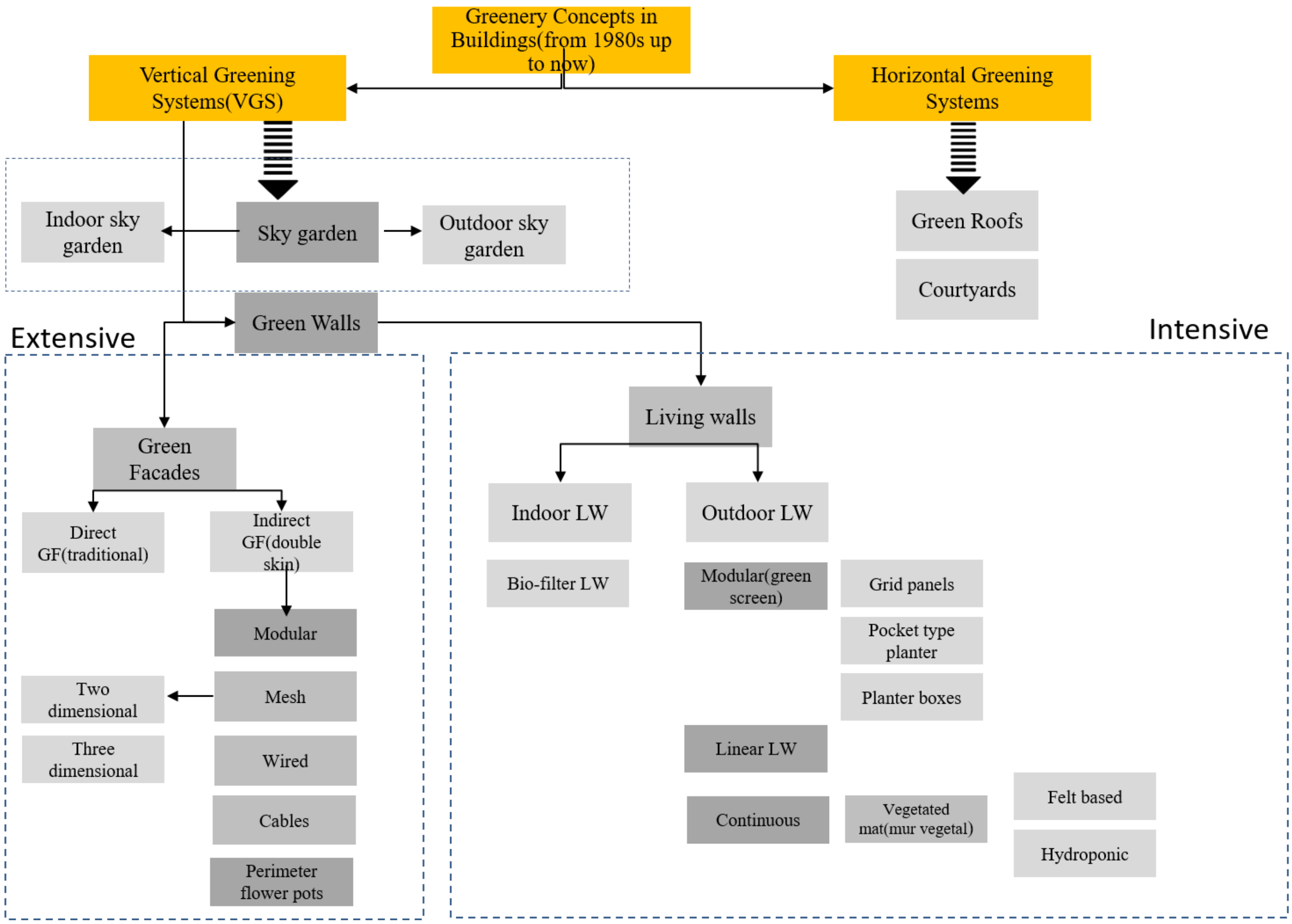


Fig. 2.5 New proposed VGS classification

Looking at the research background, this study proposes a different schematic approach to VGS classification. All VGS is divided into vertical and horizontal green systems due to exposure to sunlight and wind patterns. Horizontal systems include green courtyards and green roofs that are not the subject of this study. Vertical systems are divided based on indoor and outdoor placement, growing plants and their growing method, the technique of construction, maintenance requirements. High-rise buildings, based on greening location, can be divided into two indoor and outdoor sky garden types. The green facade is only used outside, while the living wall can apply both inside and outside. In addition to balconies, there is also a type of green space attached to the facade in the section of the green facade called perimeter flower pot. The living interior wall consists of a biofilter, given that this study intends to examine the thermal performance of vertical green systems in the building envelope.

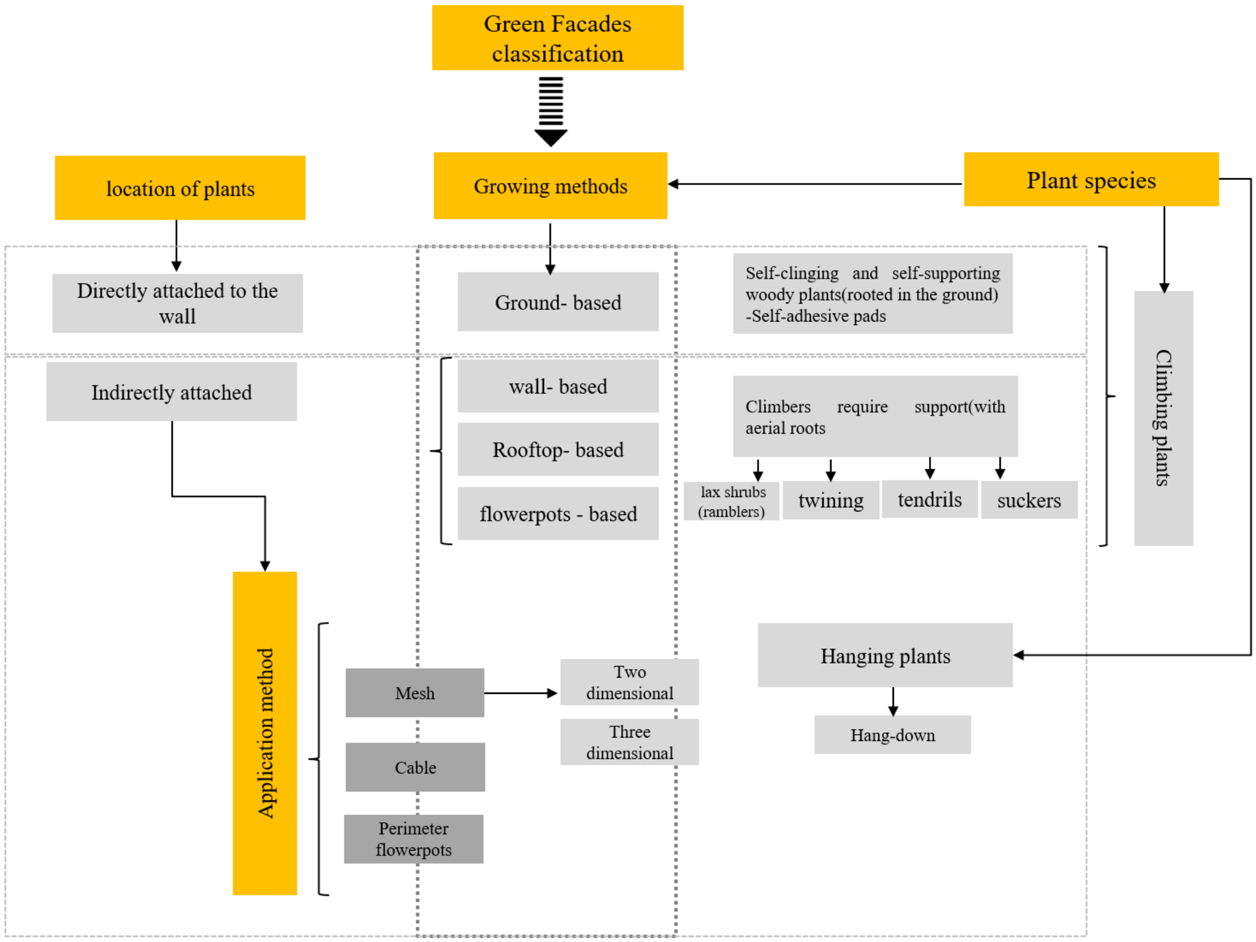


Fig 2.6 new proposed classification of green facades

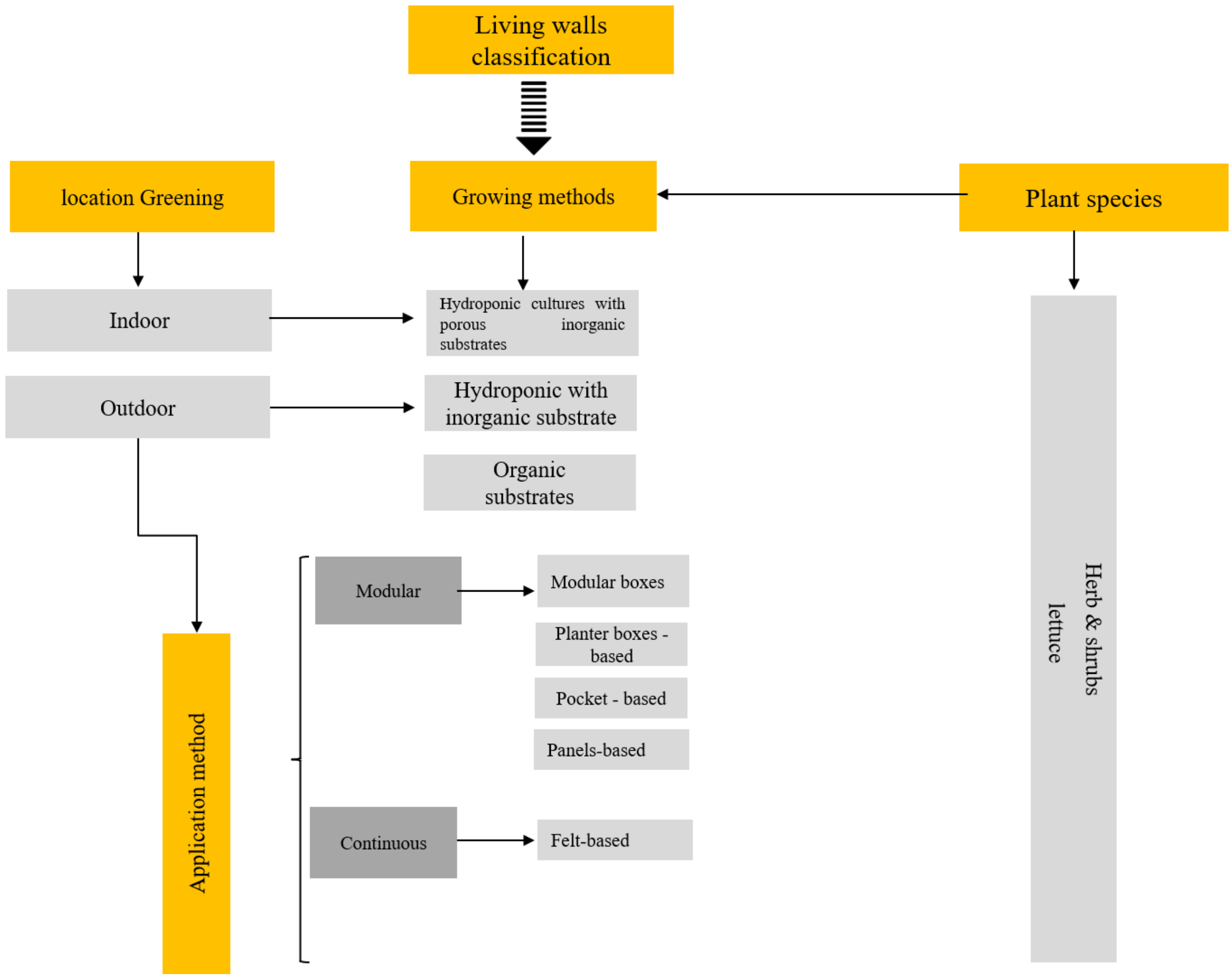


Fig 2.7 New proposed classification of Living walls

Green facades with vertical reinforcement display a rise in species diversity (Jim, 2015) Climbing plants such *as Parthenocissus quinquefolia*, *Wisteria* apply in indirect green facades. Moreover, evergreen shrubs like *Pterospida*, *Lamium galeobdolon*, *Carex*, *Alchemilla*, *Hosta*, *Geraniums*, *Pachysandra*, grasses, and perennials *Laurus nobilis*, *Pittosporum*, *Nerium oleander*, *Genisteae Jasminum* can be found in living walls. Evergreen climbing *Hedera Helix*, *Vitis*, *Clematis*, *Jasmine*, *Pyracantha* deciduous climbing *Parthenocissus*, *Wisteria Sinensis* use in indirect green facades combined with planter boxes (Perini et al., 2013). Plant species such as evergreen and deciduous climbing like *Hedera Helix*, *Vitis*, *Clematis*, *Jasmine*, *Pyracantha* growth in green facades. Definitely, the plants are varied by geographical and weather condition.

Green Facades Characteristics

Green facades, which refer to the establishment of root climbing plants grow directly on the walls' surface or a covering wire or frame (Chen et al., 2013a) to cover vertical surfaces and are divided into direct and indirect type. It is mainly rooted in the base of these structures, in the ground, in the middle pots, or even on the roofs. The green facade can be attached to existing walls or built as a stand-alone structure such as railings or columns (Kontoleon & Eumorfopoulou, 2010). It is formed by the growth of climbing plants that grow vertically all over the wall. Depending on the

plant growth medium's location, it can be divided into different types, including ground-base, planter-base, roof-base, or wall-based.
It can also be classified according to the type of plants, which includes two groups of ascending and descending plants, each of which includes various types, and based on the growth habit, can be used. On the other hand, GF can be divided based on direct and immediate attachment to the wall surface and indirect attachment with a holder. These retainers are responsible for guiding the plants to grow, which today are made of different materials and are introduced. The green facade attached to the wall, which is called the direct or traditional green facade, is usually ground-based. It means that the plants' roots are located in the ground and are the oldest type. After that, with the growth of technology and in order to increase the environmental efficiency, changes were made in their structure, and a new type was introduced as a double-skin or indirect GF. The double-skin type can be divided into modular, mesh, wire, cable, and box types, taking into account the conditions of the executive wall and the environmental factors.
The modular type includes two-dimensional and three-dimensional modular grids (Manso & Castro-Gomes, 2015) categorized GF into traditional or direct green facades that are self-adhesive and do not require support to guide plants to grow. Indirect ones include continuous and modular. The difference between the two types is the number of modular elements along the surface, but in a continuous system, it has support. Also, the green facade is classified according to the plants' position, plants that can be placed directly in the soil or boxes full of soil plants. Plants can grow upwards vertically or grow vertically downwards, like traditional, if hung at a certain height (Dunnett N, Kingsbury, 2008).

Direct GF

As referred to in traditional GF, that does not require structural support because climbing plants cling to external walls through adventitious roots or self-adhesive pads. Climbers attach themselves to the building's exterior using adventurous roots (e.g., *Hedera helix*) or self-adhesive pads (e.g., *Parthenocissus quinquifolia*). Self-adhesive climbers may penetrate the wall surfaces . However, evidence also suggests that the coating provided by self-adhesive climbers can play a "bioprotective" role, causing a sharp drop in wall temperature resulting in weathering (Sternberg et al., 2011).

Fig 2.8 Virginia creeper

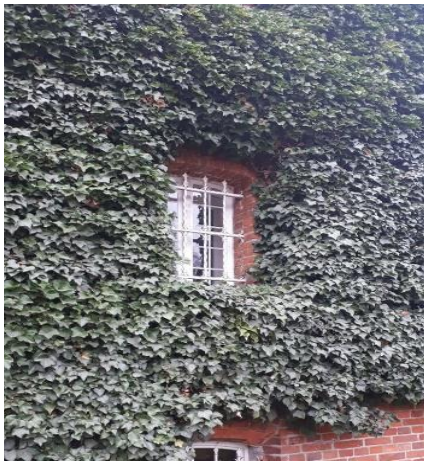


Fig 2.9 High foliage density Climbing plant

Fig 2.10 Direct GF (ground-based), Germany

the direct green façade GF can provide a more beautiful urban landscape, It has environmental benefits such as providing shade and purify the air, and reducing energy consumption; simultaneously, some types can cause damage to the wall surface due to direct incorporation. Although, the environmental benefits of this type are lower than other types of VGS and due to deciduous plant species' use in the cold seasons of the year can cause visual pollution.

0Fig 2.11 Direct GF, ground-based, Italy

0Fig 2.12 Direct GF, roof top-based, Belgium

Double-skin green facades

The indirect green facade acts as a "two-layer facade" and creates an air gap between the building surface and the vegetation, use a support structure to prevent plant fall. In a modular or continuous, these systems anchor the plants' weight and increase the resistance of the system to environmental actions (e.g., wind, rain, snow). Most indirect green facade support structures include continuous or modular guides, such as cables, wires, or nets made of stainless steel or galvanized (Yap et al., 2011). It can be two-dimensional, created by cable, rope, mesh, or three-dimensional, formed by solid frames and trellis. It is referred to as Double-skin green facades, including support systems such as stainless-steel cables, modular grids, or stainless-steel mesh to help upland climbing plants by creating a second layer skin at a distance to the wall (Heydariana and Mazharyb., 2014). The three most commonly used green facade systems are the Modular Trellis Panel and the Grid System and Wire - Rope Net (Laurenz et al., 2005; Gonchar 2009; Yeh 2010). These systems use twin stem and petiole climbers and tendril bearers (Dunnettand Kingsbury, 2004; Melzer et al., 2012). the double-skin green façade relies on engineering support structures (modular grilles, stainless steel cables, or stainless steel / HDPE grilles) to assist in the upward growth of a broader range of climbing plants In addition to the presence of plant canopies, it can provide a layer of air insulation between the foliage and the building wall (Kohler, 2008; Perez et al., 2011). it can be shown as creeping plants and vegetation of the waterfall and restored on railings or columns embedded in existing walls. In fact, only modular systems need to select a growing environment that should be light, assuming that each element is suspended and suitable with a certain plant type and environment.

Fig 2.13 Cable as a supporter of plants

Climbing plants are into two categories: ‘self-clinging climbers’ and ‘climbers requiring support’ depending on the growth mechanism. First, one themselves can stick to the wall surface without any help. The second category is further divided into three separate subsets based on how the grapes are connected to a support structure (Fig 2.13). Climbing plants cover the building surface to provide a flexible and adaptable tool for the environment's design (Oke, 1988). According to foliage density after monitoring a year, in the Mediterranean Continental climate comparing the growth of climbing plants, both perennials (Hereda helix, Lonicerajaponica) and deciduous (Clematissp , Parthenocissus quinquefolia), Virginia creeper, Parthenocissus quinquefolia, offered the most foliage density, but none of the other species could cover the whole surface after one year. Some plant species find it difficult to adapt to climatic conditions, with high-temperature changes throughout the year and low rainfall, such as Clematis, affected by summer conditions (Manso & Castro-Gomes, 2015).

A key point in climber green wall design is choosing the suitable plant species (Jim,2015). For instance, the climbing plants have growing limitations, some species take 5 or 6 meters to reach full coverage, others 10 meters and others 25 meters taller, and take about 3-5 years. Climbing plants and vines grow from the ground or at some intervals along with the facade's height. As plants play an essential role in the survival and performance of the green facade, especially in multi-story buildings exposed to wind and heavy rainfall throughout the year, twinning plants are preferred because they can be firmly attached to the wall by using either high-tension steel cables or a wire mesh (Figure 2.14).

Fig 2.14 A ground-based vertical garden covers the Issaquah Transit Center in Issaquah, WA. Credit: greenscreen.

Ground-based methods rely on natural land and refer to the green facade, while wall-based methods, including planting directly on the wall without connecting to the natural land, refer to green walls (Mansou and Castro-Gomez, 2015).

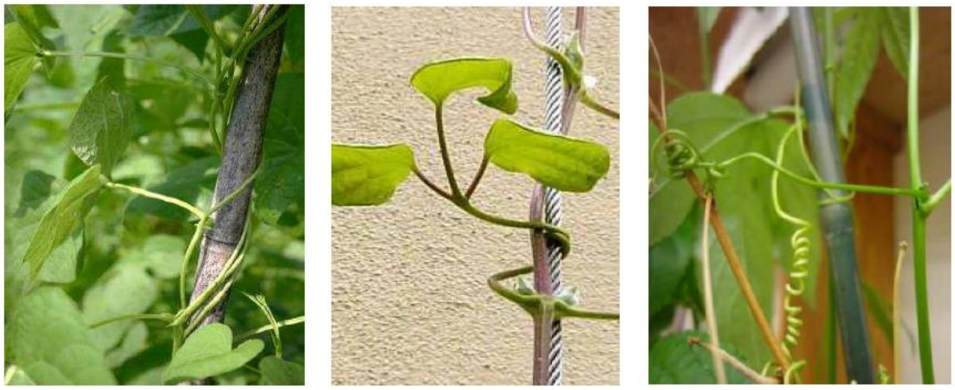


Fig 2.15 Pictures of twin climbers (left) and two types of branch climbers including climber leaves (middle) and stem climbers (right), http://www.vertology.uk.com/

Depending on the floor, the roof can be from the roof and indirectly attached to the walls. As the definition of the green facade is provided by (Hermy, 2005), it is a green cover on vertical surfaces by plants that have roots in the soil. However, it can be rooted in the soil at the ground's surface and in the boxes of plants that may have been placed on the building. In German literature, they are usually planted as climbing plants in front of a facade. Additionally, advocate providing a constant suitable area of plants to enable the necessary minimum interior daylighting (Stec et al., 2005).

Cable wire system

Structural green facade schemes are divided into two categories. The first two-dimensional solutions consist of vertical cables, horizontal cables, rods, grids are made of different materials. Manufacturers have created complete systems of solutions for assembly and connection to the facade of a building or vertical plate. 2D cable configurations require traction, and loading connections at junctions that is an important factor. The design and placement of fittings are related to the façade and require unique engineering and structure to ensure performance under increasing loads. Cable systems and their connecting components are often made of stainless steel, which can add durability and strength, but also increase costs. This system is usually installed on a simple screen and requires additional structure to create shapes, rotate corners or adjust the surface. The cables' connection depth is shallow, and in the absence of additional support connection methods, and the green facade will be close to the building surface. If the structure is available, a vertical two-dimensional cable facade can connect at the top and bottom but cannot be used for console configuration. Rigid 2D system components, larger than steel or wood, are larger than flexible 2D system components made of materials such as cables, rods, cable nets, or woven wire fabrics. An initial consideration for a two-dimensional design system is how plants live and connect to the facade's structure and how the design of the system affects the growth of the plant and the filling of the façade.

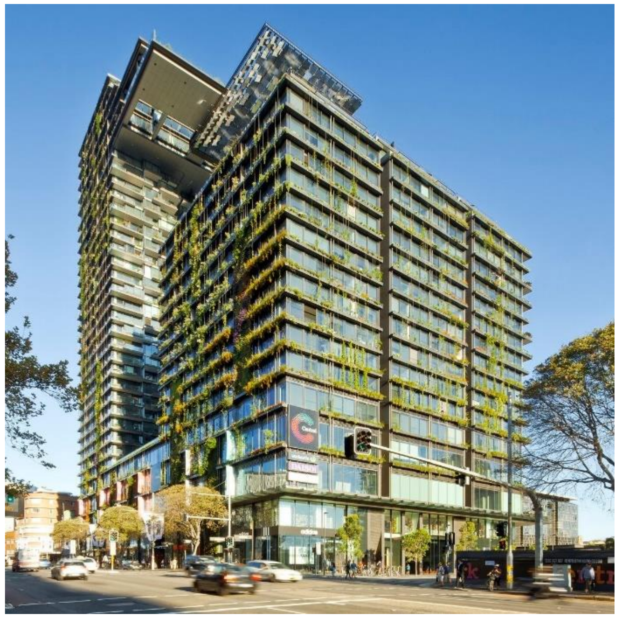


Fig 2.16 Towers designed by Jean Nouvel, cable GF by Jakob company, Sydney

Fig 2.17 cable GF by Jakob company, Barcelona

Wire-rope net system

For medium to wide greening trellises, the stainless steel wire mesh is suitable. The net forms a modular framework with the accompanying spacers and linking pieces conveniently and effectively scaled to the project's size. Climbing plants and their normal loads on facades need cable diameter and mesh aperture specifically engineered. The modules are pre-installed stainless-steel templates. The mesh gap and cable diameter are ideally matched to the desires of climbing plants.

Fig 2.18 Wire-rope net system by Jakob company

Plant species

A key point in designing with a two-dimensional façade system is how the plants live and connect it to the façade structure and how the system's design affects plant growth and façade filling. Ivy and wisteria, for example, are also tenacious and capable of causing significant harm to a building's exterior. Some grapes are the leading twins of the stem, and other grapes use stems that can be twisted or looped around other plants or components. This plant group is suitable for two-dimensional systems and usually moves along a cable or rod system and connects opportunistically. In this case, the plant must grow significantly to fill the space between the supports and increase the leaf canopy. Many green plants can look like grapes in terms of vertical growth characteristics, but they are actually woody plants that are runners and mixers. This group grows to support the plant lying down or through the host, trusting the structural host, and they tend to have long pants and leg extensions such as Bougainvillea. In these various descriptions, some plants prefer to grow directly on top of the holding and then require considerable time to propagate. In contrast, others prefer to propagate quickly and then grow vertically.

Fig 2.19 Cable system, credit by Jakob company

Cables are designed to support climbing plants with faster foliage growth. Wire networks, on the other hand, are often used at shorter intervals to support slower-growing plants that need more support. They are more adaptable than cables and allow for design programming. Therefore, when connecting vertical and horizontal wire ropes through cross clamps, different sizes and patterns can be accommodated. Both systems use stainless steel cables, anchors, and accessories. By connecting vertical and horizontal wire ropes through cross clamps, different sizes and patterns can be accommodated (Green Roof Organization 2008; Yeh 2012).

Modular trellis panel system

This kind is made up of welded steel wire and plants that have a face grid and a panel depth. This device is designed to capture a green façade on the wall surface and keep plant components from sticking to the building exterior. A robust, lightweight, three-dimensional panel composed of welded steel wire supports plants with a face grid and a screen depth and powder-coated galvanized in this modular system. It provides a "captive" growing environment for the plant with multiple supports for the tendrils and maintains a building membrane's integrity (figure 2.20). Since the panels are fixed, they can be used to stretch between buildings and as freestanding green walls (Green roof organization 2008).

Modular trellises are made up of separate support structures and containers filled with substrate which allow the elements to be strung at various heights along the wall. A curved grid is used in new types of modular trellises to provide the façade rhythm and three-dimensionality(Yap et al., 2011). Modular trellises have containers for roots and an individual support structure for guiding plant development, which are the primary distinctions (Manso & Castro-Gomes, 2015).

Fig 2.20 Panels attach to the surface as a plant supporter

Three-dimensional panel systems

Another group of structural solutions for green facades are three-dimensional systems that have a unique design capability.Three-dimensional panels are composed of thin wires in different ways. One approach uses two wired networks separated by alternating wires and welded to a peripheral steel frame to resist installation. 3D systems are made up of long, comprehensive, and deep panels and are explicitly designed to increase plants' growth and maintenance. 3D panels are made of thin wires in different ways. One approach uses two wired grids separated by alternating wires and welded to a peripheral steel frame for installation resistance.

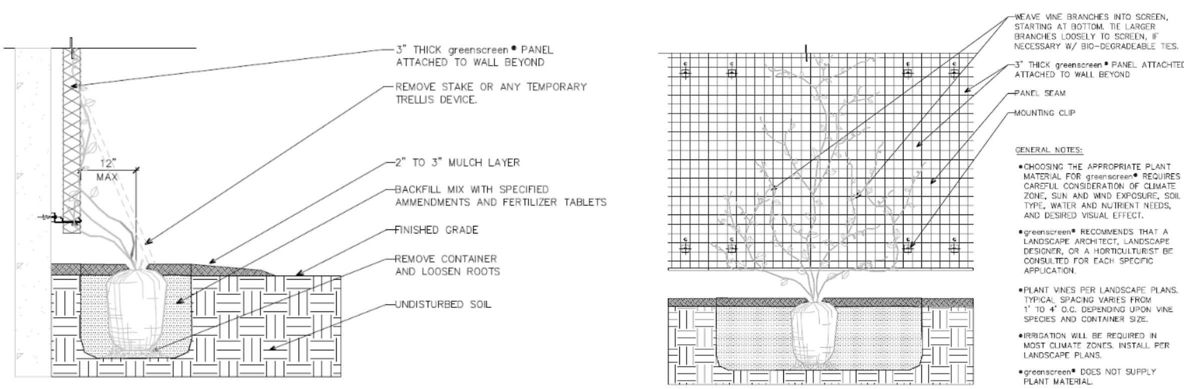


Fig 2.21 Vine planting detail, Credit by, greenscreen

Fig 2.22 Engineered for wind and snow loads, www.Green screen.com

Fig 2.23 Modular, three-dimensional green facade, www.Green screen.com

Wired nets are either woven or welded at different distances. The other 3D system uses a structural plate with an integral truss that does not require mounting or resistance to a surrounding frame. This modular plate reduces the material's weight and creates unique opportunities to cover large surfaces without perimeter frames and create shapes. Structural panel systems are rigid, able to make openings, and installed as independent facades vertically, horizontally, or between structural elements. Attachment details for 3D panels are attached to the perimeter frame, or when using truss panels, they can be placed alternately on edge or in the panel section. The plate's installation details are available to create a variable distance from the building surface and create more flexibility.

Fig 2.24 Steel Channel Trim

Fig 2.25 Steel Edge Trim

Fig 2.26 Adjustable clip, credit by Green screen

3D panels are rigid, and the annex design does not need to withstand tensile forces like 2D cable systems. Panel fittings are primarily designed to withstand weight loads and wind forces, and in some cases, can be designed for limited containers. The apparent advantage of 3D systems for facade design is the depth of field, which provides additional structure to support plant materials and long-term storage. Vine plants need a host to grow and support vertically to attach to it, and they use a variety of evolutionary features to support the host.

Plant species

Some plants with vertical growth habits, such as climbing Hydrangea and Sunspot Euonymus, may be successful in a three-dimensional system. Preference should be given to local plant materials as they are usually drought tolerant and adapt to local climatic conditions. Typically, cable systems require one plant per vertical cable, while multiple forces can be used in 3D systems. Plant spacing in 3D systems can be very different and is determined by the plant's size during installation and the size of maturity expected.

Fig 2.27 Vine tendril attached to a three-dimensional panel, credit by Modular three-dimensional panels, with standoff brackets, provide access to keep plants off the wall, Oakland, Green screen

Climber pruning responses should be decided in order to monitor or maximize development. Long-lived climbers may reduce the need for replanting and have longer-term landscape features. Evergreen, annual, and woody climber plants are favored because they have a visible and long-lasting effect and need less horticultural maintenance. Deciduous plants and shrubs with colorful fall leaves are also proper option (Jim, 2015). Panels are made of recycled material steel and are recyclable. They can be assembled and joined to fill broad areas or shaped to create forms and curves. Since the panels are fixed, they can stretch between buildings and as freestanding green walls. The wire trellis configuration can be used as a freestanding fence for green walls that extend vertical structural members. Once plants can completely penetrate the wire truss system, it can apply as a vegetated privacy screen or shade feature.

Fig 2.28 Modular trellis panel, Zurich. Jakob company

Air gap

The air layer between the green wall and the exterior wall beneficial effect on the thermal efficiency of the façade because it creates a microclimate within the façade structure that distinguishes the building façade from the external environment, just as it does in current ventilated façades.The analyzed studies on the thickness of the air layer vary from 0.03 m to 0.15 m (although in one experiment, it can achieve up to 0.60 m), and this air gap can be opened or closed (Perrez et al., 2014). Given that one of the key design features is the impact of possible insulation of the air cavity behind the canopy, it's shocking that wind speed or convective air flow within and behind the plant layer has gotten too little coverage.
There is little consensus on the optimal cavity depth: in fifteen studies of green faces with two skins, the cavity depth varies from 8 mm narrow to 1500 mm, and six studies provide no information. In addition, the prediction of green facade modeling is limited by the lack of experimental data on convective heat transfer coefficients specific for vertical plant surfaces (Susorova et al., 2013).

Perimeter flowerpots

A Planted Perimeter is a totally enclosed area surrounded by various materials such as wood, PVC, and metal, which is then backfilled with soil and planted. Because a Planted Perimeter lacks a frame, it must almost always be secured to a concrete base for stability. A planter is a full construction with sides and a base that is filled and planted with a container planter media that is suited for the container. If a planter is very big, it may arrive in sections that must be put together on-site; however, most planters arrive completely constructed and ready to use. There are certain limitations to using this sort of greening system, such as the ones listed below:

- The planting scheme is not only very long, but also very wide [indicatively > 2000mm]
- Trees will be grown in the subsoil under the surface.
- A perimeter is necessary to encircle an existing tree that has already been planted due to site restrictions that prevent huge planters from being moved or stored.

- Lower initial investment, but higher installation fees
- Delivered in long, thin portions that are simple to handle and store.
- It is usually implemented at a later stage of the overall project, causing more on-site interruption.
- Almost usually necessitates anchoring to a concrete foundation for stability, which adds to the expense of the planter perimeters (https://www.iotagarden.com)

Fig 2.29 Perimeter flowerpot, Barcelona

Living walls characteristics

Green facades differ from living walls throughout that they support a framework which may be placed in the ground or in a bed to protect plants, rather than just at the base of the wall (Kohler, 2008). Living walls are classified as more complex systems with different support mechanisms for transporting plants and growing environments, typically composed of irrigation systems. They use various methods of connecting and enhancing the environment, such as modular systems and hydroponic systems (Kontoleon & Eumorfopoulou, 2010; Manso & Gomes, 2015).

Live wall systems, also referred to as green walls and vertical gardens, are built using modular panels, each based on its soil or other artificial growth environments such as foam, felt, perlite, and mineral wool. In hydroponics, balanced nutrient solutions are often used to satisfy the needs of all or portion of the plant for food and water (Dunnett and Kingsbury, 2008). This type of living wall technology is often modular and allows plants to grow on separate parts before installation, easy replacement if needed. In addition to the modular design, an alternative design uses a thin layer (1 cm) of PVC and felt applied to a light metal frame on the surface of the water-supplied wall, which represents a light coating that also separates. By preventing roots from entering the surface, it protects the wall surface. It may be seen on the walls of the pioneered "vertical garden" by (Blanc, 2010). In this case, the vegetation is selected according to Blanc's desired aesthetic effect (1996). Vitality, patterns, variations in color, texture, leaf forms and density and development with plant species are all explored with living wall systems, allowing for the production of new green wall aesthetic concepts (Manso & Gomes, 2015). there is a need for proper irrigation and nutrients for adequate plant growth. Therefore, it is essential to analyze plant development, color, bloom, foliage, and plant composition according to artistic goals for a particular building (e.g., building framing in an urban context, advertising a particular company, or marking distinction of a particular plant.

Continuous Living walls

Continuous living walls are a system that no longer needs soil due to the use of a fabric layer, such as geotextile, and based on using lightweight and permeable plates in which plants are planted (Bribach, 2011). Plants can rely on hydroponic techniques to obtain nutrients through irrigation water. Several layers of waterproof membrane and holding structure, such as a metal frame or solid walls, are generally connected to the fabric layer (Jim, 2015).

Felt-based living walls

In general, plant cultivation in nutrient-rich soils is known, but hydroponic soil systems are less well-known. All hydroponic cultures rely on the nutrient solution to transfer essential elements to plants. Because Hydroponics is water-based, plants are created in holes that form on the surface of the felt, known as the growth medium, and are fed by a solution of water-based mineral nutrients. However, they need a growing environment, the material needed to grow inside it (Weinmaster, 2009). Some researchers (Manso, 2015) drop LW based on felt in the Continuous LWS group. This is based on installing a fixed frame on the wall that creates space between the system and the wall surface. This frame holds the base panel and protects the wall from moisture. The base panel also supports other layers, so it is made of high mechanical strength materials. These layers are covered with layers of permeable, flexible, and waterproof plates attached to the base. The outer layer of the plate is then cut to create pockets (Corradi, 2009). Recently, pre-planting geotextile felt is one of the most widely used materials in green wall production and design companies (Perez et al., 2011). This can support vegetation formed by overgrown plants, ferns, small shrubs, and perennial flowers. This system needs constant moisture to maintain, so it is more fragile than other systems. Continued demand for compost speeds up development but still accelerates the plant's death.

There are approximately 1.5 to 2 inches of air space between the existing wall and the panels to create air circulation behind the green wall. water and nutrients are transferred to plant roots by irrigation pipes behind fabric layers. The roots of the plants grow in the "pockets" created between the two sheets of felt. This allows creating different patterns on the wall canvas and a flexible mix of plant species to grow in the system. Water demand is high due to the growing environment, in which case the felt layers are not designed to hold water and require constant watering and feeding to keep the plants alive. Therefore, the water supply system plays an important role and can ensure the life of the green system by using the most appropriate type. Felt-based living walls use more design-oriented techniques to create vegetation surfaces that can also be applied to curved walls and also this system has more biodiversity than other living walls. Medium plays an important role in this type of system because providing the maximum nutrients required by the plant has the task of bearing the weight of the plant and delivering moisture and oxygen. An important advantage of water-based systems over soil foundations is that they eliminate the risk of pests and diseases commonly present in the soil. It also means that it can be used where there is poor quality soil - or none at all, such as sidewalks, rooftops, and even indoors. In addition, weed shortages and additional the resulting costs are some of the benefits of the system. Plants can also grow faster and healthier.

Fig 2.30 Continuous LW credit by Highgreenwall.com

Patrick Blanc can be called the father of this type of green walls. He first designed living hydroponic walls in 1994. "Mur vegetal" means green wall, a word coined by Blanche and still used today in hydroponic systems. The basic idea is to maintain the growth of algae and moss on surfaces that can be completely attached to the surface while maintaining moisture and free growth of roots. He sought to create materials that could provide such a structure. Eventually, he was able to find waterproof plastic as a base for the plant to grow. This type of green wall's high durability is about 30 years, and these plastics can be recycled and reused (Weinmaster, 2009). Because these types of living walls need water to survive as a growing medium, felt does not have a water-retaining role in the system. It needs constant irrigation (Dunnett and Kingsbury, 2008).
Hydroponic system components are classified as follows:

- Plants
- Substrate
- Growing environment (Providing a suitable substrate for plant cultivation, made from reusable and recyclable materials)
- Irrigation system (consisting of tanks, pumps, irrigation timers, and rain gutters at the base of the wall and collecting excess water, sometimes returning and recycling the water source)
- Drainage (maintaining sufficient moisture for plant growth)
- Air gap

Living wall components

Essential components of a VGS are growing environments such as substrate and containers, and the irrigation system (NParks, 2018a), supporting elements that can hold plants (Wood et al. 2014), and drainage (Manso, 2015). In the case of living walls, five design factors, including a substrate, container, air gap, water nutrients, and vegetation, can be considered (Jim, 2015).

Plant species

The green walls of shrubs are entirely separated from the green walls of climbers. It records relatively small non-climber plants with their supporting tissues (mechanically independent), mainly herb plants and secondarily shrubs and low shrubs. The support of non-climbing herbaceous plants is by soft, woodless textures . living walls are usually influenced by broadleaf plants (Forbes) that tend to flower exponentially and pollinate insects with more prominent petals or sepals and is sometimes accompanied by grasses (Poaceae) and black plants (Cyperaceae). Shrubs and tall trees are unsuitable for vertical restraint, limited root volume, unsafe anchorage, and the risk of displacement (Jim, 2015). Shrubs, grasses, perennials, and succulent plants (Perini et al., 2011; Jim, 2011; Mazzali 2013) are the most popular plants type. In Living walls, herbaceous and shrub species (rare climbing plants) are the most common types of plants, usually well adapted to local climatic conditions. They are compatible and are always green. The number of species used in the analyzed studies on green walls was high. However, this suggests different thermal behaviors in the same green wall. Further studies on any plant's properties in any climate are needed (Pérez et al., 2014). These plant species grow in an environment with limited root area volume, so they should have:

- A string root system
- Strong attachment to the root
- Resistance to wind buffer
- A good habit to grow
- Orientation to full sun or shading

Care must be taken with the species' growing habits, as some spices tend to change habit as they mature, such as phototropism, where they grow out of the full sun (light) to absorb gravity, and the plant begins to bend. It can create a shading effect that immediately shades the plants. If the following plants need full sun, they will suffer or even die in this condition.

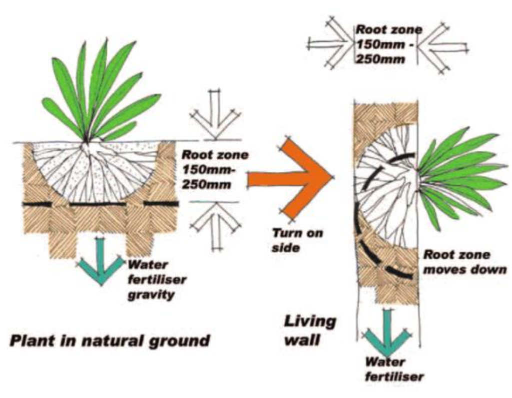


Fig 2.31 The root zone in the living wall has similar requirements to in-Ground planting, Hopkins & Goodwin (2011)

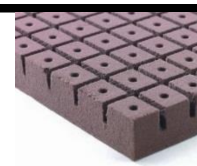
Growing media

Growing media are the materials that provide plant growth. Soil is widely considered one of the most well-known media. In the hydroponic system, manufacturers create it with different materials to protect the plant roots and maintain a good ratio of water and oxygen. The choice of a substrate is important because it affects the plant's root growth and the subsequent growth of living wall plants (Manso and Castro-Gomes, 2015). Minerals such as perlite sand, rock wool, sandstone, recycled glass, organic matter such as pine bark, spaghetti peat moss, coconut fiber, and even air are used to create growing conditions in hydroponic systems. It can be divided into three categories, including grains and pebbles, fibrous organic matter, and foam matrix, in various ways. Recently, many materials are available as media, are chosen according to the characteristics of the system and the designer's priorities, consider the advantages and disadvantages of each choice. in other words, to finding the right media for hydroponic projects, several factors must be taken into account, including plants type, the cost, and the availability of different media. Although different growing media can be applu in this system, the main purpose is to maintain the moisture of plants' roots and not to oxygenate them because if the roots are saturated with water, they prevent proper oxygenation, and the wall will have died. Therefore, the main factor is the type of green system and its design.

The media in the hydroponic system should be capable of the same moisture distribution in the substrate. If the media is unable to retain moisture while the upper part is dry, the lower part of the plant becomes too wet and which is contribute to the stem becomes rotten. The size and form of plants and the type of hydroponic method being used would all influence the total selection. It is noticeable the research into the selection of growing media in living walls is limited. Relatively low Specific Gravity (SG) substrate materials can partially or wholly replace conventional mineral soils. With an average mineral content of SG 2.7, natural soil minerals are heavy. Lightweight minerals such as perlite and vermiculite (Papado-pulos et al., 2008) and organic matter such as peat moss and coconut fiber (Mahler et al., 2008) are often used as lightweight substitutes.

Table 2.6. The most common options for growing media

Name	**Advantages and Disadvantages**	**characteristics**	
Lightweight Expanded Clay(LECA) grow rock, clay pellets, and clay pebbles	• Environment-Friendly • Long Life Cycle ——— • Costly • Harm to the pumps and plumbing	It is made by baking clay in a kiln. Clay pellets are full of tiny air pockets, which give them good drainage. Clay pellets are best for ebb and flow systems or other systems that have frequent watering. Though pellets are rather expensive, they are one of the few kinds of media that can be easily reused.	
Growstones	• Lightwe ight • Great air to water ratio • Sustainable ——— • Hard to clean	Made of recycled glass, the large stones are somewhat similar to LECA. In addition to being porous and light, they can be reused. Growstones provide excellent aeration and humidity and have the capacity to hold water up to four inches above the water lines of your Hydroponic system.	
Perlite	• Lightweight • High oxygen retention level	Perlite is a substance made from volcanic rock. The biggest drawback to perlite is that it doesn't retain water very well, which means it will dry out quickly Between watering.	

		• Not eco-friendly • Potential particle inhalation damge		
Vermiculite	• Water retention	• Hard to find • Expensive • Can hold too much water	It’s a mineral that is heated until it expands into pebbles. It retains more water than perlite and can wick (draw) water and nutrients upwards. Often used in combination with other types of media to create a highly customized media for specific hydroponic applications.	
Sand	• Cheap • Easy to find	• Heavy • Low water retention • Small size	Sand is not widely used today, mostly because of its low water-holding capacity and weight.	
Rockwool	• Great water retention • Easy to dispose of	• No eco-friendly • High PH	Made from rock that has been melted and spun into fibrous cubes and growing slabs, rockwool has the texture of insulation and provides roots with a good balance of water and oxygen. rockwool can hold water and retain sufficient air space (at least 18 percent) to promote	
Oasis Cubes	• Inexpensive • Nopresoaking	• Not ecofriendly • None organic	Made from phenolic foam and they are rigid, open-celled, water-absorbing pieces of foam specifically designed for optimal callus and rapid root formation. it holds over 40 times it weights in water and have wicking action that draws water to the top of the foam.	
Floral Foam	• Enormous power to uptake water	• contains toxic elements	Absorbs water well. However, it should not in constant contact with water, as it can easily get flooded.	
peat moss	• Extremely absorbent and water-retentive substance • Peat moss is not compact	• Doesn’t contain nutrients	the peat moss originates as the first process of sphagnum moss rot. it has a low pH. Contributes nutrients and retention humidity. Low porosity.	

Coconut fiber Or Coco Coir	• sustainable • Organic • compactable • water holding ability	It is the first totally "organic" medium that offers top performance in hydroponic systems. culture medium coming from the skin of the coconut. Provides aeration, retention of moisture and retention nutrients. pH around 6.5. There is variability in conductivity. Normally used as component of another mixture.	
Parboiled Rice Husks (PRH)	• Retains little water • Inexpensive • effective medium in rice production areas	they are not pre-sterilized. Growers need to take care by using hulls that have not been stored outside or uncovered.	
	• Decays over time • High level of Manganese • tendency to build up salt		
Pine Bark	• Reduce Inflammation • Boost Antioxidant • Unstable size	Pine is the preferred type of bark because it is more resistant to decomposition and has fewer organic acids that it can extract from other bark. There are three types of pine bark: fresh, composted and aged. in fresh pine bark, should be add extra nitrogen. Old pine bark has more nitrogen than fresh but less than its composition.	
Pine Shavings	• Eco-friendly • Dries out droppings	Pine shavings are another alternative that's inexpensive and commonly available.	
	• Reduction of Soil Nitrogen • Possible Fire Hazard		
Sphagnum moss	• High capacity water retention • Good relationship air / water.	Sphagnum moss has long strands of highly absorbent, spongelike material that hold and retain large amounts of water while simultaneously having good aeration. Because of this structure, it is best used in larger lattice or net-pot production where the long strands can spill out the holes in the pots to wick up water without falling out Moss dehydrated with high capacity water retention, low ph (4) and low conductivity.	
	• Decompose over time and shed small particles that can plug up pump or drip emitters.		
Pumice	• Lightweight • High oxygen retention level	It's similar to perlite. Lightweight mineral that is crushed and used in some hydroponics systems.	
	• Too lightweight for some hydroponic systems if bought as small pieces		

Substrate

The substrate physically supports the plants, and acts as a thermal insulator. the substrate's thermal composition and properties are fundamental and need further research in this field because this aspect seems to be an aspect that has been neglected in research so far (Perrez et al., 2014). as mentioned earlier, LW use lightweight, the absorbent layer where plants are placed in pockets. A continuous living wall is usually depending on the hydroponic method, which requires a constant supply of water and nutrients due to a lack of bedding. Hydroponic systems allow plants to grow without soil by using plates that are frequently moistened by the irrigation system. Soil deficiency is compensated by providing the necessary nutrients for plant growth through irrigation water.

In a study, polyurethane and polyamide - synthetic polypropylene was the three layers used in an active living wall to compare the volume of water retained, pressure drop, saturation efficiency, and water consumption. Substrate analysis shows that the best performance in saturation efficiency for polyamide-polypropylene with a high-pressure drop, average water volume is maintained, and water consumption is low. Polyurethane has the lowest airflow as well as the lowest pressure drop. It has the highest water consumption and the most significant volume of water. Polyester has the worst saturation efficiency and the worst volume of water stored, moderate pressure drops, and high-water consumption (Franco et al., 2012). The physical and chemical properties of soil or substrate are essential for plant yield and affect parameters such as relative growth rate, growth habit, total leaf area, and plant health. The the most basic forms of direct and double-skin facade include planting directly in the soil at street level. Because of their density, urban soils generally have limited oxygen and water retention capacity. They may also be contaminated, hydrophobic, or have a limited root volume. In addition, they tend to be highly heterogeneous due to repeated human disturbances (Crowley, 1999).

Irrigation system system

Ranifall roofs harvesting

All stormwater on the roofs must be collected and stored for reuse, including preparing the wall. Rainwater storage is usually located in the basement or the parking. If these storage tanks are not initially designed for construction, they can take up considerable space. In the past, most systems were circular properties, which is not a tiny form of savings. However, a modular system is now prepared as a flat and cohesive package in a rectangular cult to create residual spaces, such as the following stairs easily are created.

Storm water harvesting storage

Water paving can be removed and stored or cleaned with biofiltration tape or a switch to make it suitable for reuse in a living wall or green roof system. It is possible to store this water in public or private territory under pavement or landscape areas. It can be stored without compromising the integrity of the structure in pavement infrastructure or even road pavement while still allowing the surface's use and helpful for densely built-up areas (Hopkins & Goodwin, 2011).

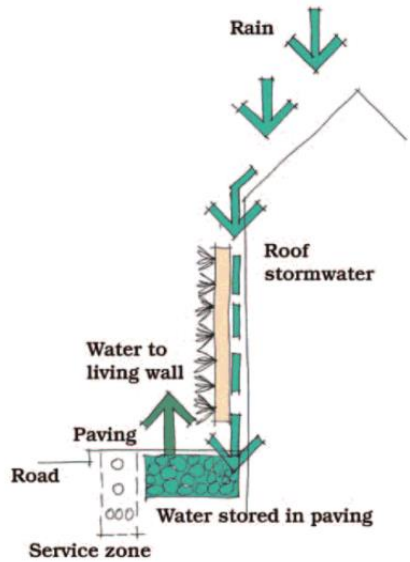


Fig 2.32 Rain from the roof can be stored under pavement and used to water living walls (Hopkins & Goodwin, 2011)

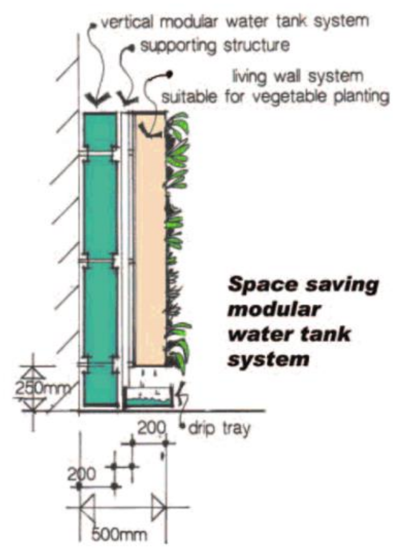


Fig 2.33 Space saving modular water tank system (Hopkins & Goodwin., 2011)

Drain Systems

Proper drainage provides the water supply requierment and prevents water wastage in the green wall structure. It means that the plant layers are not submerged. The drainage system must effectively separate the surface water from the building wall. According to some factors, the time required to irrigate each location varies from three to five times a day for one to three minutes (Blanc, 2008).

Depending on the kind of VGS, one of two watering systems can be used: recirculating or direct irrigation. As its name implies, recirculating type of irrigation system regains water, which consists of a water source that is a remote-controlled irrigation tank or directly under a green wall. The

irrigation system's reservoir should be filled regularly and manually to provide sufficient water for plants. Water is drained from the tank to the green wall, where it is transferred to the plants, Excess water is drained by gravity. Additional drainage water is stored at the bottom of the wall and returned to the feed tank.
Due to the water pressure in the water lines, no pump is needed for direct irrigation. As the water is drawn down by gravity, any excess irrigation water is collected and directed to the sewer, unlike the recirculating system. The use or not of the drainage solution will depend on the costs of an installation that Monitor the input pH and EC, and the output pH and EC. An excess of salts can cause problems irreversible in the garden (https://www.ambius.com/green-walls)

Drip Systems
With good drainage, moisture can be controlled in drip systems. Placing mediums such as river stones at the bottom and using materials like pine shaving can keep moisture on the plants. Irrigation in this living wall is done along with 1/4"drip irrigation pipes connected to the urban irrigation system with a digital hose timer with regulator and filter. A significant point is the importance of the scale and size of the executive wall, as well as the height of the wall, which are essential factors in choosing the type of water supply systems. For example, in smaller sizes, drip irrigation pipes are suitable. For more enormous walls than larger irrigation pipes, 3/4" inches can be used with drop gallons of 1/2 gallon per hour, which can be changed if necessary. Also, for tall walls, the use of single irrigation in the top row of pockets is recommended. It can make it easier to maintain and reduces the intensity of water flow. Which causes the moisture in the felt to sink downwards and sideways, providing more time for it to absorb into any complex root plant.

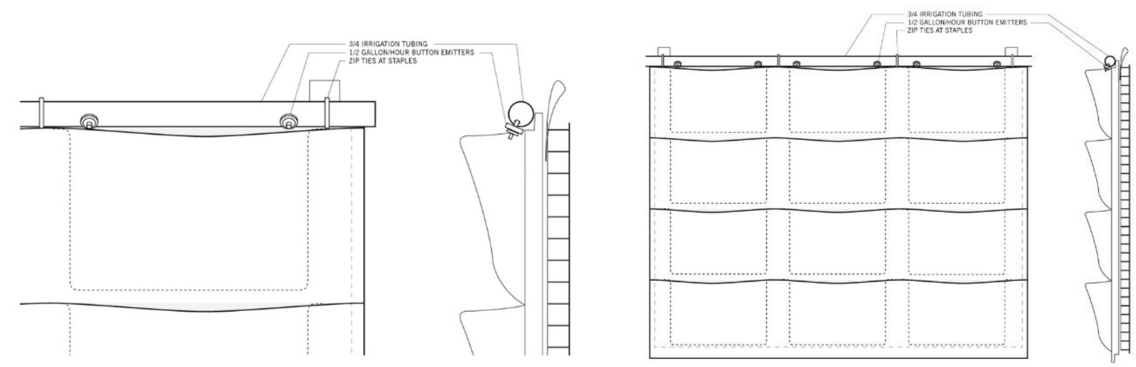


Fig 2.34 Drip irrigation for large installations, www.florafelt.com

It is best to use two droppers for each pocket on the far edge. This makes it easier for a plant to enter the top pocket and allows the droppers to be unobstructed. In addition, it can visually see the dropper. It does not matter if it drips into the soil. The corrugated felt system carries water down where water collects in the bottom slot of each pocket. Therefore, should wrap plants narrowly and wide to make contact with the lower crease. Examine new planting carefully to make sure each plant absorbs moisture properly.

Drip irrigation of elements such as:

- Water source hose
- Orbit digital hose timer
- Regulator and mesh filter
- Adapters

There are two standard options: connecting drinking water or a tank. This tank is an example of a hydroponic flow and hydroponic system with fertilizer previously mixed in water and used continuously until one or more variables such as temperature, pH, aeration, disease. Change and have to Maintained to dispose of and clean the tank. A drinking water source directly connects to a city or water source that is not recycled and has a fertilizer injector. This type of bond eliminates many hydroponic variables but is exposed to water treatment additives such as fluoride and chlorine (www.folrafelt.com).

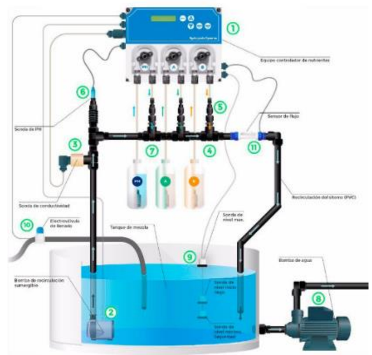


Fig 2.35 Irrigation regime in continuous LW

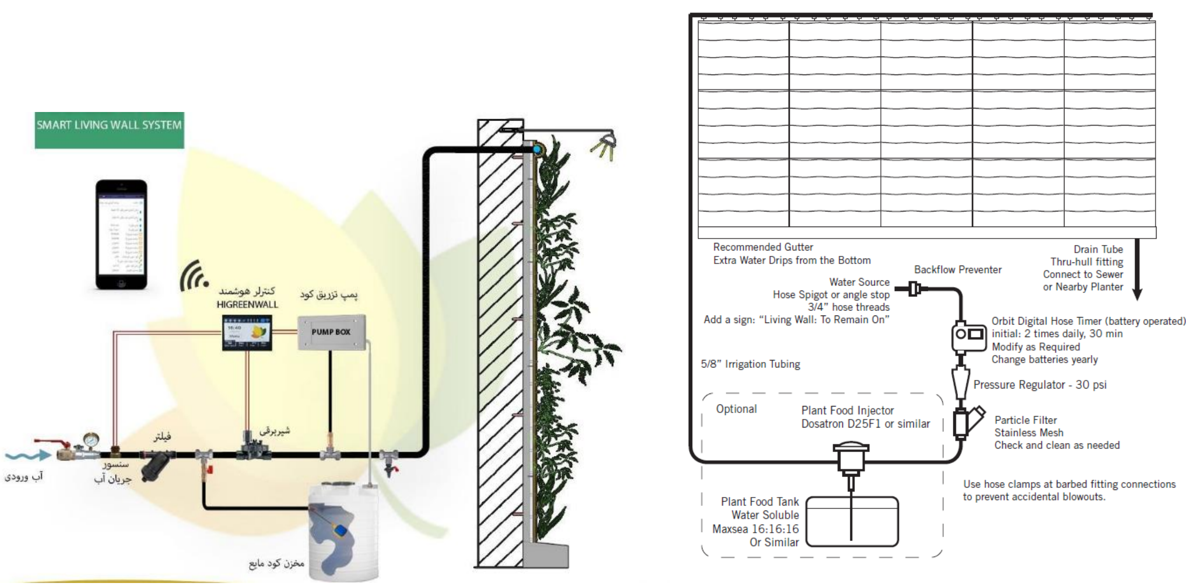


Fig 2.36 Different types of dripping irrigation systems

Fig 2.37 Fertilizer injector

Fig 2.38 Water Timing and Control

Fig 2.39 Drip irrigation

Irrigation control for hydroonic LW

Check the condition of gardens and any incidents every day (if sensors are used).

- Follow the total and partial consumption of irrigation.
- Check the status of different parts of the control.
- Analyzing the graph of sensors and determining the condition of the garden by visiting the first days (15 to 20 days).
- Clean the irrigation head every six months from the valves.

Fig 2.40 Over watering of a felt system. www.plants on Walls.com

The following should be considered for planning and designing a drainage system:

- Average monthly and annual rainfall
- Rainfall and especially in the worst weather conditions
- The lowest and highest annual rainfall according to the rainy season
- Planned discharge capacity, including discharge dimensions and diameter of gutters and evacuation pipes
- Depending on the existing system and substrate, consult irrigation times
- Modular mesh systems that hide the substrate should indicate the irrigation time because it is difficult to check the moisture status.
- Check the maximum load with irrigation water saturation (structural calculation)
- Determine the amount of influence at different times of the year.
- Find the available mixture to determine irrigation needs
- Perform tests to determine flooding in lower areas.

Fig 2.41 Pour irrigation in felt-based Living wall, Barcelona

Water purification

Osmosis is a membrane-based water treatment method. Reverse osmosis is a semi-permeable to remove ions, molecules, and larger particles in drinking water. To achieve reverse osmosis to overcome osmotic pressure, pressure is applied, which is a synergistic property that produces a thermodynamic parameter with a difference in the solvent's chemical potential.

Fig 2.42 Water purification

Non-purified water is water treated with a cation exchange team, where Ca ++ (calcium) and Mg ++ (magnesium) ions are removed, and Na + (sodium) ions are replaced. So, changing the lime for salt, then irrigate with saltwater. It should be avoiding this situation as much as possible by connecting directly to the network.

Fig 2.43 Water purification tool

Fertilizer

As the roots grow directly in the flow solution, the system needs growing environments to set up the plants. As with other water culture systems, ensure that only the bottom of the starting cube or basket is moistened to prevent stem rot.

An automated release mechanism for nutrients and water into the absorbent layers of the wall may be mounted. In addition, the wall stores nutrients and water until plants absorb it through its permeable layers. This technology can be used to make both small and wide vertical gardens (Corradi, 2009). In comparison to the irrigation system, living wall principles necessitate a fertilizer approach, which is not considered due to its low environmental effects (1 percent).

Modular living walls

Planter boxes or other devices for anchoring plants that can be turned into modular wall-mounted systems to promote plant development without relying on ground-based rooting space are used in living wall systems.This technology is most correlated with green roofs and allows for more plant growth forms comparing the green facades (Köhler, 2008). Contrary to the blanket effect provided by continuous LWs, modular LWs can be divided into different types of pots, pocket pots, and panels. Modular panels can be a single panel or a grid. A single panel consists of several plantings for grid panels, where plants can be inserted vertically or angled. Each component is designed to hold the soil or bed and is fixed to a backing frame. Characterized by additional space for soil and modular components, this type of LWs has the advantage of creating additional planting depth and facilitating the replacement of dead plants (Jim, 2015).

LW module differences in their composition, weight, and assembly are corrected. They can be in the form of trays, containers, planting tiles, or flexible bags (Manso & Castro-Gomes, 2015). Some types, such as microfibers, are now available in PET by which all plants are watered equally. Felt is a non-toxic, non-degradable, and hard material constructed from recycled plastic water bottles. Modular LWS can also be in the form of elongated bags, filled with growing medium, made of flexible polymeric material that is cut to accommodate each plant (Fukuzumi, 1996). In terms of green GW features, the primary issues are finding innovative approaches to improve performance and long-term viability by integrating water-retaining materials, more accessible drainage and assembly tools, and maintenance processes (Manso & Castro-Gomes, 2015).

Pocket-based modular LW

In live felt walls, the plants are placed in a felt pocket of the growing medium and placed in a low waterproof layer that attaches to the steel frame's rigid support, poured concrete, or masonry wall. Felt is constantly moistened with water that contains plant nutrients (Loh, 2008). Felt systems consist of felt pockets filled with plants and attached to waterproof walls add to structures. The industrialized cladding system allows the advantage of hydroponics (lightness, mechanical support for roots, industrialization) and cultivation with substrates. It consists of a 4mm thick recycled polystyrene panel with an inner layer of 3mm geotextile and an outer layer of geotextile of 4mm. In the outer layer, there are standard measurements: 1m wide x 2.5m high Pre-grown l standard measurements: 0.5m wide x 1.25m high. The modular panel system consists of flat-bed units and irrigation equipment. The units are located on vertical structures to provide a basis for plant growth. In the panel system, it is possible to plant in a place where the structure is attached to the wall or to use pre-vegetation panels prepared before planting in specially designed structures.

Fig 2.44 Pocket-based living wall made by Felorafelt


Fig 2.45 The example of pocket- based living wall, Singapore. Credit by Vertical green

Fig 2.46 Pocket-based Living wall, Barcelona. Credit by Verditco

Fig 2.47 Pocket-based Living wall, Barcelona. Credit by Veritco

This living wall technology allows plants to grow on separate sections before installation and, if necessary, facilitate plant replacement. In addition to the modular design, an intermittent design uses a thin layer (1 cm) of PVC. It is applied to a light metal frame on the wall surface supplied with water, indicating a light coating of the wall is detached and therefore prevents the penetration of roots. Fabric (or felt) and boards (or boxes) are the most common methods of connecting vegetation to the supporting structure.
Modular systems have the advantages of saving construction time and cost and reduced maintenance time, which are divided into smaller sections. Each unit includes a predetermined growing medium that includes compost and aeration materials such as crushed bricks (compost-based system) and horticultural mineral wool panel (hydroponic system). Compost-based systems are usually made up of modular panels with small pockets designed to hold an organic growing medium, and the plants take root in these filled compost cells. Slope angle from right to slightly sloping (_20 _), sloping (> 20 _), and vertical is divided into four classes Absorbent layers hang vertically (Jim, 2015).

Irrigation regime

Flexible bags contain a large number of containers with openings that communicate with the outside to receive planting and the plant-soil environment. The soil is loaded through openings inside the bag compartments, and the bags are placed horizontally while the plants are allowed to grow. The multi-compartment bag is then suspended along the vertical wall to "green." Water can be poured into bag containers to boost plant growth. One challenge with such a wall hanging bag is that the wall has to support the bag, soil, and planting weight. In addition, the pockets may rupture over time, and the green wall may deteriorate, for example, from the growth of the plant's root structure or air. Water that falls from the rain down the wall may be used to keep the back of the bags and the plants in it moist. Fluid retention plates, which are placed in the rear wall of the implant, may be included. They may be sloping upward and collecting water to prevent water's rapid transfer through the planting material.

Fig 2.48 Lack of water supply contributed to plant destruction

A network of water pipes and drains buried in the thickness of boxes in a planting bed. A vertical water pipe is connected on several levels with horizontal water pipes to irrigate the boxes. A photovoltaic panel and battery may provide electrical energy to run the irrigation and lighting

pump. A single modular greening device is equipped with gears that have holes in the rear wall. The top and bottom walls of a module are similarly equipped with holes in the bottom of the side walls that form a V-shape. Thus, the water collected in a V is transferred from a top module through a hole in the bottom V to the following structure below. There appear to be gaps between the lower wall of the upper module and the lower module's upper wall in each shape.
Such a structure may cause water to splash and dissipate until the water is effectively supplied by feeding gravity to the planted vegetation in the modules. In addition, special locking sections are required to keep the modules in place and potentially prevent theft of the modules. An open irrigation system consists of a gutter and a vertical and horizontal irrigation pipe system installed separately from the modules. A fiber optic device can also be used to feed light into a number of circular channels or diffraction in the module's rear wall. When flowering plants are not in bloom or are not for decorative or even advertising purposes, circular channels or apertures can apply to create a decorative display of processor-controlled light (Koumoudis, 2011).
The drip irrigation system in the 10-piece compact living material holds the plants moist at all times. Modular living green wall systems may form continuous porous vertical water flow channels and a water circulation system using plant modules and water treatment modules stacked side by side. Plant modules may consist of an internal porous media layer, an exposed porous substrate layer connected, and a flexible module housing. Water purification modules available in the disclosure may include fiber-reinforced side walls/faces and perforated back walls/faces. These modules may be conveniently stacked in an interconnected manner and may be attached to an existing wall support structure, installed according to the existing wall support structure, or replaced instead to form a living green wall be used. In arid areas, subject-appropriate systems provide direct cooling and circumvent the need for process equipment typically served by cooling tower technology. Therefore, for example, the water from the systems can be transferred directly from the system to the building panels according to the leaked subject to cool the building's interior panels. A grid wall structure consists of horizontal bars connected to a vertical wall structure. The upper wall of a lower mounted green wall module consists of an integral slot that is compatible with receiving a horizontal irrigation pipe or hose that, when mounted on a modular device, may be placed horizontally in and longitudinally along the slit. A controlled irrigation system including tank and rain barrel for recirculation of rainwater collected in horizontally planted fields is provided by the green wall planting module.

Modular Living walls based on Planter boxes

The planting tray design allows it to be installed through various methods: on a dedicated rail installation system, wire mesh, or perforated directly into the wall. Mold holders at each tray base allow ordinary 100 mm plant pots to be placed, allowing easy and quick installation. Each tray has a water tank to keep the plant growing. An automatic irrigation system can be used to reduce practical work for daily irrigation needs. LWS-based plastic boxes for planting (HDPE) are filled with potting soil.

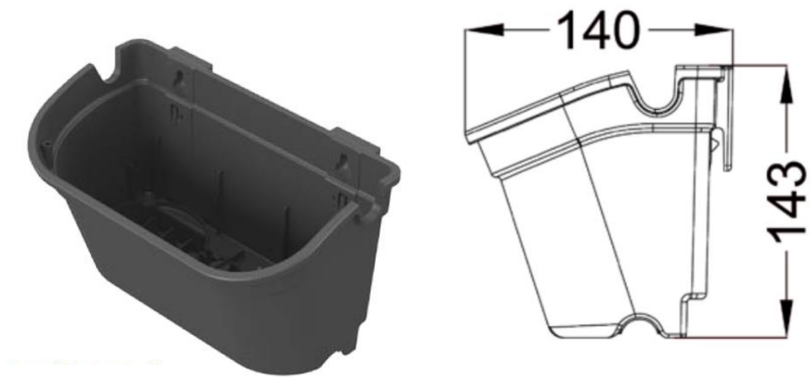


Fig 2.49 Detail of planter boxes

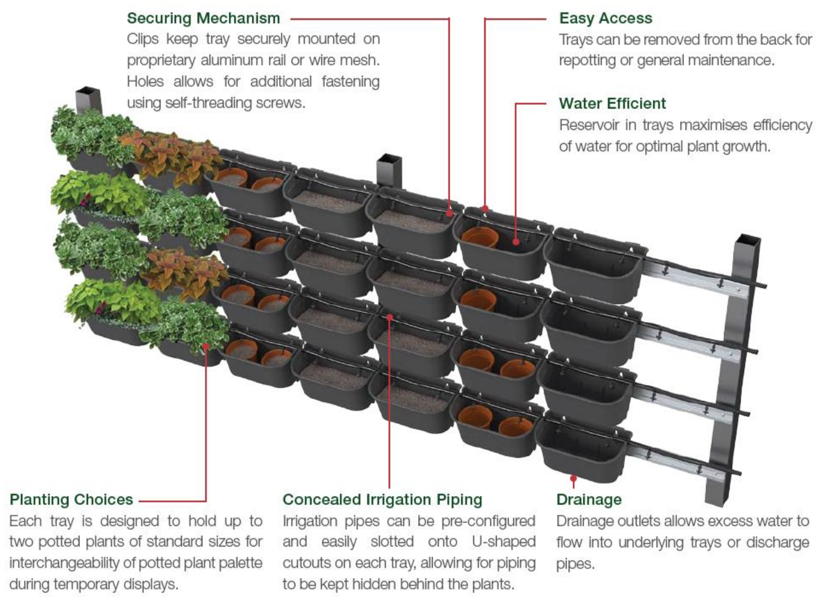


Fig 2.50 Detail of planter-based living walls

Fig 2.51 Various type of Living walls based on Planters

In container systems, plants are potted in containers (Safikhani et al., 2014), including VGP, which is made from UV-resistant recycled polypropylene that qualifies for the "Green Building" international certification. The flexibility of the system allows architects and designers to create the perfect expression by using a palette of plants to express spaces with green walls, creating environment-inspired habitats for living and working. It is available in a fire-resistant form, Fire Code Requirements for toxicity, smoke density, and fire spread. VGP can be used for outdoor installation and, most importantly, for installing indoor green walls, following building code regulations. Also, allows proper plant maintenance and design change; it can be easily separate the trays from bases. In addition, each tray has a coated water tank designed to reuse water stored through capillaries to maintain plant growth and minimize maintenance.

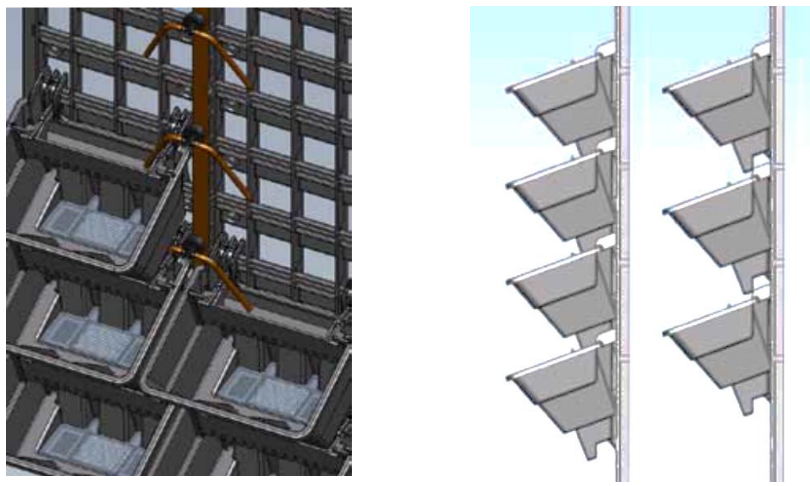


Fig 2.52 The configuration and angel of planter boxes

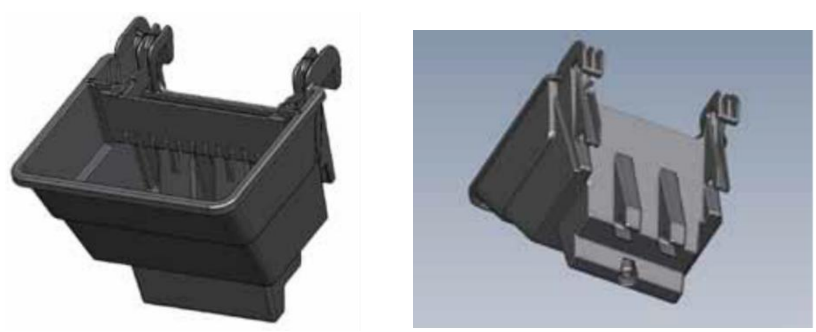


Fig 2.53 The configuration and angel of planter boxes

Fig 2.54 An examples of Planter boxes Living walls, Singapore, credit by Emlich

Irrigation systems

A plant tray drip irrigation with a large number of trays piled on top of one another is exposed. Water is delivered to the upper tray on time by a pumping mechanism from a reservoir tray at the bottom of the machine. Each tray has a drain with a stack and an overflow with a peripheral edge that defines the depth of water in the tray for the overflow.The environment drains a small amount of water at the base of the tray and a drain. It is located centrally from the drain stack and is hollowed out to provide a capillary function for draining and drying the tray at the end of irrigation. A drain guide is in the form of a string or an elastic member vertically, secured to the base of the discharge guide wick pit and attached to the bottom tray, directing drainage in a constant flow to prevent dripping splashing. In one embodiment, the discharge and overflow guide wick is provided by moving the tray so that the tray can be hooked on top of a light tray to provide light for the plants' type of growth in the tray. The need for green wall maintenance is reduced as trays can accommodate irrigation pipes and facilitate excess water drainage. When maintenance is necessary, clips assist in their easy removal and secure mounting (United States Patent, US3772827A * 1971-10-061973-11-20, R Ware, plant tray irrigation system).

Modular panels

Modular panels offer a complete, durable, and reliable solution for transforming heat-absorbing and often dull and monotonous walls into living, attractive walls that seamlessly transform into a natural environment or garden. It is an insulating barrier that protects the building from the harmful effects of sunlight and ultraviolet rays, provides sound attenuation, and helps improve air quality. Panel systems are pre-installed panels that are attached to structures.

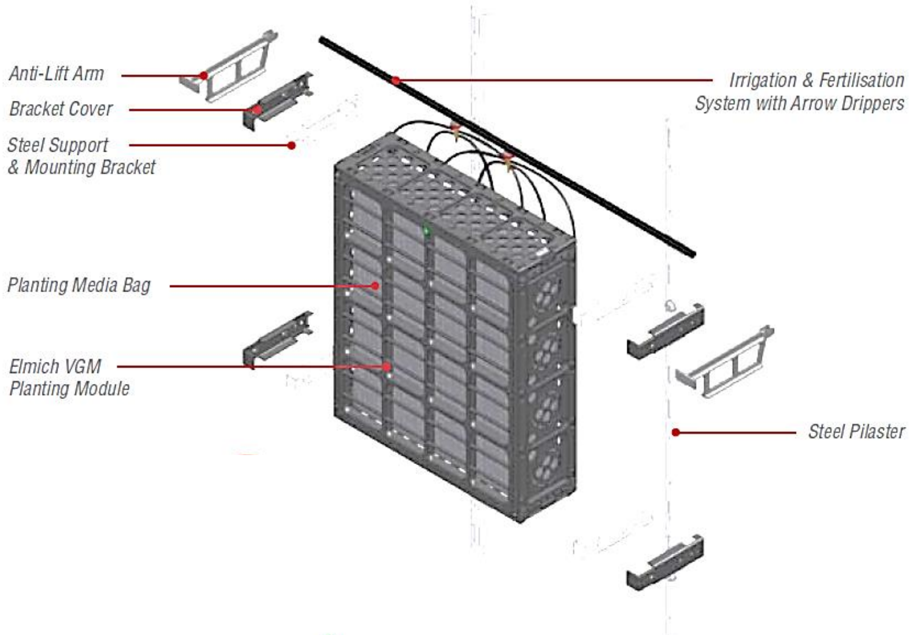


Fig 2.55 Structure of modular panel, Credit by ANS group

This type is an engineered living wall system that includes planting modules, each with a geotextile media bag, cladding support brackets, anti-lift arms, and anchor systems. It is combined with a dedicated planting medium and an automatic drip irrigation system (fertilizer) to ensure optimal results. Also, it uses UV-stabilized plastic modules and stainless steel brackets, and retaining columns with high wind resistance.

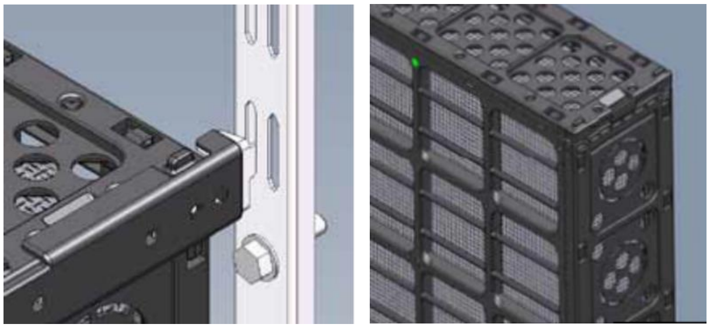


Fig 2.56 Modular panel living wall, Credit by ANS group

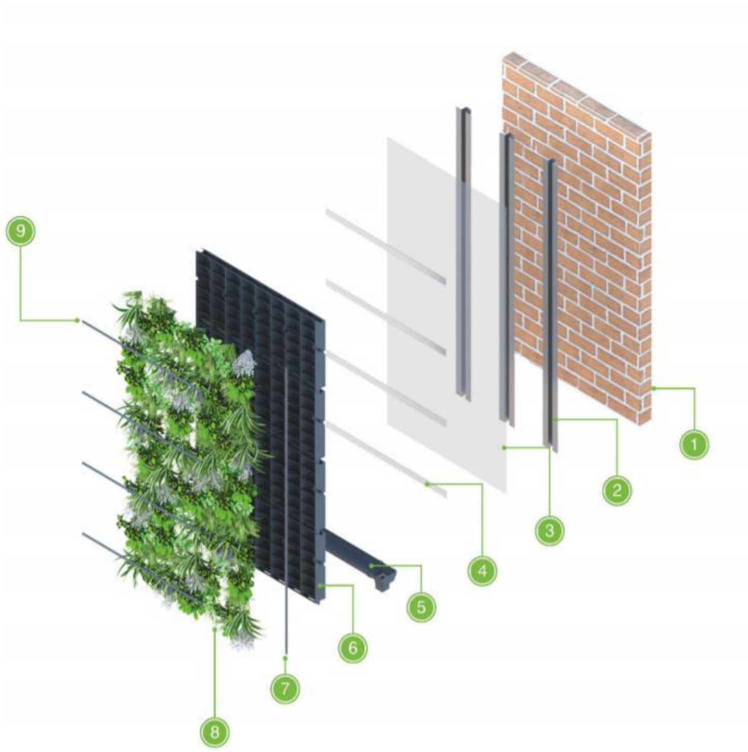


Fig 2.57 Modular panel living wall, Credit by ANS group

Irrigation system

Irrigation pipes are concealed from view, but they play an essential part. The provision of water to the wall is important for the growth of healthy plants. The back of each living wall module is kept damp, allowing mature roots to compost naturally. Rainwater collected from the building's roof will be used to construct the wall.

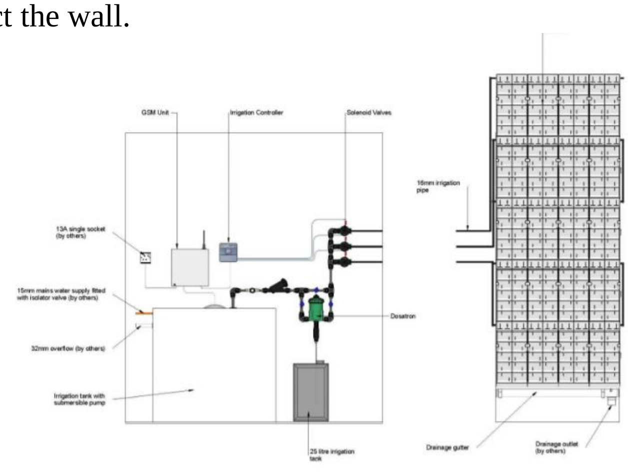


Fig 2.58 Irrigation system of panel systems

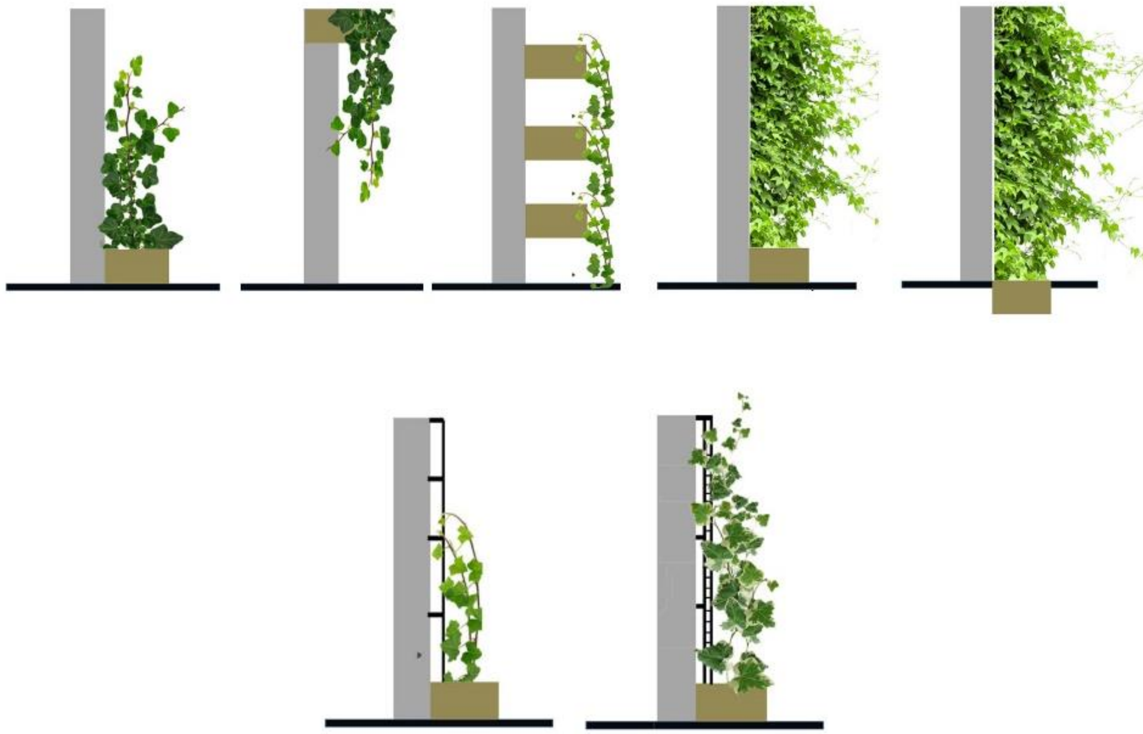


Fig 2.59 Schematic profile of Green facades

Fig 2.60 Schematic profile of Living walls

2.4 Benefits of VGS

Nature-based strategies, such as vertical green systems (VGS), have environmental, social, and economic benefits (European Commission, 2015; Safikhani et al., 2014). With the typology of the green wall, the range and degree of benefits will vary (Cameron et al., 2014). the benefits of a GF can be divided into two scales: the public and the private benefit scale (Shewka & Muhammed, 2012).The benefits of VGS in this research are split into ecological, environmental, social & aesthetic, and economic benefits. Ecological advantages include urban-scale adaptation and mitigation, and protection of natural resources. Environmental benefits are known as the key advantages function in urban and building scale. Like, decreeing negative effect of UHI (Akbari, 1992), improved air quality (Ottelé et al. 2010), water efficiency, urban wildlife falls into the category of urban scale benefits while, energy-saving (Wong et al., 2009), sound reduction (Perez et al. 2016) and thermal comfort (Safikhani et al., 2014) located in building scale. Aesthetic value and human wellbeing are applicable in urban and buildings scale. From an economic point of view, costs from energy-saving and enhance landing value are in building scale. Envelope protection, life cycle cost reduction at the same time act in urban and building scale. The remarkable point is the relation between these benefits and they can affect each other. For example, decrease the harmful effects of UHI can influence wellbeing and human health, although they are in different categories. Also, reducing energy demand can enhance the real state value of building, especially in the residential sector. Moreover, due to residential buildings' contribution to increasing energy consumption, some of the benefits can be seen in the scale of residential buildings, including these benefits, which can be directly and indirectly affected.

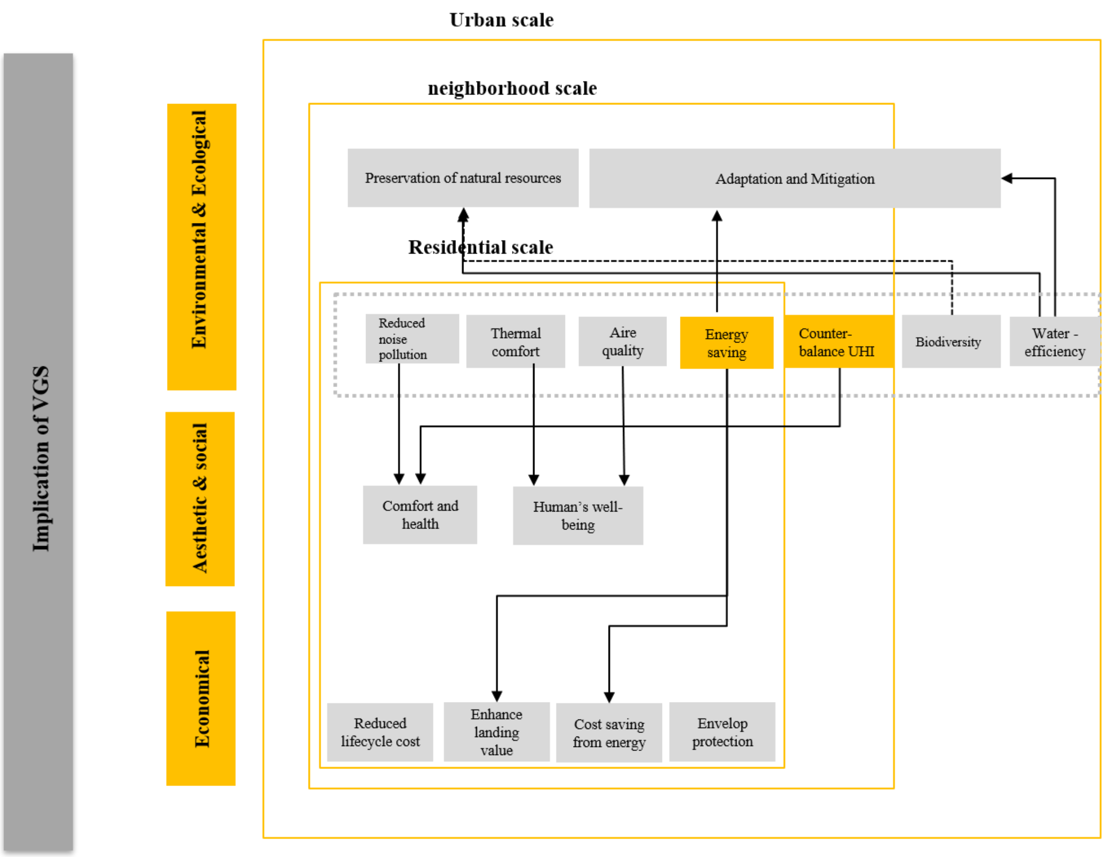


Fig 2.61 Benefits of VGS, based on urban, neighborhood and residential scales

2.4.1 Environmental benefits

Thermal comfort

Covered exterior facades by plants are a successful bioclimatic technique that has many advantages for residents' environmental, acoustic, and psychological comfort. It also has environmental benefits by reducing energy for space heating/cooling and CO2 emissions. Green facades, like other types of green infrastructure, are becoming more common as a design element for lowering a building's internal temperature. (Hunter et al, 2014). A study showed that the VGS test reduced the indoor temperature to 3-4 ° C regarding indoor thermal comfort. It also reduced the cavity temperature to 6.5-8 ° C in a hot and humid climate (Safikhani et al., 2014). Larsen et al. (2014) studied double-skin GF's appearance, and two models are presented to simulate it in Enery-Plus software.

Sound barrier

Noise reduction is one of the many benefits of green envelope (Van Renterghem et al. 2013; Paul et al., 2000). At the building level, Perez et al. (2016) demonstrate the sound performance of VGS, which shows the improvement of wall sound insulation using a thin layer of vegetation (20-30 cm). The depth of the plants determines the degree of sound insulation, the type of plants, the materials used for the living wall system's structural components, and the air layer between the plants and the wall (Haggag, 2010).

An experimental study analyzed different VGS to assess their acoustic effect (Wong et al., 2010b). The results showed that at low and medium frequencies, there is strong damping due to the effect of layer absorption. In contrast, at high frequencies, more negligible damping is observed due to the scattering phenomena in green space. Another study found that depression and heart problems increased by 25% for people living in noisy road traffic compared to those living in a quiet neighborhood (Sheikh, 2018). Complete 2D and 3D full-wave numerical methods have been studied. This study is related to propagating road traffic noise to the non-traffic side of inner-city buildings (yards). The findings of this research suggest that green roofs have the greatest potential for increasing yard noise barriers. Plant walls are very effective when used in the city's narrow valleys with suitable hard facade materials (Van Renterghem et al., 2013). An experiment showed that using the green wall system can reduce internal noise by 15 decibels. This represents a significant benefit for vertical gardens as sound insulation. Also, this experiment is aimed at determining the amount of sound that a vertical garden can absorb. A green wall with an area of 10 square meters was placed on the building at frequencies of 100-5000 Hz. the results showed that the absorbs 40% of the sound. Although noise can be reduced by 30 to 70 dB using other systems such as double glazing, green wall insulation is environmentally friendly. With other benefits such as filtering air pollution, reducing the temperature, improving biodiversity, quality is visual and creative (Azkorra & others, 2015). coefficient are mainly due to substrate presence. In another study by (Manuel Posse, 2019), PVC modular vertical green sound absorption was studied. The advantage over other systems is that the absorption depends on the plants and development and the degree of coverage.

(Whisten et al., 2012) estimated that a 9.2 m high green wall view reduces the sound level by 4.1 while a 3 m high reduces the sound level by 4.5 dB. The first study of five experimental cases compared the noise reduction benefits for seven types of living walls and one kind of green façade built at HortPark in Singapore (Wong et al., 2010b). Experimental evidence from this study shows that "stronger attenuation at low to medium frequencies is due to the effect of layer adsorption, while smaller attenuation is observed at higher frequencies due to scattering of green space."

Biodiversity

In addition to the social, environmental, and aesthetic benefits of vertical green sysVGS , the use of plants in buildings increases the biodiversity (Francis & Lorimer 2011; Collins et al., 2017) By creating a habitat for microorganisms and smaller animals (bees, bats, birds) and through part of the urban wildlife corridors (Mayrand & Clergeau, 2018), biodiversity can be integrated by improved building coverage in urban areas. The VGS surface provides an excellent opportunity to identify with urban biodiversity (Darlington, 1981). Green systems also increase urban diversity by allowing spontaneous vegetation to colonize these systems (Dunnet and Kingsbury, 2008), also to provide habitat for biodiversity (Getter and Rowe, 2006). Green facades and living walls using suitable plant species are favorable for birds and butterflies and Provide nests for birds (Hop and Himestra, 2010). For example, *Hedera* is ideal for Robin's habitat, Wrenches, and winter butterflies (Timur & Karaca, 2013).

Mainly sparrows, black chickens, and greenfinches are found among green-faced climbers in Berlin (Kohler, 1993). Thus, greening systems act as a food source (insects) and as an opportunity for nesting or reproduction. There is a high capacity for living walls to have a wide range of plants. Suppose living roofs and walls are well constructed and maintained, however. In such scenario, they may improve people's perceptions and utilization of the host building by offering psychologically positive interaction with non-humans (Weinmaster, 2009).

Fig 2.62 Vertical garden with 250 different plant species at the CaixaForum Museum in Madrid Beatle, Patric Blanc (2007)

According to the desired aesthetic effect, perennial and evergreen species are selected in terms of diversity in color, shape and density, fertility, and growth. In comparison, recent studies try to select wild plants appropriate to the climate of certain species (Martensson et al., 2014). Indigenous plant prioritization can be an optimal management method to ensure plant survival and restore local biodiversity (Deguines et al., 2016). Because the diversity of plants used in greenery is limited, it is not exempt from the diversity of non-living conditions. In the case of living walls, although they are a diverse plant system, the use of ornamental plants and the lack of natural and systematic growth of plants keep them away from the shape that can provide a bed for wildlife (Jorgensen et al., 2014). modular LWS shows the highest incidence of beetles and spiders, but GF is also an alternative habitat for regular and general invertebrates and rare and specialized species. The GF is also visited by flower visitors (e.g., bees, bees, noisy flies, and butterflies) as sources (Mayrand et al., 2018). Even if upgrading biodiversity is one of the benefits of a vertical garden, insects and birds are annoying, especially in residential buildings. A study by (Maglioko and Perini, 2015), examining residents' perceptions, stated that biodiversity with the presence of birds and insects is one of the disadvantages for residents. However, despite observations that living walls support a wide range of animals, this is largely anecdotal and has not been studied in depth (Köhler, 2008; Weinmaster, 2009). Research is still scarce but shows that all forms of green walls can be animal habitats.

Water efficiency

Vertical green systems improve urban hydrology, stormwater management (Schmid, 2003), and retention (Buccola and Spolek, 2011). This effect is evident if the VGS works with roof technologies that act as a water buffer and a water collection system, even if it is challenging to quantify profits. Transpiration - Evaporation is the most important environmental advantage of vegetation roofs and facades in urban areas. It affects urban hydrology, reduces surface temperature, and improves rainwater runoff management (Stec et al., 2005). Some living walls from the rain discharge collected rain they use sewage to storm the city (Lohe and Stow, 2008). Plant boxes act as evaporation systems to reduce stormwater runoff (Kohler, 2008). Living walls can use renewable energy sources to generate electricity (such as photovoltaic panels), which is necessary for the water pump's operation. A drip system can use so-called gray water or rainwater to irrigate VGS plants. In addition, a drainage system can be installed to collect excess water and return it to the system (Radi'c et al., 2011).

Counterbalance UHI

One of the most straightforward solutions to reduce the UHI effect is to go back to the past. Declining vegetation and the greater prevalence of solid materials and structures, as described earlier, is an important reason for the UHI effect (Oke, 1982; Akbari et al., 2001; Stone and Norman, 2006). Not only does more vegetation reduce heat in the city, but it also helps manage environmental impacts. Vegetation further prevents the formation of smoke fog (Gorsfsky et al., 1998) and creates favorable conditions for evaporation and transpiration and is 2 to 8 degrees Celsius cooler than its environment (Taha, 1997). UHI reduction strategies are aimed at reducing excessive UHI-related heat stress. These strategies form commonalities between energy and water cycles, environmental and economic measures, and human activities and natural systems. Various global strategies are commonly applied to reduce UHI, such as green (plant) infrastructure developments (Tzoulas et al., 2007; Matthews, Lo, & Byrne, 2015). The basic principle of these strategies generally relies on the correction of surface energy balance in built-up lands.

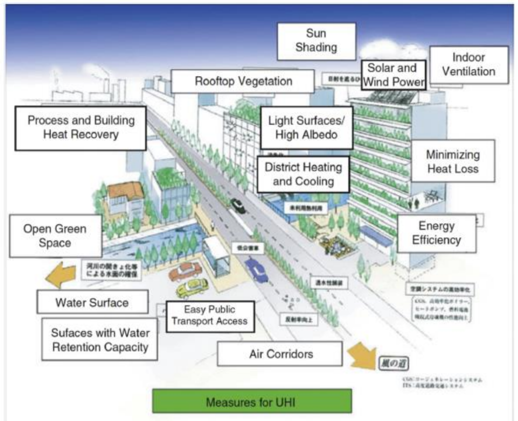


Fig. 2.63 Mitigation measures for the Urban Heat Island, (Ichinose et al., 2008)

Lowering the ambient temperature, which is achieved due to the use of UHI reduction strategies, can significantly reduce the cooling loads of buildings, thus leading to significant energy savings in warm seasons (Salamanca. et al., 2013; Santamouris et al., 2001; Wang et al., 2016). Plants contribute to reducing urban heat islands (Onishi et al., 2010) and ultimately reduce the climate of the built environment (Alexandri and Jones, 2004). Several scholars propose urban greenery as a method for mitigating the effects of higher temperatures caused by the heat island phenomenon (Boehler et al., 2010). According to (Wong et al., 2010), three elements affect the city's temperature on a local scale: buildings, green space, and pavement. Findings show that, in general, urban greenery can, directly and indirectly, lower the UHI intensity, which led to a decrease in global air temperature and average radiant temperature of up to 4 - 4.5 ° C degrees, respectively (Aflaki et al., 2017). Green can lower the temperature due to evaporation-transpiration and shading. This reduction in temperature reduces the adverse effects of UHIE, no matter what type of plant is used (Muahram et al., 2019). Evapotranspiration is a key process that describes plant water loss as vapor released into the air. It happens if the relative humidity is less than 100%, the energy is transferred to a surface that can evaporate water. Because this energy comes from sunlight, the annual and daily evolution of evapotranspiration depends on sunlight. Evapotranspiration cools the leaves and the air temperature around them (Dimoudi & Nikolopoulou, 2003).

VGS has been proposed as an option for passive cooling retrofitting in the building. Installing other heating or cooling system options is costly and time-consuming (Natarajan et al., 2014). vegetated building envelopes are one of the most promising ways to save energy in buildings and help reduce the urban heat island effec (Perez et al., 2017). By moving to an urban scale, extensive coverage of surfaces exposed to sunlight can significantly reduce the effect of an urban heat island (Djedjig et al., 2002; Alexandri and Jones, 2008; Dahanayake & Chow, 2017; Afshari, 2017) and leads to lowering the thermal load on buildings, reduce the need for mechanized air conditioning, and help reduce urban heat islands (Cameron et al., 2014). The higher the influence of vegetation on the city's temperature occurs in warmer and drier climates.Reduction of temperature depend on plants that are more influenced by plant characteristics than wind pattern and canyon orientation during warm days (Alexandri and Jones, 2005). A pilot monitoring campaign was conducted on an experimental cell located in Turin (northern Italy) to evaluate biometric parameters and energy issues that positively impact outdoor comfort and reduce the thermal island (Bianco et al., 2017).

The vegetated surface does not reach high temperatures due to the latent cooling of leaves and substrate. The severity of this phenomenon strongly depends on the growing medium's water content (Djedjig et al., 2012) and contribute to increased humidity in the valley. It was found that the green wall may reduce one-third of the overheating in street valleys by keeping the average temperature in the green façade warm by evapotranspiration (Djedjig et al., 2015).

Due to plants' ability to absorb significant amounts of solar radiation for biological function, green facade play a key role in the formation of urban microclimate (Wong et al., 2010a ; Pe´rez et al., 2017). Another positive effect is the fact that the air entering from outside in the air conditioning system has a lower temperature and saves electrical energy to cool down (Wong et al., 2010b). Research conducted by (Akabari et al., 2001) shows that reducing the effect of an urban heat island with trees, green roofs, and green facades can reduce US national energy consumption for air conditioning by up to 20% and save more than $ 10 than energy consumption. The simulation performed with a new numerical model examines mitigation measures to limit urban heat islands' effect (Saneinejad et al., 2014).

Near the windows, VGS greatly decreases air temperature and wind speed. It also has a positive effect on the strength of UHI . which is achieved mainly by converting sensible heat to latent heat mediated by evaporation and transpiration from the VGS foliage. It confirms that the UHI increases the buildings' cooling load. In this study, the cooling load rise by 7% by placing the building in an urban setting. The second important outcome of the study is that the VGS while having a negligible benefit in the rural case, reduces the cooling load by 4.8% for LAI = 2 (resp. 7.6% for LAI = 3) in the urban case. And the maximum wall surface temperature drops by about10◦C for LAI = 2 (resp. 14◦C for LAI = 3). It is significant but may not, in itself, be sufficient to justify the cost of a VGS. However, the most impressive result is the reduction in UHI intensity. It decreases from 2.14◦C to 1.59◦C for LAI = 2 (resp. 1.22◦C for LAI = 3), a drop of 25% (resp. 43%). It must be kept in mind that the UHI mitigation effect of the VGS may be less dramatic if the assumptions of full irrigation and no stomatal resistance to water flow do not hold. In arid climates, VGS can deliver the highest benefits in cooling and, more importantly, UHI mitigation—if irrigation water is not a constraint (Afshari, 2017).

Energy saving in buildings

By 2030, (Nash and Di Souza, 2002) are projected to live in cities with more than 60% of the world's population. A significant amount of energy consumption and CO_2 emissions come from the building sector, which accounts for 40% of the world's energy consumption today (Raji et al., 2015). At present, about three-quarters of the total energy supplied to meet the heat demand in buildings is used directly for decentralized heat generation in boilers and other separate heating options (Persson et al., 2014).

Hence, improving building design, renewable energy sources, greater efficiency in heating, cooling, ventilation, appliances, and equipment, using nature-based solutions and approaches that look at buildings within their ecosystem should be considered. It is necessary to redouble our energy efficiency efforts by earning at least 3% a year.

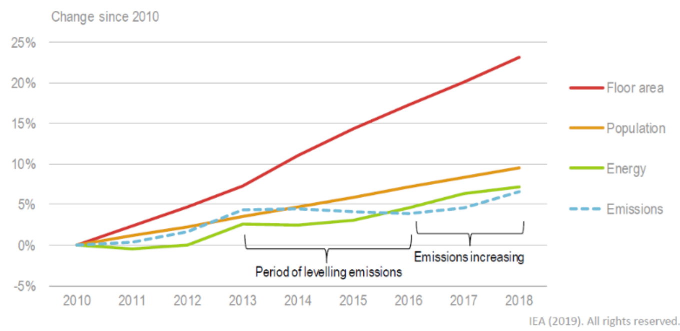


Fig 2.64 Global increases in floor space, economy, electricity usage in the construction industry, and energy-related pollution, 2010-18. Based on IEA (2019a), world energy statistics and Balances 2019 and IEA (2019b) Energy Technology perspective, build

The primary source of increased energy consumption and greenhouse gas emissions by the global building inventory is electricity, which has increased by more than 19% since 2010, mainly produced from coal and natural gas. It shows how vital it is to access clean and renewable energy sources and use passive and energy-saving designs more widely in building construction.

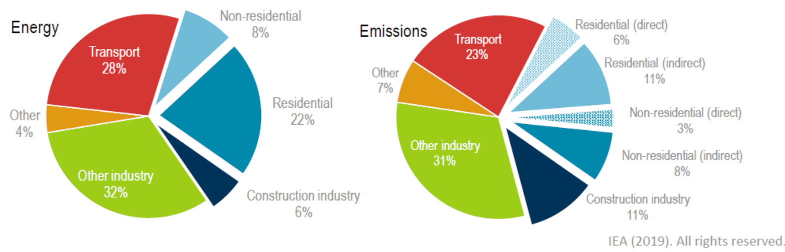


Fig 2.65 Global distribution of final electricity and pollution from buildings and construction 2018. Adapted from IEA (2019a), World Energy Statistics and Balances (database), www.iea.org/statistics and IEA (2019b), Energy Technology Perspectives, build

The construction industry is part of the general industry dedicated to building materials such as steel, cement, and glass. Indirect emissions are emissions from electricity generation for electricity and commercial heat. The buildings and construction sector should be the main target to reduce greenhouse gas emissions, as it accounts for 36% of final energy consumption and 39% of energy and process-related production in 2018. Construction and operations accounted for the largest share of global final energy consumption (36%) and energy-related CO2 emissions (39%) in 2018 (Figure, 2.63).

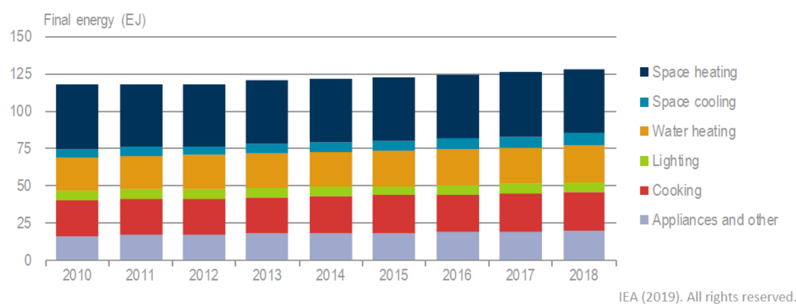


Fig 2.66 End-use energy usage in the global construction market Sources: Adapted from IEA (2019a), World Energy Statistics and Balances (database), www.iea.org/statistics and IEA (2019b), Energy Technology Perspectives, buildings model, www.iea.org/build

Despite the fact that space heating, water heating, and cooking continue to be the critical final energy use demands in the construction sector around the world, they are the fastest-growing use of space cooling, home appliances, and other plug-in loads.

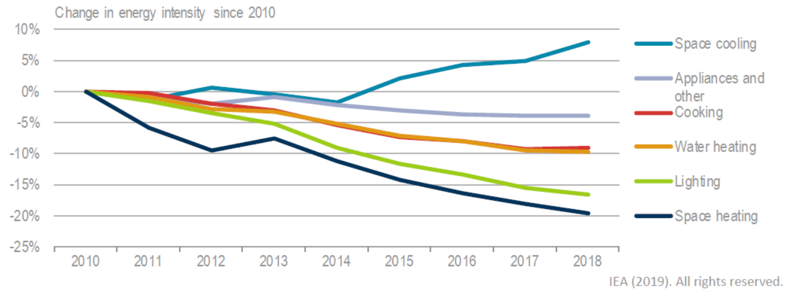


Fig 2.67 The global building sector's final energy intensity varies by end-use., 2010-18, Adapted from IEA (2019a), World Energy Statistics and Balances (database), www.iea.org/statistics and IEA (2019b), Energy Technology Perspectives, buildings model

Due to technological advances, energy intensity has generally decreased for space heating, lighting, appliances, cooking, and water heating. However, the intensity of space cooling energy has increased as a result of greater cooling demand in warm regions. Final energy consumption in residential buildings will account for more than 70% of the entire world in 2018. Growth is mainly due to rising floor levels and population growth, while floor level alone is the leading cause of higher consumption in non-residential buildings (Figure 2.65).

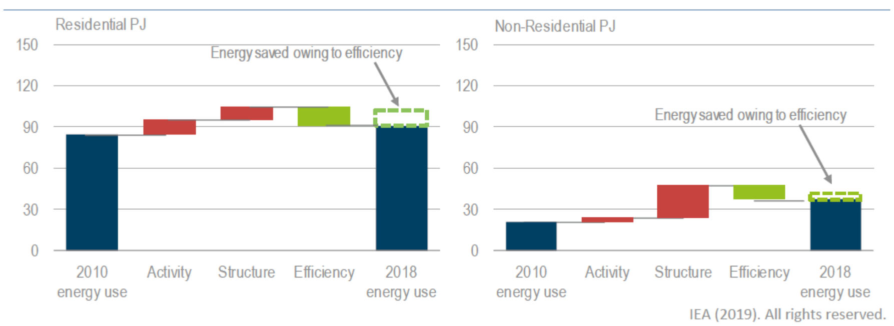


Fig 2.68 Factors influencing building energy use by building type, 2010-18, Notes: Activities include changes in population, climate, and use of buildings and appliances. The structure includes changes in floor level, occupation, and access to services

Low-consumption building systems and envelopes continue to reduce residential and non-residential buildings' energy consumption, although continued efforts are needed to reduce energy intensity. IEA (2019a), *World Energy Statistics and Balances* (database), www.iea.org/statistics.

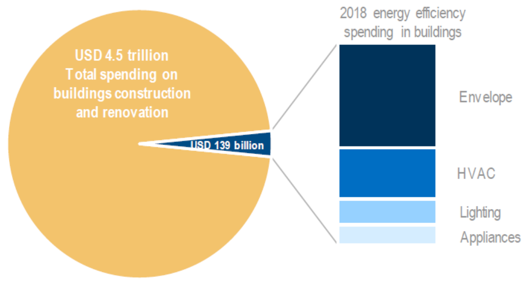


Fig 2.69 Global energy efficiency programs and overall construction budget, 2018, Note: HVAC heating, ventilation and air conditioning, Source: Adapted from IEA (2019d), Energy Efficiency 2019, https://www.iea.org/efficiency2019/

Because more than 40% of projected savings by 2050 in Europe (EU) can be directly attributed to progress in building envelopes (Cao et al., 2016), Therefore, promote high-performance building envelopes as one of the most potential ways to reduce the overall energy demand in buildings and an effective way to reduce cities' temperature. The VGS becomes a greening strategy by utilizing larger wall spaces in urban areas. It reduces heat and energy consumption and increases the cooling effect around the building (Chiang And Tan., 2009). VGS acts as a passive tool in energy saving in buildings (Perez et al., 2014), and widely accepted by researchers as a logical way to make buildings more efficient. Two benefits are important for reducing climate, as green systems play a key role not only as an efficient measure to reduce building energy consumption but also as a source of carbon dioxide (CO2) emissions (Charoenkit, & Yiemwattana, 2016).

Energy saving value by VGS

Recent researches on the use of VGS as an energy-saving solution in buildings mention to four main factors based on (Perez et al., 2014; Wong et al., 2009)

• The type of VGS, taking into account the type of construction, materials used, and equipment and components required

• Climatic factors that affect not only the thermal behavior of VGS but also the plant selection and the effect of this factor on the growth rate and habit of plants.

• The structural parameters (height and leaf area index (LAI), radiative properties (albedo and dispersion), plant traits (leaf hairs, colour, thickness), and processes (aperture / Deciduous water) of plant species used in VGS (Monteiro et al., 2017).

• The main element related to various processes makes this device a method of saving energy in buildings, such as shading, insulation, evaporation and transpiration as well as wind effects.

Climatic factors

Climate not only directly affects the thermal performance of a building but also specific aspects of plants such as their growth (leaf density, plant height) and their physiological responses (transpiration, leaf position) and thus more from the thermal behavior of the whole system. In this regard, the most influential climatic parameters will be solar radiation, temperature, and relative humidity, rainfall, and finally, the wind (Perez et al., 2014). The effectiveness of green concepts also strongly depends on climatic factors such as temperature, relative humidity, solar radiation (clear sky and angular distribution of radiation), and wind speed (Raji et al., 2015). Environmental conditions are one of the factors affecting plant survival. Salt spraying or salt in fog in coastal areas and acid rain from industrial areas can affect plant selection.

Also, heat build-up will be harmful to most plants in warmer climates (Snodgrass EC & Snodgrass LL, 2006). The total amount of resistance to heat transfer created by the vegetation wall and the effect on the building's energy balance depends significantly on the weather conditions and how the vegetation wall is formed. Vegetation walls were observed to help reduce the reference wall surfaces' temperature during the summer period. The whole solar radiation that falls on the leaf of the plant wall is regulated as follows: part is reflected, the part is used for plant photosynthesis, and part is used in the process of evapotranspiration, while the smaller part reaches the wall surface (Sudimac et al., 2019). Leaves with less leaf thickness helps maintain the leaf temperature in smaller amounts to increase heat loss. Stomatal resistance indicates the rate at which water evaporates on the leaf surface.

These changes with changing environmental conditions to retain moisture at the building scale can help modify the building envelope's heat exchange, for example, in temperate and humid climates (Dahanayake & Chow, 2017). Evapotranspiration in summer is about 50% of heat dissipation. In winter, it is very low convection eliminates most of the heat. They found that under all the combined effects (shading, evapotranspiration, thermal insulation and storage), the absolute amount of summer heat average through the LW wall is 3.9W / m2 less than the average heat flux transferred from a standard wall and 3.5 W / m2 less in winter. It leads to a decrease in energy demand in summer and sometimes in winter, depending on climatic conditions (He et al., 2017).

This experiment showed that the facade's vegetation layer could effectively reduce the facade's surface temperature, daily temperature changes in the enclosed space, and temperature gradients from the outer wall, thus reducing the heat transfer coefficient through the wall. The effect of external air factors and parameters, primarily the intensity of solar radiation, wind speed, relative humidity, and outdoor air temperature, results from the heat transfer coefficient (Bartfelder and Kohler, 1987; Harmati et al., 2016; Sudimak et al., 2019). The most influential climatic parameters of solar radiation, temperature, and relative humidity will be rainfall. Climate not only directly affects the building's thermal performance but also affects certain aspects of plants, such as their growth (leaf density, plant height) and their physiological responses (transpiration, leaf position). Environmental conditions are factors affecting plants' survival.

The facade's vegetation layer can effectively reduce the surface temperature, daily temperature changes in the closed space, and temperature gradients from the outer wall. Therefore, reduce the heat transfer coefficient through the wall in temperate and humid climates where evapotranspiration is about 50% heat loss in summer. At the same time, in winter, it is very low and eliminates most heat convection. Leaves with a lower leaf thickness helps maintain the leaf temperature in smaller amounts to increase heat loss. Stomatal resistance indicates the rate at which water evaporates on the leaf surface.

Plant characteristics

Vegetation plays an important role in its particular function as energy balance and improves human health by improving air quality and temperature regulation in urban areas. It has become a vital construction principle to increase modern buildings' viability and sustainability, both outdoors and indoors (Feng and Hewage, 2014).

Plants can respond to climate change by changing their leaf traits. Plant species selection relies on various factors, including preferential visual impact, plant species availability, water, and nutrient requirements, environmental conditions, and system configuration. Plant characteristics used in VGS design can affect the thermal behavior of VGS. The type of plant is definitely changing based on the construction of the system. Green facade using climbing plants sometimes creates evergreen or deciduous. Climbing species can place themselves on walls through morphological features such as leaf tendrils, aerial roots, or adhesive pads. They can be trained diagonally or in a frame against the wall (Cameron, 2013). While living walls are made up of shrubs, grasses are evergreen. Therefore, the green facade by deciduous plants on the wall in summer has a cooling effect, while living walls with evergreen plants can serve as an insulation layer in winter and also reduce the demand for heating.

To achieve the best results, the relationship between the types of plants used and the aspect of the walls in which they grow should be considered. For instance, if the blooms are considered an important feature, a south-facing wall works best. In many cases, the most satisfactory solution may be to use a combination of different species (annual and perennial, deciduous and evergreen, foliage, creeping, and climbing to combine with others successfully. (Kruse et al. 1982; Gabriel Pérez et al., 2011) described the process of absorption of excess sunlight by foliage as 50% absorption, 30% reflection, and approximately 20% passage through foliage and reaching the facade surface. Thus preventing further heat loss from the wall surface through foliage which acts as a buffer against wind movement, as shown by Krushe et al. (1982). Also, direct sunlight on the effect is filtered by the leaves, thanks to phototropism's impact. 100% of the sun falling on a leaf, 5-30% reflected, 5-20% used for photosynthesis, 10-50% converted to heat, 40-40% for evapotranspiration, and 5 -30% used is passed through the leaf (Ottelé et al., 2011). Some of the sunlight that drops on the leaf surface of plant walls is reflected; a portion is used for photosynthesis, another part is used in the evapotranspiration process, and the remaining portion is used for photosynthesis. The envelope has reached its destination (Sudimac et al., 2019).

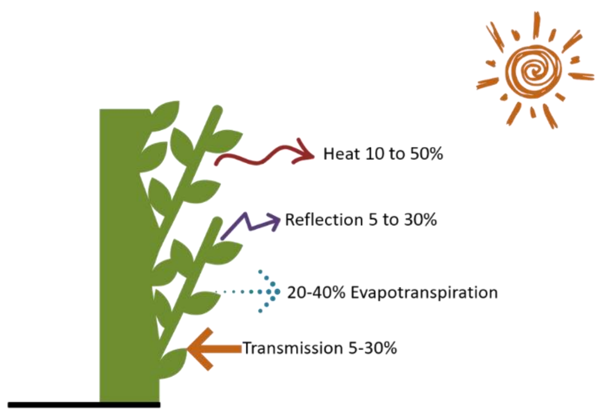


Fig 2.70 Scheme of the energy balance of plants by (Krushe et al., 1982)

The rate of radiation reflection is approximately equal to that of transmission, mainly from 20 to 30% of the sun's radiation. Apart from plant characteristics, plants' ability to reflect and transmit depends on the radiation wave band. plants are effective reflectors and transmitters in long-wave radiation in their potential to reflect 50% of near-infrared radiation. They are helpful absorbers in short-wave radiation, especially photosynthetic active radiation (PAR), 85% absorbable. The amount of plant reflectance and transfer in LW was in the range of 10-58% and 6-38%, respectively (Krushe et al., 1982). In addition, heat transfer in LWs results from heat exchange through the convection of plants and air in the environment, plants and air in the canopy, plant and litter, and litter and air in the canopy (Charoenkit & Yiemwattana, 2016).

The success of VGS mainly depends on the selection of suitable species (Kalani et al., 2017). Plant and substrate characteristics are the main factors that affect energy performance and air purification (Charoenkit and Yiemwattana, 2016 ; Pérez et al., 2015). The cooling process is strongly related to the type of plant species (Cameron et al., 2014). Also, (Bianco et al., 2017) showed that the effects on building energy demand, surface temperature control, and outdoor air quality are closely related to substrate characteristics and plant characteristics: foliage type, deciduous / non-deciduous leaves, cover density ratio (LAI), And the evapotranspiration regime, in addition to demonstrating the cooling ability of green walls.

Fig 2.71 Low foliage density of climbing plants to surface coverage

Many plant species have not only different cooling capacities but also different surface cooling mechanisms. Therefore, to select plants to optimize cooling in green wall applications, various plant physiological parameters such as leaf area index, leaf absorptivity, and average leaf dimension (Susorova et al., 2013) and morphological characteristics should be considered (Cameron et al. 2014; Montiro et al., 2016).
The biophysical properties of the plants, moisture gradations, and temperature values in the plant wall structure can influence the amount of energy consumed by the vegetation (Hadba et al., 2017). Even the mechanisms that plants provide through cooling may be different: shading, evapotranspiration, wind barrier, and insulation effect. Insulation layers inside the building envelope, absorbing sunlight (Basically short wave) and convert to biomass and change the surface albedo. The relative contribution of these cooling mechanisms will depend on the plant form, species, canopy, moisture availability, seasonality, and plant vigor. Plants tested by (Cameron et al., 2014) show that Hedera, Lonicera, and Jasminum officinale coils cool the air and wall surface by shading, while Fuchsia cools evapotranspiration. The cooling effect of Prunus *laurocerasus* and *Stachys byzantina* can be attributed equally to shade, evapotranspiration. The amount of this cooling effect depends on the density of the foliage. *Boston ivy* is the species that offers the maximum cooling effect. These values are comparable to the shading effect of trees (Georgi and Zephyriadis, 2006). Leaf capacity for reflecting, absorbing, and transmitting sunlight varies considerably between and within species due to morphological and physiological differences such as leaf thickness, age, water content, leaf surface texture (smooth, loose, mature, or waxy), and Leaf orientation (Jones, 1992).

The main physiological parameters

Several studies highlight a strong inverse relationship between LAI or the number of leaf layers and sunlight transmission from the green landscape (Hoyano, 1988; Ip et al., 2010; Susorovaet al., 2013). plant's normal growth rate and its physiological characteristics, such as maximum plant height and leaf density, are effective factors (Susorova, 2015). The potential success of greenery depends on the mass and thickness of the vegetation. *English ivy* is usually the most effective climber with positive effects throughout the year. If the building has low insulation values, an additional layer of vegetation structure has more significant relative insulation benefits than a new building with proper insulation (Köhler et al., 1993).

Leaf area index (LAI), the ratio of total leaf area to the land area covered by the plant, that is the most critical parameter, higher LAI contributing to higher energy benefits. LAI is used to describe the leaf mass of a plant set described as a one-sided leaf area per unit area (LAI = leaf area/ground area, square meters per square meter), which is a dimensionless value. This ratio varies from <1 for young plants with loose foliage that does not completely cover the wall to 3-5 for adult plants with dense foliage (Cameron et al., 2014). The results show that increasing the LAI from 1 to 5 can reduce the external surface temperature peak from 12 ° C, reasonable heat transfer from 48 watts per square meter, and latent heat transfer from 40 watts per square meter hot summer day. In addition, the annual cooling load has increased by 1.4% (Cameron, 2017). Increasing the LAI from 1 to 5 significantly reduces the VGS outer surface temperature from 52 ° C to 40 ° C. same results were shown by Susorova et al. (2013). Another study, from experimental study, obtained interesting energy savings (up to 34% for Boston ivy plant species with LAI 3.5-4, during summer under Mediterranean continental climate). In addition, the orientation dependence was confirmed with the participation of the representative in the overall energy saving from the east and west (Pérez-Urrestarazu et al., 2017).

Leaf diffusion is the thermal radiation emitted from the leaf surface, which plays a role in obtaining pure radiation through long-wave output radiation. It can be said that surface conditions, primarily through the LAI factor and the rate of evapotranspiration from the upper surface, greatly impact the heat flow in the air below. LAI up to 3 can significantly increase the cooling effect (Takakura et al., 2000). Simulation of two different LWs in various plants, herbaceous plant, and grass, shows better thermal performance, which had denser leaves and LAI (Scarpa et al., 2014). It is recommended that plants with LAI 4 or higher be preferred for LWs because of their contribution to energy savings, while plants with LAI below two should be avoided (Stav & Lawson, 2012). with less dense vegetation or LAI below three, the insulation capacity of LWs reduced, thus increasing the heating load by 8.3 for a building in Portugal in winter was observed (Carlos, 2014). Therefore, the plant's density is an influential factor in protecting from sunlight in a warm season and storing sunlight in a cold season. Increasing leaf reflectivity and diffusion rates by 21-22% and 15-19%, respectively, contribute to increased energy savings in warm, humid climates (Stav & Lawson, 2012). While decreasing leaf reflectance promotes uptake, most walls can reduce sunlight and heating load by 8.6 to 1.8% in temperate climates (Carlos, 2014).

Numerical model by Assimakopoulos and colleagues on single-family apartment located in the Mediterranean climatic zone, a reconstruction of the building envelope with a living wall has been done. Maximum savings in cooling energy consumption are achieved by plants (tall grass) with maximum height and LAI and moderate values of minimum stomatal resistance and leaf reflectance relative to the rest (Assimakopoulos et al., 2020). Although LAI can be an important indicator of solar radiation transmission, it should be noted that this is not a static value (Hunter et al., 2014). The amount of water vapor in plants through the leaf surface pores during transpiration with regular leaf stomatal conductance is one of the physiological characteristics of individual plant species (stomatal conduction interaction, stomatal resistance). Stomatal conductance depends on the pores' size and the number of them per leaf surface, which typically reaches 0.2-2 of the leaf surfaces. The stomata can be at either level of a leaf (Amphi stomatous leaves) or only at the lower level (hypo stomatous leaves) (Nobel, 2009).

The main morphological parameters

Plant height is another structural parameter that affects wind speed in foliage. Short plants have many stems and dead material with much vegetation. Radiation properties depend on the type, season, leaf color, texture, and age of the plant. Lighter leaf color and longer hair species such as *Heuchera* and *Salvia* have lower leaf temperatures (Dahanayake & Chow, 2017). Increased albedo and diffusion reduce the temperature of the leaves and thus bring more energy. Light-colored plants (on mature leaves) with longer hair lengths are more successful in having a cooling effect. Plants with less leaf thickness are more profitable because of better heat loss and less heat accumulation. Plants with higher aperture conduction help to improve the lower temperature of the leaves and thus gain more energy (Dahanayake & Chow, 2017). Experimental results by (Monteiro et al., 2017; Kalani et al., 2017) showed that plant height is not an important factor in cooling load. The use of shorter plants in VGS increases the energy benefits. The absorption of plant leaves strongly depends on water content, leaf hairs and leaf thickness. Thick, waxy leaves like conical needles absorb up to 88% of the sun's rays (Jone, 1992).

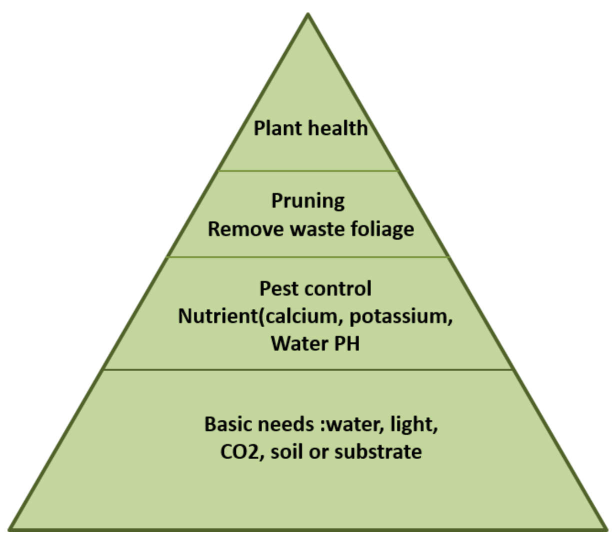


Fig 2.72 Proposed plants needs based on Maslow pyramid

Because plants are live members of VGS, it is essential to meet all the plant's needs to survive. Like humans, according to Maslow's pyramid, which depicts the series of human needs in order of importance, the proposed pyramid for plants consists of the plant's essential survival needs. Including water, light, carbon dioxide, and soil or growth medium, without which the plant cannot be alive at all. At the second level is the need to control insects. Nutrients include calcium and potassium. Also, controlling water consumption can affect the long life of the plant.

The third level is pruning the plant and removing excess leaves, although not one of the plant's basic needs, can hinder the proper growth of the plant. At the top of the health a pyramid is plant health, which is affected by lower levels and can also be caused by environmental factors. The purpose of designing a plant needs pyramid based on Maslow's pyramid of human needs is to pay enough attention to the hierarchy of needs and their importance. It is clear that for the proper functioning of the green wall, it is necessary to consider all these requirements and ensure it’s success. In terms of energy savings, the plant-covered wall can lower the ambient air temperature (reduce the effect of the heat island) and reduce the surface temperature directly behind the vegetation, which can transmit conduction. Minimize heat into the building envelope, thereby reducing cooling loads. Air infiltration into buildings affects the building's energy use for heating and cooling (Happle et al., 2017). A study of green facades covered with Parthenocissus tricuspidata showed that the vegetation layer in front of the building facade reduces air infiltration into the building and helps save energy (Susorova et al., 2014).

Plant mechanism for energy balance

The reduction of temperature in vegetation is achieved by a decrease in heat absorption, evaporative water cooling for plant irrigation, thermal resistance due to the low thermal conductivity of plants that act as thermal insulation (Haggag et al., 2012). The exact cooling mechanism depends on several factors, including plant maturity, LAI, canopy structure, leaf size, pore size, density, pore conductance and dynamic climatic conditions (Susorova, 2015).

Evapotranspiration

Carbon dioxide is absorbed by the plant's leaves from the atmosphere and release oxygen to the plants, while at the same time, water evaporates from the leaf surfaces in the atmosphere. This process is called evapotranspiration (Papadakis et al., 2001; Miller et al., 2005; Schmidt, 2006). The process of plant evapotranspiration requires energy and this physical process leading to cooling so-called "evaporative cooler" (Perez et al., 2011). Evaporating vegetation also photosynthesizes; it absorbs and converts it into photochemical energy, otherwise absorbed and reflected as infrared radiation. Photosynthetic inefficiencies mean that part of the radiation received by the leaves can still be lost as heat, for example, 40-60% depending on the plant species and the prevailing environmental conditions (Cameron, 2014). The type of plant and the amount of sunlight determine the evaporative cooling of the leaves. Dry environments or the effects of wind can increase the evapotranspiration of plants. In the case of living walls, evaporative cooling of the layer will be necessary and substrate moisture is an essential factor (Pérez et al., 2011). The external surface temperature of VGS decreases in the range of 3.7-11.3 ° C, while the percentage of plant foliage in the system increases between 13% and 54%. green facades and roofs heat hot air by evaporating water (Besir & Cuce, 2018), This process improves thermal insulation in winter (Alexandri and Jones, 2008). Therefore, plant evapotranspiration has significant potential in reducing urban and global temperatures (Chen et al., 2013b). three ranges of this ratio 60-75 for a humid environment with high wind speed and humidity, 45-65 for mild conditions with lower wind speed and lower humidity, and 23-40 for the dry or desert climate with low wind speed and low humidity suggested by (Larsen et al., 2014).

Effect of insulation by plants and substrate

The effect of VGS insulation (Papadakis et al. 2001; Hoyano 1988) can be created by changing the ambient conditions (temperature and humidity) of the space between the green screen and the building wall. This layer of air can create an interesting insulating effect. Air freshening in this space, foliage density, and facade openings design should be considered.

The insulation capacity can depend on the thickness of the substrate for living walls (Pérez et al., 2011). For example, in humid and cold regions of China's Hunan Province, due to the green vertical system's additional thermal insulation, an energy-saving rate of 18% was achieved during a heating experiment. The role of insulation materials and stagnant layers of air is to reduce the rate of heat transfer between inside and outside the building, which is a function of the difference between indoor and outdoor temperatures (Xing et al.,2019). The amount of insulation of VGS surfaces can be increased in several ways:

- Covering the building surface with plants prevents the heat of summer from reaching the skin of the building and prevents the escape of internal heat in winter.
- Because wind reduces the energy efficiency of a building by 50%, a plant layer acts as a buffer that prevents wind from moving along the building's surface.
- The materials and substrates used in the living wall between the facade and the dense vertical green layer, both in the soil and in roots in systems based on artificial pre-planted (hydroponics), there is a layer of stagnant air has an insulating effect.

So, the green facade can be used as "additional insulation" for the building envelope (Minke & Witter, 1982; Perini et al., 2011). The insulation effect of *ivy* covering traditional facades has been cooling in summer, and insulation around 5 ° C in severe winter is measurable effects (Köhler, 2007). in studies of traditional facades, the improvement in heat loss of up to 25% was measured in the northern façade, although this improvement depended on the insulation level of the building (Koehler, 2008). By simulated different living walls by EnergyPlus to evaluate their thermal performance in the Portuguese climate and confirms that in addition to reducing the cooling load in summer, VGS potentially acts as an insulating layer. Which can reduce heat loss through the walls, therefore, save energy in winter. In winter, this system works differently, and the heat radiation is separated from the outer walls by evergreen plants (Carlos, 2015).

In addition, dense foliage reduces wind flow around the façade and helps prevent the building from cooling down. It suggests that VGS with less vegetation has an offensive effect during the winter instead of a cooling effect (Kalani et al., 2017).

Due to the increased insulation properties with green systems, additional heat resistance of 0.09 sq. Km W_1 is assumed. This value is used for green, direct and indirect systems because there is a layer of stagnant air inside and behind the foliage. It can also reduce the external surface heat transfer coefficient by reducing wind speed (Perini et al., 2011). When winter temperatures are close to freezing (Johnston Jay & Newton, 2004) recorded an insulating effect of up to 30% for green walls, in cold weather, the effect of a heat island can significantly influence the heating energy demand buildings. Because the ambient temperature is higher, less energy is required to heat (Givoni, 1998). An experimental study performed on a modular green wall in a Mediterranean climate shows the green system provided additional thermal insulation. It estimated a 60% reduction in output heat flux. Daily energy showed that the green system could reduce heat loss during a cloudy winter day by about 56 percent compared to a plastered wall (Manso and Castro-Gomes, 2016). Due to thermal insulation provided by vegetation and substrate (Papadakis et al. 2001; Hoyano 1988), plants may increase heat demand (Stec et al., 2005) if the plants have not been selected carefully enough and the climatic characteristics have not been analyzed.

Shading effect

A green wall can protect the building envelope by shading. The solar radiation that hits the green wall depends on the physical characteristics of the canopy and is distributed in three ways: it is transmitted to the atmosphere or through the leaves or the canopy absorbs it (Tilley et al., 2012). Vegetation can provide shade to buildings, protect them from direct sunlight, and at the same time create a homogeneous microclimatic phase between plants and building surfaces. Shading is often cited as the most important aspect of plant cooling, indicating that the greater the foliage

cover/volume, the more effective (Takakura et al., 2000). A layer of plants placed on the building's outer wall cuts off part of the leaf's entire radiation, reflects the radiation, and transfers the rest to the outer wall behind it. This shading effect is important in hot months when the surface temperature of the facade behind the plant layer and the temperature gradient of the facade surface (temperature difference between the outer and inner surface) of the outer wall is much more important than the reference wall.
The effect of shading may have different effects depending on the cooling and heating seasons. In the summer, plant canopies that are strategically integrated into the building facade may act as solar panels to filter sunlight (Ip et al. 2010). In experiments with traditional green facades, Kohler (2007 and 2008) found that the extent of this shadow effect depended on foliage density. Ivy is a species that offers the maximum cooling effect, comparable to the shade of trees. Differences of up to 3 ° C were observed in indoor temperatures in winter (Kohler, 2008). Shading has no role at night, on cloudy days, and when the green facade is constantly shaded by the surrounding objects (Evmorfopoulou, 2009; Hoyano, 1988; Wong, 2010a ;Susorova, 2014). Shading by vertical green systems is mostly used in places with high vertical radiation (Raji et al., 2015).

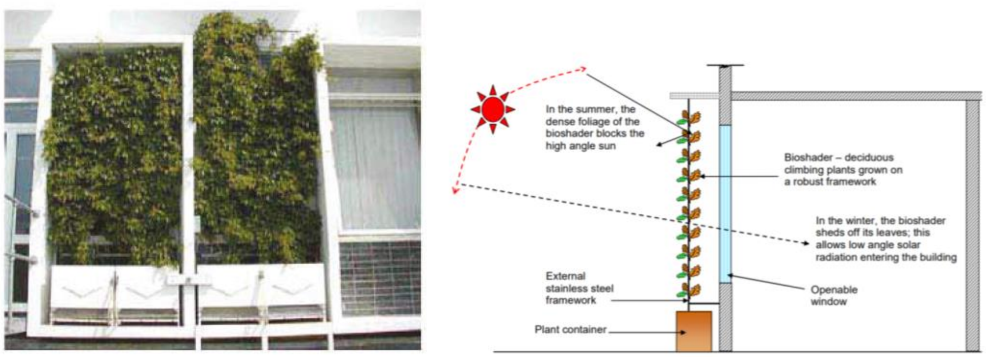


Fig 2.73 Bio-shader experiment (Lam et al., 2005)

In the Bioshader experiment at the University of Brighton, the office was compared to a window covered with plants like no other covering. The internal temperature was calculated at 3.5% C, with a maximum temperature of 5.6 ° C. Also, It measured the solar transfer of foliage, which varied from 0.43, with single-layer leaves, to 0.14 with five-layer leaves, which corresponds to a reduction in solar pass radiation from 37% for one layer to 86%, with five layers Leaves (Miller et al., 2007).

Wind barrier

The degree of wind protection provided by a green barrier depends primarily on the speed and direction of the wind, the dimensions of the barrier (height, width, and length), the density and permeability of the material that is finally on the way. Considering the plant type space should be careful not to obstruct air conditioning in summer and should not encourage drafts in winter (OCHOA, 1999). the VGS acts as a wind barrier and confirms the evapotranspiration effect of the plants (Pérez et al., 2011).
(Perini et al., 2011) investigated the relationship between air cavity thickness and the thermal insulation properties provided by green walls. They found that direct greening facades and living walls (with a 4 cm air gap) were more effective in reducing wind speed around the facade of the building than indirect green walls (with a 20 cm air gap) due to the shorter distance from vegetation

and walls. They also noted that reducing the thickness of the air layer of the indirect green system 4-6 cm improves its thermal insulation in the building. There is no study of the effects of mechanical damage caused by wind on the green facade's growth, durability, and thermal performance. On the wind side of tall buildings, local winds can form, create strong drafts toward the street level, and be reconstructed toward the upper floors (Blockenand Carmeliet, 2004). Strong winds and the usual increase in air temperature in urban areas can lead to a lack of high-water vapor pressure or low relative humidity (Oke, 1988; Stone and Rodgers, 2001). Under these conditions, the plant transpiration rate increases until we reach the maximum orifice conduction velocity, assuming that the substrate moisture is not limited. After crossing this threshold, the stomachs approach to prevent further water loss and the formation of fatty vascular cavities (Whitehead and Beadle, 2004; Hernández-Santana et al., 2008; Chen et al., 2011).

Thermal behavior of VGS based on characteristics

The main feature of VGS like substrate, plant species, the material used, and the air cavity between the facade and vegetated wall, which vary in different types of greening system, can change thermal qualities. Therefore, the thermal behavior was analyzed based on green facades, living walls, and studies comparing them with reference walls. For instance, the green facade requires climbing plants while living wall systems allow for a variety of plants, including shrubs, grasses, and perennials (Jim, 2015).

Direct Green Facades

In an experimental study with climbing plants (Parthenocissus, tricuspidata) points to a 13 ° C drop in building surface during summer (Hoyano, 1988). Similarly, Bartfelder and Koehler (2008) examined surface temperature by comparing plant-covered walls and bar facades with Boston ivy, which shows a complete four-story house, indicating a decrease in green facade temperature between 2 and 6 degrees Celsius. It is Modeling measurements performed by Eumorfopoulou & Kontoleon (2009) in hot, humid climates in Greece, with experiments with full coverage by climbing plants on summer days, show a 5.7 ° C reduction in the outer surface of the bar facade. In the summer. (Cameron et al., 2014) studied the climbers (*Hedera Helix, Stachys Byzantine*) to understand the effect of plant appearance on lowering surface temperature. It is concluded that it decreases by about 7.7 ° C. Bolton et al. (2014) tested the *Hedera Helix* in the winter and shows a + 5 ◦C increase in building surface area.

Indirect green facades

An initial experimental study by Hoyano (1988) evaluating the thermal performance in summer days by climbers on the building surface showed a decrease in ambient air temperature. An experimental investigation in Hong Kong shows that in August and September, the hot and humid summer months, VGS provides up to 16% of the energy saved air conditioning (Pan & Chu, 2016). In another study, significant energy savings were observed from experimental measurements (up to 34% for Boston ivy species with LAI 3.5-4, in summer under Mediterranean continental climate). In addition, the importance of orientation in the east and west directions and more than the total electricity savings was confirmed (Perez et al., 2017). Another study by (Pérez et al., 2011) analyzed the thermal behavior of two-color green facades in arid Mediterranean continental conditions from April 2009 to September 2009. No significant differences were measured between outer and middle space, showing slightly lower temperatures in middle space in the hottest months of May, June, July, and August. The interior temperature of the facade with VGS was 1.7 ° C on a sunny day and 1.3 ° C lower than the bare wall on a cloudy day. It means that the green coverage acts as a wind barrier and confirms the effect of evapotranspiration of perennial plants. In a building tested with a two-tone green façade in Hong Kong, reduced heat dissipation in winter keeps the building warmer by up to 3 ° C (Hong et al., 2013). Similarly, a modular panel system helps reduce energy by about 1% in July by reducing the maximum off-temperature between 39-37◦C (Kontoleon &Eumorfopoulou, 2010). (Alexandri & Jones, 2008) simulated the decrease in temperature in the urban valley with green facade, which reduced the temperature by 4.5 ◦C for the Mediterranean climate and 2.6 ◦ C for the temperate climate. A report by Perini et al. (2011) analyzed double-skin green facades in the fall and observed a decrease of 2.7 ◦C and have been reported to save up to 15 to 30% in energy consumption in climatic regions such as Central and Northern Europe and Japan (Xu and Ojima, 2007). A study by (Price, 2010), who developed a mathematical model based on his previous experimental findings to evaluate energy savings in low-rise buildings with plant-covered, found that the building's cooling load was up to 28%, in a temperate climate.

Living walls

by examining LW based on continuous felt (pocket type) in North of Italy, found that there is a decrease in surface temperature compared to the bare wall of 12-20 ° C on sunny days (Mazzali et al., 2013). An experimental study by (Chen et al., 2013) proves the significant cooling effect of living walls. It can reduce the maximum temperature by 20.8 ° C compared to the bar wall. It also showed that substrates indirectly and directly affect the cooling of LWs because they are strongly associated with plant growth. Substrates have an indirect effect on the energy performance of LWs because a fertile and moist growing environment can enhance plant growth. This study in China shows a positive relationship between plant cover and LW surface temperature difference, showing that healthy plant growth is essential for LW capacity in reducing air temperature (Chen, Li & Liu,2013). The substrate is an important component of LWs, especially for a modular system. Moisture content and thickness are important factors affecting the thermal performance of LWs.

Maintaining adequate moisture levels in the substrate keeps plants healthy and crucial for optimizing the effect of transpiration-mediated cooling (Cheng et al., 2010). Also, changing the thickness of the substrate has a significant effect on the cooling capacity of LWs and heat a building. Increasing the substrate thickness from 6 cm to 8 cm improves the insulation capacity of LWs and significantly increases energy savings for space cooling from 2% to 18% (Stav & Lawson, 2011). A facade (south-facing) with a green coverage can reduce the energy demand for air conditioning in the Mediterranean climate. Depending on the type of exterior walls: in the case where the wall (30 cm of concrete) is insulated with 15 cm of exterior by polystyrene, energy-saving values for cooling compared to a non-green case between 1.4 and 2.6%. In the second scenario, with an internal insulation wall (15 cm polystyrene with 30 cm concrete), a green layer reduces the cooling energy consumption from 4.7 to 6.2. (Olivieri et al., 2009) performed an experimental analysis that revealed that the internal temperature of a vegetable module is 20% lower than the internal temperature data obtained by sensors in a vegetation-free module. Some modular LWs have an air gap between the LW support structure and the exterior building walls. This layer of air weakens the cooling effect of plant evaporation (Scarpa, Mazzali, and Peron, 2014). between four different distances - 30 mm, 200 mm, 400 mm, and 600 mm - the results of an experiment showed that LW with the lowest air gap of 30 mm had the best performance in relation to the lowest wall surface temperature of the outdoor building (Chen et al., 2013).

Modular systems with vertical panels also perform better than LW based on plants in temperate and Mediterranean climates. It was found that the average surface temperature of LWs with vertical panels is about 8-9 ° C lower than the reference wall, which is 2-3 ° C higher than the factory-based LW in the Netherlands (Ottelé, 2011). The use of LW testes in the Mediterranean climate (Athens) reduces the need for cooling and heating of buildings by about 10% and 4%, respectively (Asimacopoulos et al. 2020). Determine the correlation between the temperature values of the vegetation wall elements, the plant species used in the vegetation wall, and its design, an experimental model has been developed to understand the dynamic thermal processes taking place in the vegetation wall. Based on the measurement and observation of the experimental model, heat flux and temperature ratio simulations were performed. Thermal analysis is made for the reference wall and the wall with a modular system of GW. The survey was conducted in the summer weather of Belgrade. Experimental and theoretical, continental average with prominent local features. Measurements have shown that the use of plant walls in architectural buildings reduces the cooling energy required during the summer in the range of 6-12% (Mayer and Hppe, 1987a; Salisbury and Ross, 1992; Papadakis et al., 2001; Miller et al., 2007; Wong, 2009; Sudimack et al., 2018). It is noteworthy that during the test period, the vegetation on the wall reduces the external surface temperature about 0.56-14.3 using ° C , by changing the type of outer envelope (insulated with extruded polystyrene or massive rock bearing wall) and the type of air cavity (ventilated or closed). The results show that LW seems to be more effective with a ventilation cavity (Pulselli et al., 2014).

Comparison of green facades and living walls

VGS thermal advantage tests include the study of direct green facades, living walls over bare walls without greening. Also, a contradiction of the thermal efficiency of the living wall and the green facade. Energy savings are calculated thanks to the thermal properties of the systems by subtracting the amount of energy saved by the "extra" insulation layer. For direct and indirect green systems, energy savings for heating are estimated at 1.2% of annual consumption. For living wall systems based on planting boxes and felt layers, 6.3%, and 4% were saved, respectively. Temperature reduction is estimated because of a green layer in the Mediterranean climate of about 4.5 ° C (43% energy saving for air conditioning) and in temperate climate2.6 ° C, according to (Alexandri & Jones, 2008).

In a experimental study, they measured the thermal performance of eight types of VGS (one type of green facade and seven types of living walls) using the same method of measuring VGS under the same conditions and then comparing their performance in terms of maximum reduction of average wall surface temperature compared to control wall, VGSs 4 (living wall - modular plate, vertical interface, inorganic substrate) and 3 (living wall - lattice and modular, vertical interface, mixed substrate) have the best thermal performance. These results point to the thermal benefits of VGS in reducing the surface temperature of buildings in tropical climates.

A comparison of green facades and living walls has also been made. In tropical Singapore, maximum surface temperature drops of 11.58 ° C were recorded for living walls and 4.36 ° C for green facades (Wong et al. 2010). Numerous studies have shown that green facades and living walls produce more energy efficiency in hot and humid areas. In Madrid, for example, overall energy savings are close to 30%, and in Vancouver, almost 9%. Resistance of plant seedlings to low temperatures depends on the intrinsic characteristics of plants, balanced nutrition, plant species, and its resistance, seed quality, and irrigation systems. This analysis required familiarity

with the biological-horticultural characteristics of the plant species used and their growing conditions (Thomazelli et al., 2016).
The paper by (Coma et al., 2017) compares the behavior of LW and GF under similar conditions: the reference wall is composed of gypsum, alveolar brick, and cement mortar. During the summer, LW ensures the highest temperature drop for each exposure, with a better result on the south side.

Reduction of Air Pollution
Some studies show that plants in the facade envelope, in addition to a significant reduction in energy consumption, has an ecological contribution simultaneously. They are improving the effects of urban heat islands, improving air quality in its environment, and influencing micro-local climatic conditions and biodiversity in its surrounding (Jaafar et al., 2011). Ultrafine dust particles (< 2.5 μm) are critical in dense urban areas because they can be breathed deep into the respiratory system and damage human health (Powe & Willis, 2004). Traffic-related particulate matter (PM), consisting of fine and ultrafine dust, nitrogen dioxide (NO2), and ozone (O3), are the primary contaminants impacting urban air quality (European Environment Agency, 2015). Recent studies confirmed that vegetation can filter and clean contaminated air by trapping particulate matter (Ottelé et al., 2010). they prevents and filters the movement of dust and soil particles over the sides of buildings (Peck & Callaghan, 1999). Also, increases the air quality by the deposition and dispersion phenomenon. Air quality depends on the amount of dust, particulates, and nitrates in the air (Peck et al., 1999; Carter and Keeler, 2007). So, depending on the variety of plants, their location, the degree of air pollution, and the wind direction, which is related to the source of pollution can be moderate. Generally, as they get to their surface, plants may deposit airborne particles. In contrast to artificial surfaces such as glass and cement in the dense urban area especially, plants have 10 to 30 times quicker deposition.
When it rains, the airborne particles hang on the leaves for a while and then turn back to the surface. Hairy plants have broad leaves, and infiltrate for air movement to better deposition (Muahram et al., 2019). vegetation will improve the air quality during the day in crowded cities where CO2 is emitted heavily by vehicles (Muharam,2015). "plants act as a natural filter—taking carbon dioxide from the air and replacing it with much-needed oxygen" (Timur & Karaca, 2013).

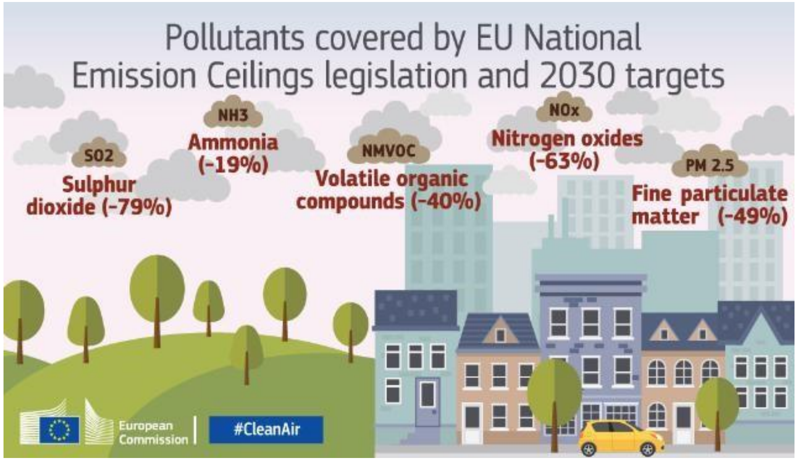


Fig 2.74 Reduction of national emission, https://ec.europa.eu

The Commission reviewed EU air policies from 2011 to 2013, culminating in implementing the Clean Air Regulation Package. The Commission introduced a Clean Air Programme for Europe as part of the package, reviewing to set the standard for the thematic strategy on air pollution, current EU air policy goals for 2020 and 2030.

By stomata on leaves and plants can be dissolved or sequester gaseous compounds (McPherson et al. 1994; McPherson et al., 1998). PM removal capacity by plants relies on their interaction with plant surfaces, which can be defined by plant morphological properties. Like the shape, size, and orientation (Petroff et al., 2008), the plants' density, type, and configuration (Tonneijck and Blom-Zandstra, 2002; Lin et al., 2016; Tong et al., 2016,) and structure of plants (leaf shape, epidermis, roughness) on the total amount (number) of particles collected (Perini et al., 2017). LAI has a strong association with trapping dust (Dunnett & Kingsbury, 2004). In terms of PM removal effects of VGS, the collection of particular plants increases VGS' efficiency and it is crucial to optimize its collection capacity. By the ESEM micrographs (n = 144) indicate that plant performance in capturing fine dust with Trachelospermum jasminoides > Hedera helix > Cistus 'Jessamy Beauty'> Phlomis fruticose (Perini et al., 2017).

The effectiveness of English Ivy (Hedera helix) in dust and pollutant absorption was studied by Scanning Electron Microscopy (Sternberg et al., 2010). It showed that ivy behaves as a 'particle sink,' particularly in high-traffic areas, which absorbs particulate matter. It was influential in adhering to fine (b2.5 μm) particles and ultra-fine (b1 μm) at densities of up to 2.9 × 1010 per m2. Their results indicate that ivy, by trapping pollutant particles, can delay bio-deteriorative processes on historic walls. That human vulnerability to respiratory issues caused by emissions from automobiles (Song et al., 2015). by using scanning electron microscopy (SEM) and energy dispersive X-rays (EDX) test Particulate matter deposited to evaluating leaf of five evergreen species in China efficiency in urban area. This study proves the important role of urban plants in mitigating urban airborne PM. Best PM-removing species, and the important leaf traits, were identified using living wall plants and natural/synthetic leaf models. The influence of leaf size on PM accumulation was dominant over other examined characters (leaf size, shape, and micromorphology); smaller leaved species with a high Leaf Area Index were identified as the most efficacious (Weerakkody et al., 2018). Analysis of captured PM from rail and road traffic showed the ability of living wall plants to immobilize a wide range of elements that are known to be hazardous to health. The ability for the rain to wash particles off leaves and renovate catch surfaces to ensure their consistent activity was shown by simulated rainfall; wash-off eliminated between 48.4 percent and 92.5 percent of particles depending on the plant. Hairy leaves have also been reported as being useful in catching more particles than smooth-leaved plants by trapping them on the leaf hairs / trichromes with a complicated micromorphology (Leonard et al., 2016). Besides, (Perini, et al., 2017) showed the influence of plant species and structure (leaf shape, epidermis, roughness) on the total amount (number) of particles collected. Waxy leaves (T. jasminoides) collect the highest significant number of particles from the atmosphere. Hairy leaves P. fruticosa) are less effective and thus not a suitable option for improving air quality.

2.4.2 Economic benefits

In addition to ecological, social, aesthetic, and environmental values, various studies have demonstrated economic benefits of VGS (Kontoleon & Eumorfopoulou, 2010; Cuce, 2017). The impact of green on the economic growth of buildings can be described in two ways, direct and indirect benefits. Facade green has benefits not only for the environment and nature but also for long-term construction that can reduce operating costs (S. M. Sheweka & Mohamed, 2012). As the name implies, direct economic benefits reduce costs without any intermediaries, while indirect benefits are economically viable through the presence of an intermediary.

The significant economic benefits are related to energy saving for heating in winter (Krusche et al., 1982;) and cooling in summer (Mazzali et al., 2012). Vertical green systems enhance the visual, aesthetic, and social development of urban spaces, which affects the economic value of buildings and neighborhoods—increasing the value of the property due to enhancing the visual appeal. It is attracting more customers in commercial buildings, hotels, due to the beauty of the facade, which is a factor in the direction of greater economic profit.

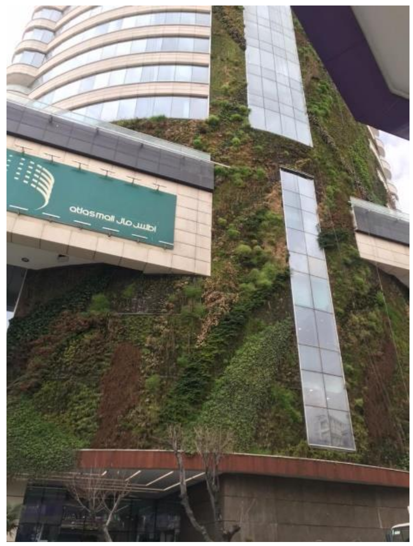


Fig 2.75 Living wall in commercial building of Atlas mall by Patric Blanc, Tehran

Increased internal comfort as a result of thermal comfort can be considered in the category of indirect benefits of green walls. Also, extending the building's life span due to the longer durability of the materials used, which is covered by a layer of plants, reduces the maintenance costs of the building according to (Perini & Magliocco, 2012). VGS improves the visual, aesthetic, and social aspects of the urban area, which significantly impacts the economic value of a building and a neighborhood. Additionally, indoor comfort as a result of reduced noise levels in the surroundings is linked to real state value (Wisten et al., 2012).

Increase Real state value

Vertical green also increases the building's real estate value (Ichihara, & Cohen, 2011) according to specific areas of the local real estate market. Several authors evaluate the increase in value due to the presence of a green wall (Hunt, 2008). Des Rosiers et al. (2002) estimate that hedges or green walls increase property values by 3.9%. A scientific article by (Veisten et al., 2012) evaluated market prospects in Toronto, where herbal measures increase property by 6-15%, with a midpoint of 10.5. "The cost-benefit analysis of the Green Wall shows that this measure is economically promising when assessing the attenuation of noise reduction in a quieter area and adding value to the welfare/beauty of the Green Wall" (Veisten et al., 2012).

Increased durability

VGS can reduce the demolition and erosion of the building surface and improve durability aspects rather than being exposed to ultraviolet radiation (Wong et al., 2009). High durability affects the cost of repair and replacement of materials. Also, plants help reduce internal stresses in building materials by lowering daily temperature fluctuations, leading to cracking and deterioration of materials. On severe days, the temperature of the exposed façade can vary between 10 ° C and 60 ° C, while the temperature of the vegetated façade fluctuates only between 5 ° C and 30 ° C (Minke, 1985). VGS could extend the life of existing facades by using waterproof panels and separating the layer by air, as this can protect the building from wind, sunlight, causes moisture to escape rain (Hogg, 2010), also helps reduce expansion and contraction of building materials (Wong et al., 2010). Adds: "By limiting the daily fluctuation of wall surface temperature, the life of the building facade is extended, slows wear and tear, as well as saves on maintenance and replacement costs." by increasing the durability of some building components, such as plaster facades (Perini & Rosasco, 2013).

2.4.2 Social and aesthetic value

Apart from the ecological value of VGS (Hunter et al., 2014; Wonget al., 2010), many studies have also pointed to the benefits of beauty, which may also serve as public art to increase interest in beauty in public spaces with visual relaxation (Bakar et al., 2014). Plant walls are also promoted because they are aesthetically pleasing. most people effectively prefer a building with integrated vegetation (White & Guttersleben, 2011).

Fig 2.76 Aesthetic value of living wall, Credit by Vertico company

Green can improve visual and aesthetic value, positively affecting economic value (Mill et al., 2016). Visual criteria mainly include four aspects: interest in winter or dormant season, flowering, diverse form, and foliage of greenery (Dunnett & Kingsbury, 2004). The number of experimental studies evaluating the visual effect of VGS is increasing. An experimental study by (Meral et al., 2018) shows how people evaluate living walls about their visual perception of parameters, such as biodiversity, beauty, color, complexity, application, value, naturalness, plant diversity. Light, the number of species, size, and colorful design better aesthetics may help market a project and provide a space (S. M. Sheweka & Mohamed, 2012). in public buildings such as hotels, shopping malls is one of the decorative factors that has attracted more customers, which indirectly contributes to its economic growth. Plants used for vertical green are most likely hardwood species to regulate sunlight during cooling and heating periods, as well as the beauty pleasure (Wang et al., 2020).

Well-being

Greening impacts psychological health (Van Herzele & De Vries, 2012). If people live in areas without "green" components, they are more likely to suffer from several medical and psychological problems. In addition, air filtration and the ability of plants to oxygenate can be significantly beneficial for people suffering from respiratory diseases caused by urban pollution such as asthma and allergies (Pack, 1999).

Fig 2.77 Enhancing quality of life through living wall, Credit by Livewall company

The use of a vertical plant wall reduces indoor surface temperature and thus increases indoor thermal comfort (Papadakis et al. 2001). optimal outdoor temperatures and humidity contribute to human well-being (Statopoulos et al., 2004). greening can be an effective strategy to reduce heat stress indoors until the plants are sufficiently irrigated (Hoelscher et al., 2016). "Herbs give beauty uninterruptedly and providing a more comfortable living and working environment has also been proven that visual and physical contact with plants can lead to direct health benefits" (Pérez-Urrestarazu et al., 2017).

Plants can produce restorative effects that reduce stress and improve work productivity (Sheweka & Magdy, 2011). Geotextile living walls influence aesthetic value in an urban environment, improve human health and mental health, strengthen public spaces, add identity to a building (Magliocco& Perini, 2015). In contrast, the benefits of psychology are rarely considered scientifically. In terms of social benefits, herbs can help patients recover from slowing down, lowering occupant blood pressure, and improving work productivity (Khan et al., 2016), thus increasing individuals' physical and mental health. In terms of aesthetic benefits, the combination of green space helps create visual interest, hide unpleasant features, and increase the property's value (Wang et al., 2016).

References

Books

Hopkins, G., & Goodwin, C. (2011). *Living architecture: Green roofs and walls*. Csiro Publishing.

Putz, J. (1991). *The biology of vines*. Cambridge University Press.

Givoni, B. (1998). *Climate considerations in building and urban design*. John Wiley & Sons.

Kingsbury, N., & Kingsbury, N. (2004). *Planting green roofs and living walls*. Timber Press.

Papers

Hunter, A. M., Williams, N. S., Rayner, J. P., Aye, L., Hes, D., & Livesley, S. J. (2014). Quantifying the thermal performance of green façades: A critical review. *Ecological Engineering*, *63*, 102-113.

Manso, M., & Castro-Gomes, J. (2015). Green wall systems: A review of their characteristics. *Renewable and sustainable energy reviews*, *41*, 863-871.

Jim, C. Y. (2015). Greenwall classification and critical design-management assessments. *Ecological Engineering*, *77*, 348-362.

Köhler, M. (2008). Green facades—a view back and some visions. *Urban Ecosystems*, *11*(4), 423-436.

Susorova, I., Angulo, M., Bahrami, P., & Stephens, B. (2013). A model of vegetated exterior facades for evaluation of wall thermal performance. *Building and Environment*, *67*, 1-13.

Perini, K., Ottelé, M., Haas, E. M., & Raiteri, R. (2013). Vertical greening systems, a process tree for green façades and living walls. *Urban Ecosystems*, *16*(2), 265-277.

Natarajan, M., Rahimi, M., Sen, S., Mackenzie, N., & Imanbayev, Y. (2015). Living wall systems: evaluating life-cycle energy, water and carbon impacts. *Urban ecosystems*, *18*(1), 1-11.

Sheweka, S. M., & Mohamed, N. M. (2012). Green facades as a new sustainable approach towards climate change. *Energy Procedia*, *18*, 507-520.

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

Perez, G., Rincon, L., Vila, A., Gonzalez, J. M., & Cabeza, L. F. (2011). Green vertical systems for buildings as passive systems for energy savings. *Applied energy*, *88*(12), 4854-4859.

Websites

https://www.ansgroupglobal.com/
https://florafelt.com/
https://www.verdtical.com/
https://greenscreen.com/
https://jakob.co.uk/solutions/view/green-walls/
https://www.ambius.com/green-walls
https://www.iotagarden.com/
https://elmich.com/asia/products/vgm-greenwall/
https://higreenwall.com/
https://www.sempergreen.com/en/solutions/living-wall
https://livewall.com/
www.iea.org/statistics
https://www.iea.org/efficiency2019/
European Environment Agency, 2015
https://ec.europa.eu

CHAPTER3. PROPOSAL FOR A VGS INTEGRATED DESIGN APPROACH

Introduction

By urbanization growth, human beings accelerate urban warming (oke, 1999) impacting total energy consumption and peak electricity demand in the residential sector (Santamouris et al., 2001). Already VGS is a plant-based solution that can decrease the harmful effects of UHI. Although due to the infancy of this technology is deal with challenges like high Costs (Riley, 2017), maintenance needs (Pérez et al., 2014; Chew et al., 2017), low fire safety (Lau et al., 2016), installation, insufficient financial and energy payback period (Irga et al., 2017; Bustami et al., 2018). In the case of double-skin green facades, the key drawbacks of applying plants are maintenance and difficulties of transmitted light control (Stec et al., 2005). By systematic review, available papers on VGS conclude that among the main drawbacks of VGS are cost and maintenance, even if VGS has a strong potential to be incorporated into future construction projects. Recent studies have shown that green facades and living walls can reduce the effect of urban heat islands (UHI) by creating a microclimate (Scarpa et al., 2014).

One of the most important goals is to decrease energy consumption and overcome global warming's destructive environmental impact. Green building systems such as VGS play a significant role in improving environmental conditions in dense urban areas (Sheweka & Magdy, 2011). It has made significant technological advances in recent years and has been welcomed. However, there is no technical standard for VGS design (Tedesco et al., 2016). It is necessary to provide a technical standard and standardize the design process with all aspects in mind and emphasize a multi-criteria design approach (Assimakopoulos et al., 2020). Because it is a technical structure and environmental, social, and economic factors are involved in it. Lack of standardization can reverse the performance of the green wall and cause environmental degradation.

A complete standard for VGS is still a decade away (Riley, 2017). The use of plant designed and managed can be a valuable tool for passive thermal control of buildings and save energy (Sheweka & Mohamed, 2012). Therefore, low maintenance needs can also make it easier to sustain and reduce the overall costs of the green system. Also, selecting and designing an irrigation system based on careful study and considering all the practical factors can provide a more efficient and cost-effective greening system.

3.1 Green walls challenges

High cost

The biggest drawbacks of VG are their high cost and the most significant factor hindering living wall proliferation (Riley, 2017) which includes the price of installation, design, maintenance, and eventual disposal. While there have been many research approaches to prove the environmental benefits of the green envelope, information on economic sustainability is still scarce (Othman & Sahidin, 2016). The cost of various kinds of VGS depends on the façade surface and height, location, connections (Perini et al., 2011). According to the cost-benefit evaluation by (Perini & Rosasco, 2013), the results prove that not all types of VGS are economically viable.

Life cycle cost (LCC) is a logical method influencing the decision toVGS adoptation. In addition to VGS components, three main categories of duplicate cost components cover all processes throughout VGS support agents' lives: workforce, equipment, and applications (Huang et al., 2019). Factors that commonly affect LCCA include discount rates, inflation rates, green system longevity, and plant selection (Fuller, 2016). Usually, People think that VGS installation and

maintenance is more expensive than whitout greening (Wong et al., 2010c), which precludes VGS approval.
Direct green facades are sustainable, and an indirect green facade made of an HPDE mesh or a steel mesh as a supporter may be considered economically viable. The living walls based on a mat containing an aggregate mix and composed of two layers of geotextile analyzed. It does not show a sustainable rate from an economic view; due to high installation costs after initial costs, the yearly advantages outweigh the annual expenses (Perini and Rosasco, 2013). Similarly, cost analysis by (Meral et al., 2018) indicates that the most expensive forms of VGS are living walls. "Considering the costs of two wall schemes, it was found that a green facade could be built with around 12.01 of the cost of living walls (Meral et al., 2018). An outline of the cost/benefit of the living walls revealed that "considering the local walls, they have a longer payback period of 17 years, unsubsidized UAE energy prices." (Haggag & Hassan, 2015). LCA and CBA applied to VGS have shown that direct green façades are preferred for their lifetime preservation, whereas modular living walls effectively save energy. Compared to indirect green façades and modular living walls, felt layers are less eco-friendly and durable, primarily because of the material used (Feng& Hewage, 2014).

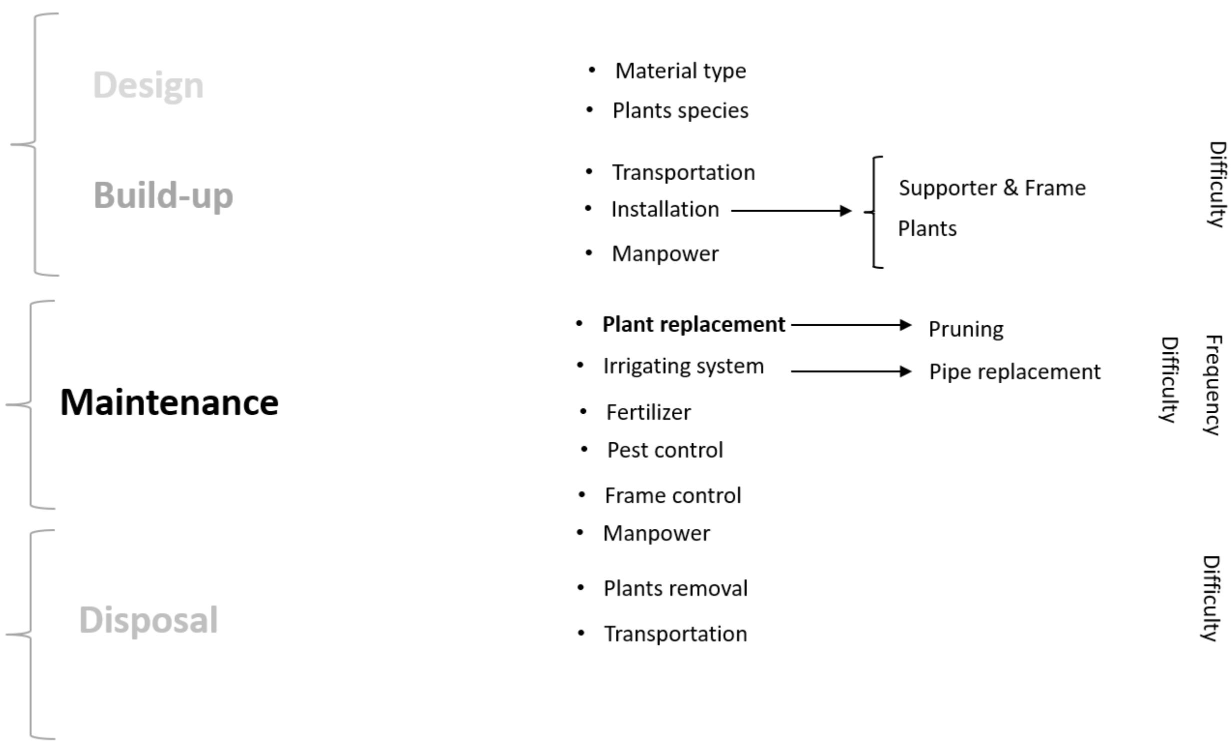


Fig 3.1 The main costs of VGS based on (Perini & Rosasco, 2013; Huang et al. 2019)

The phase of operations and repairs had the most impact on a VGS's LCC (73.7-83.9 percent). Although plant-related metrics, such as plant replacement rate and expense, have the greatest impact on LCC variances, the LCC of VGS can be offset by building energy cost savings within 30 years for the support system, but not for the other two systems (Huang et al., 2019). Irrigation has also been identified as the main cost-contributing factor (Natarajan et al., 2015).
Due to the need for long-term maintenance and the resulting costs this design solution is only welcomed by the affluent. Because it is unnecessary or incapable of paying the extra costs for the underprivileged, in line with the importance of greenery reducing the negative effects of global

warming. Especially in developing countries that have a role in increasing global warming simultaneously, green walls are not economically viable because of low levels of welfare and living standards. Convincing people to pay for long-term maintenance costs several times their installation (Veisten et al., 2012) is the main challenge. Therefore, on the one hand, designing and introducing more economical models and on the other hand, choosing the proper VGS among the examples in the market which are economically sustainable and also efficiency can help to make wide use of this strategy and public acceptance to enhance the environmental condition of dense cities. Otherwise, it will remain limited to decorative elements and only in luxury buildings, including hotels, commercial buildings, and leisure centers.

(Perini & Rosasco, 2013; Mårtensson et al., 2014) recommended using seasonal and native plants, decreased maintenance needs of plant replacement, and watering demand for living walls to reduce the overall cost. Also, (Perini & Rosasco, 2013) suggested that reducing the initial costs through subsidies from the government in the types of discounts for taxes contributes to reducing the total price. The energy payback period and carbon footprint can be minimized if optimally designed to avoid overwatering of plants, which may be supplemented further with drip irrigation, drought-tolerant plants, a rainwater harvesting system, and irrigation without a pumping system (Natarajan et al., 2015). However, advanced VGS testing approaches are planned to be more cost-effective, with the goal of using recyclable and renewable materials (Urrestarazu& Burés., 2012).

Dependency on long term maintenance by experts

The difficulty of long-term maintenance requirements is a fundamental challenge to establishing VGS in various parts of society (Pérez et al., 2014). By examining the existing green walls design process, most of them are designed for maintenance based on the specialists. Users only have the role of using. This reliance on skilled labor, especially in residential areas, can affect users' privacy and extra costs. Simultaneously, the lack of access to specialists in sensitive situations can affect the green wall's life span.

A model of citizen protection such as 'Adaptive Citizen Science' is required. Study Model 'proposed for residential by (Cooper et al., 2007) nested scales of operation from local to international are included in this (Fine to broad) comprising individuals, groups of the society, and skilled people. Their activities include the ecological selection of both sociological evidence and integrated habitat conservation. Educating the inhabitants of buildings on energy efficiency optimization is also essential, and this applies to all passive devices for ventilation, including VGS (Ascione, 2017).

Varying by climate condition

One of the biggest challenges of VGS is the inability to unify patterns, which means that due to the deep dependence of green walls on two climatic factors and plants, patterns change from region to region and from building to building. Therefore, there is a need to design water supply systems for each building, taking into account all the conditions. It created and paid attention to the orientation of the VGS, the amount and shape of the windows, the protrusions and indentations of the facade, and the height that plays an influential role in the type of water supply and maintenance system adds to the difficulty of greenery. Only by introducing the more common typologies of green walls this problem can be overcome to some extent. For example, classification should be based on the percentage of green cover, orientation, short-range, medium-high, and high-rise in terms of physical characteristics of the building and considering climatic characteristics, high rainfall, medium and low rainfall, harsh weather conditions during the year high, medium and low hardness. Defining green wall patterns according to the mentioned divisions can help to uniformize the patterns. It is important to analyze the design of passive cooling systems carefully, what has performed well in one climatic condition will not provide the same advantages in a different climate (Ascione, 2017). Furthermore, plant development in local climatic conditions must be kept in mind since plants grow in local climatic conditions. Final findings can vary dramatically from one climate zone to another (Pérez et al., 2011). However, VGS capacity and scale of advantages are not quite the same for all climates and building styles (Hunter et al., 2014). By systematically seeking opportunities for incorporating green façade testing experiments into the construction of new buildings and retrofits, the problem of lack of accurate replication can be solved (Felson & Pickett, 2005).

High water demand

Water demand of different VGS is varied, which contributes to changing evapotranspiration amount. It can directly affect the thermal behavior and the principal cooling load reduction in the summertime. In several countries, where desalination is the most common source of sweet water, water is a limited resource. The direct (cooling load reduction) and indirect (outdoor thermal comfort enhancement) advantages of irrigated urban greening must be carefully measured against the cost/energy/emissions processed of water used to irrigate the vegetation (Afshari, 2017). Even so, plants must have minimum water requirements (e.g., use of native plants), conform to local exposure conditions (e.g., sun, semi-shade, or shade) and environmental conditions in order to achieve sustainability targets (e.g., wind, rainfall, heat, drought, and frost) (Manso, 2015). one of the available types, especially living walls, are not environmentally sustainable due to the high-water needs. The importance of this issue becomes more prominent in the areas facing the water crisis. Therefore, in terms of its life cycle efficiency, a living wall system with low water consumption is always preferred (Natarajan et al., 2015). Some approaches, such as rainwater recovery, controlling the collection of water source level, time, and weather conditions. also reusing greywater, are already implemented in living walls to minimize water consumption even though plant selection plays a more substantial role in reducing water demand.

Dynamic system

This strategy is alive and dynamic since plants are the main component of VGS. It is possible to divide the entire system into biotic and abiotic sections. With the plant's physical and chemical shifts arising from climate change, nutrient requirements, demand for water, and soil products may be affected. One of the influential variables in its thermal activity is that the shape of the plant leaf can influence the thermal performance of VGS throughout the Life Cycle (Dunnett and Kingsbury, 2008; Ottelé et al., 2011).

Depending on time

The efficiency of green facades depends on time, and it takes several years to have a cooling effect on the whole wall. The reason is the time it takes for the plants to grow and cover the entire facade. While in living walls from the beginning of the installation, planting plants already have a good performance throughout the wall.

A study prove that The payback time considering costs and benefits can be assessed and accounted for direct green façades 16 to 25 years, indirect green façades 16–42 years, and over 50 years for modular living walls (Beecham et al., 2018).

Destructive environmental effects

Since VGS is part of a sustainable approach, they must provide social, economic, and environmental sustainability. Although this solution can mitigate the negative effects of global warming, the ratio of environmental benefits to social and economic harms can show whether the designed green wall can be sustainable. As mentioned earlier, VGSs are composed of biotic and abiotic members. Abiotic includes plants, and abiotic includes structure, water supply system, and other non-living components. The variety of existing systems and the types of materials used in them produce different environmental burden amounts. A comparison of the benefits and its environmental burden can be a good measure of its sustainability. For example, the use of some plastic as a planter box, although it can expand greenery, the negligence and use of non-recyclable plastics can have a devastating effect on the environment. Clearly, it is one of the main obstacles to sustainable development.

A study performed by (Ottelé, 2011) examined the life cycle of the direct and indirect green façade, living wall dependent on the planter, and geotextile in both Mediterranean and temperate climates. It is shown that the most considerable amount of environmental burden in the living wall of the felt base is due to the materials used. In contrast to low maintenance requirements, the direct green façades have a low environmental burden because it is made of only biotic members (Perini et al. 2011; Manso and Castro-Gomes 2015). Therefore, evaluating the efficiency of the VGS, considering the recyclability and reusable material, is an essential part of environmental sustainability. Any of the issues surrounding VGS should be addressed, such as the high cost of initial and maintenance, unsustainable components, intricate design, and a low life span (Riley, 2017). Many kinds of materials, such as various kinds of wood, aluminum, plastic the steel used in indirect green facades as a climbing supporter instead of stainless-steel mesh. These materials can cause the system's environmental burden to be nearly ten times smaller than stainless-steel mesh (Ottelé et al., 2011). New recycled material known as Geogreen is applied in the modular living wall and shows the cooling advantage (Manso & Castro-Gomes, 2016).

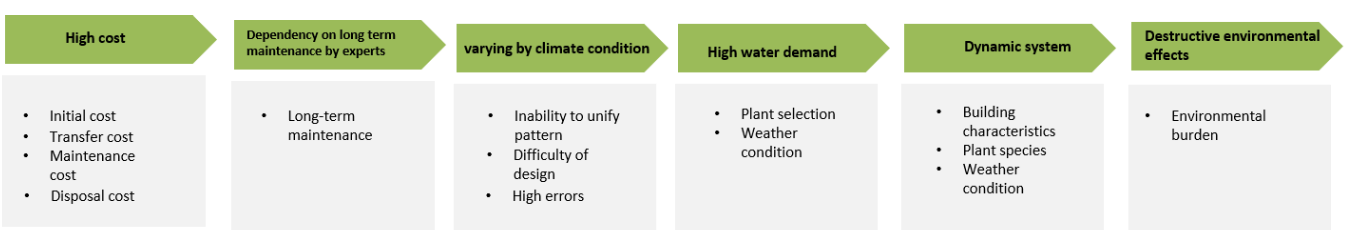


Fig 3.2 Most common drawbacks of VGS

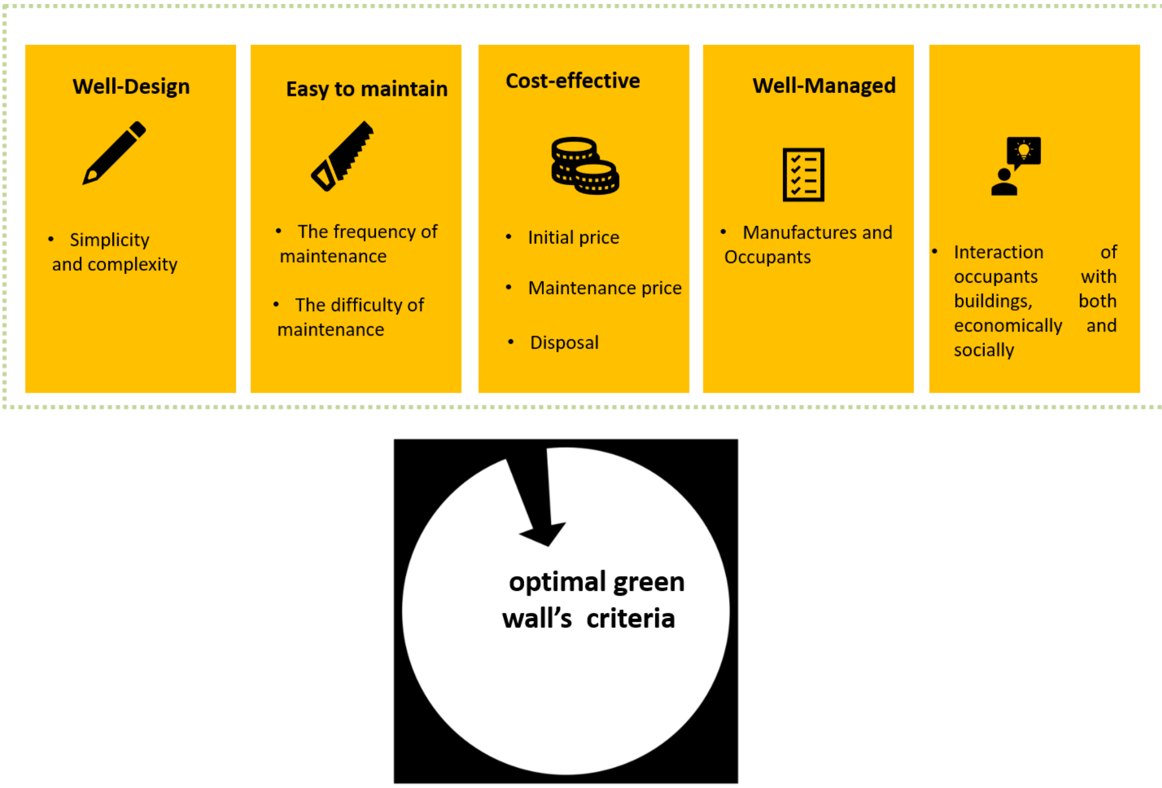


Fig 3.3 Criteria of desire green wall from occupants and architects' point of view

3.2 Why Vertical Greening Integrated approach?

Greenery today is not a choice but a necessity that should be taken out of the decorative and luxury elements and be implemented in more buildings. Especially in residential buildings that have a significant share in the consumption of fossil fuels. The environmental and economic benefits of VGS are not widely agreed. It demonstrates the need to boost public understanding of these environmental and economic advantages systems to increase the people's tendency to install VGS not only for their aesthetic views (Safikhani et al., 2014).

it can be concluded that finding an acceptable model for users (economic considerations) and having an adequate environmental impact to reduce energy consumption is essential. The fundamental question that comes to mind is to overcome the harmful effects of global warming vegetated facades as an effective large-scale strategy, whether more complicated VGS in a small number has the same effect by comparison with moderate VGS, but in large number? What is the effect of comparing the quantity and quality of VGS to combat the Urban Heat Island effect? More complex vertical gardens mean a green wall

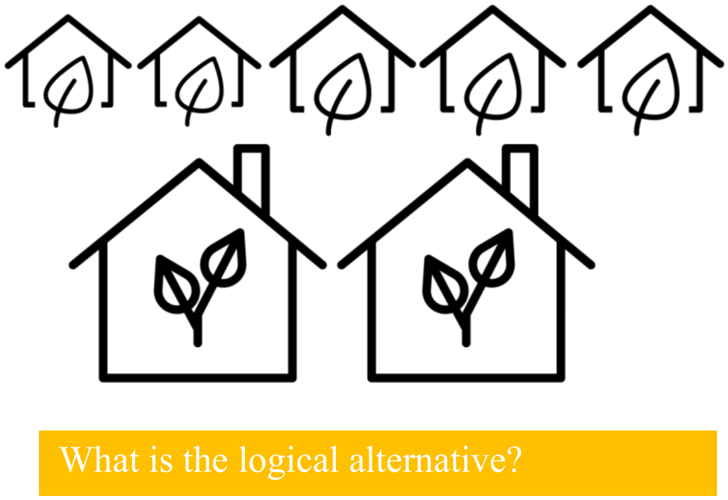


Fig 3.4 Comparing the effect of VGS quantity and quality

containing a large number of plant species and high biodiversity. It requires a more complicated maintenance system and includes a higher maintenance cost than a green wall with a more limited plant species. Moreover, the maintenance system is more straightforward. It seems that, in addition to quality, quantity plays a significant role in the success of this strategy on an urban scale. The beneficial impact of plants on reducing the urban heat island phenomena is only noticeable if there is a large area of the same area is green (e.g., gardens, parks, many green facades) (Onishi et al., 2010). Also, (Assimakopoulos et al., 2020) believe that VGS may be used as a mitigating consequence of the UHI effects if this approach become widespread in the urban area, (Bass & Baskaran, 2003) and explored the potential of rooftop gardens and VGS. Both technologies lowered surface temperatures enough to indicate that considerable reductions in UHI effects would be feasible if they were used on an everyday basis.

This study proposes the integrated approach that divides the entire life cycle of the VGS into six phases: **pre-design**, **design**, **build-up**, **maintenance**, **monitoring**, and **disposal**. In each phase, by extracting factors, it is vital to try better to understand the system's performance in detail. At the same time, it shows that there is a relationship between these phases at different levels. By addressing all of the important factors and considering these connections from the beginning of design and construction, the project can reduce the risk of VGS death and create a more cost-effective system with higher performance. It would be interesting to discuss the interconnected elements of the system and how they measure both cost and efficiency. As (Bustami et al., 2019) pointed out that research into VGSs will be highly multidisciplinary. By integrating architects, engineers, urban planners, plant biologists, horticulturists, and soil scientists in these "planned experiments," aesthetic and functional design objectives may be achieved. (Hunter et al., 2014) while also allowing rigorous research with adequate replication (Felson & Pickett, 2005). The process of producing a VGS consists of several phases. Part of the production process includes an analytical and technical vision, and the part requires both of them. Although this process is generally known as a technical operation, the analysis part is important and necessary. Ignoring the importance of the analytical step exacerbates the problems and increases the likelihood of an error occurring during the vertical garden run. For example, the central role of economic factors (in the pre-design step) requires analysis and the design phase cannot proceed only from a technical point of view. Having analysis along with technology can be a way to overcome the existing challenges of the green wall.

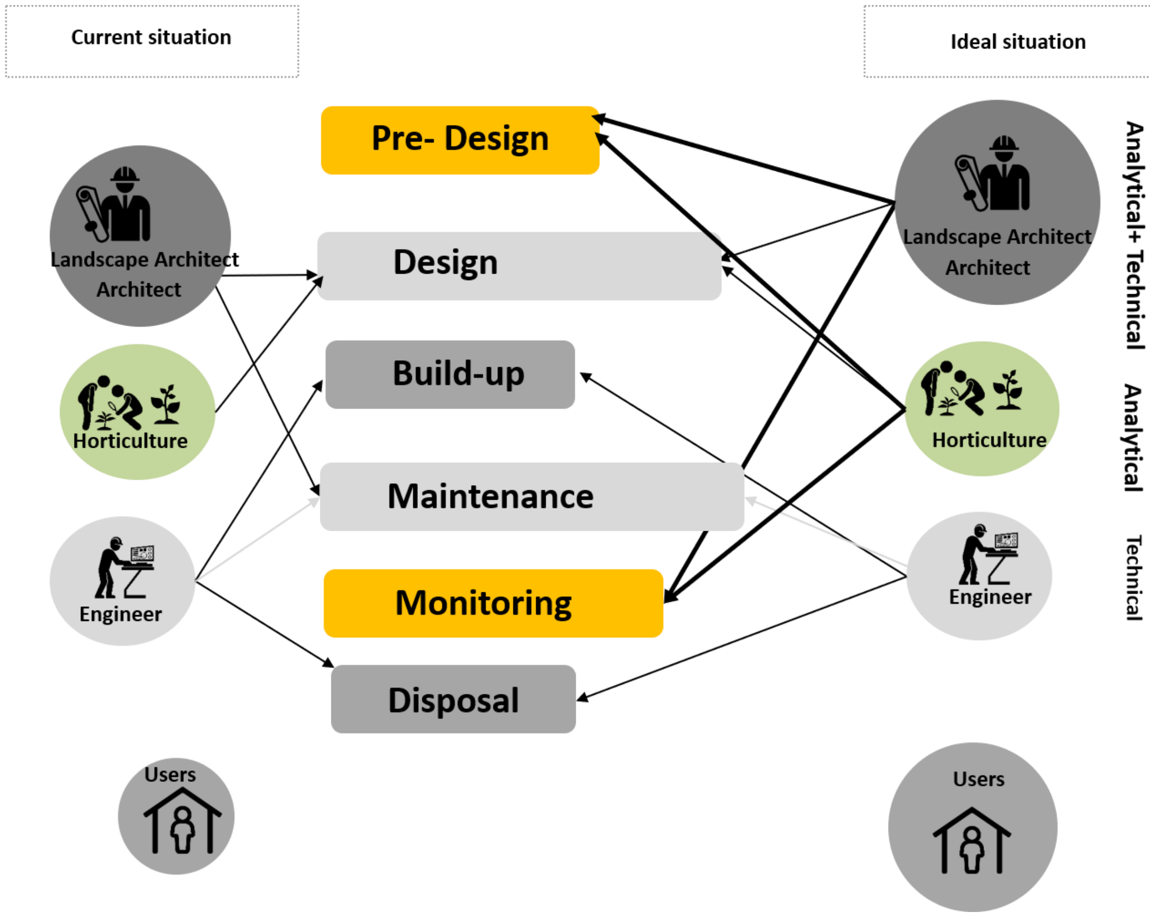


Fig 3.5 The schematic role of disciplines to provide vertical greening integrated systems

Standardization in design and construction can help the green walls succeed and reduce the risk of error because it has been done systematically and accurately. It is noteworthy that the manufacturers of green walls are now designing each based on their program, which sometimes ignores factors that can significantly affect the environmental performance and economic efficiency. Therefore, this approach can take a practical step in standardizing vertical greening' system design and production and, consequently, increasing sustainability.

It would also increase confidence in living wall production and establish a baseline for all green wall companies to adhere (Thomsit-Ireland, 2019). Designing, build-up, and maintaining throughout life requires a systematic approach and process because otherwise, it is more or less a matter of taste based on the builders' tastes. Examining the manufacturing process and construction the lack of a universal standard that can be used by all companies in all regional areas has raised the number of failures, resulting in systems that do not apply to the broader populace. It is necessary to set a standard that includes technical standards (structural requirements, maintenance, implementation) and non-technical (social, economic) that can be used in all types of green building systems. All stages in the life span of the green wall from pre-design to disposal should be considered. Identifying the most critical variables at each point, as well as the degree to which they are linked to one another will provide a baseline for manufacturing firms. It eliminates green framework failures before the plan's execution and, at the same time, aims to make the green wall's implementation more cost-effective, which is one of the main obstacles to public acceptance.

This approach will recognize the defects in the existing design process and recommend a solution, makes the VGS process more cost-effective, easier to maintain, technical with the lowest errors, more prevalent, and efficient. In addition, a technical standard, including criteria such as construction requirements, plant types, wall suitability, reinforcement methods, and typical plant irrigation volumes, significantly alongside that. Also, management requirements (pruning frequency and methods, pest and disease management) would increase confidence in living walls and provide a baseline for all living wall companies to follow.

3.3 Vertical Greening Integrated (VGIS) approach

This approach process consists of six phases: Pre-design, Design, Build up, Maintenance, Monitoring, and Disposal. Pre-design and monitoring are two new phases proposed, and the necessity will be explained in this chapter. Each phase is composed of various factors with different levels of value. Four types of relationships between criteria can be evaluated to address the relation between them, from strongest to weakest ones. While there is a connection between the phases in the mentioned degrees, sometimes the connections within the phase are also seen at different levels. The same division can be adopted in inter-phase communication. On the other hand, the whole green system can be divided into biotic and abiotic systems that the biotic part generally influences the factors located in the abiotic ones.

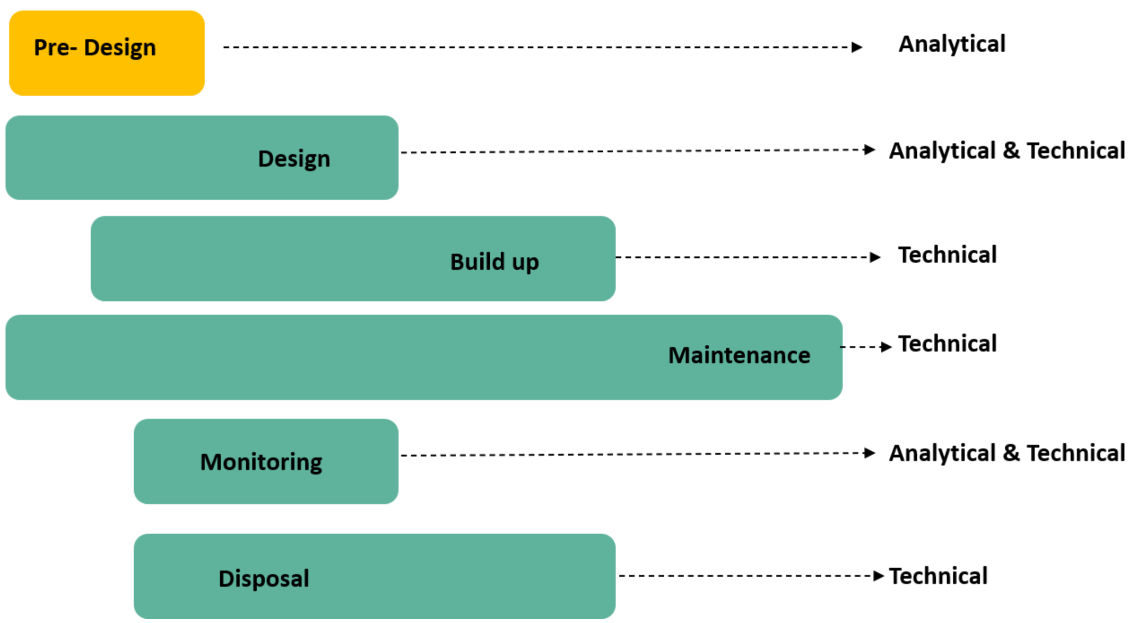


Fig 3.6 VGIS approach considering overlapping the phases and their connections

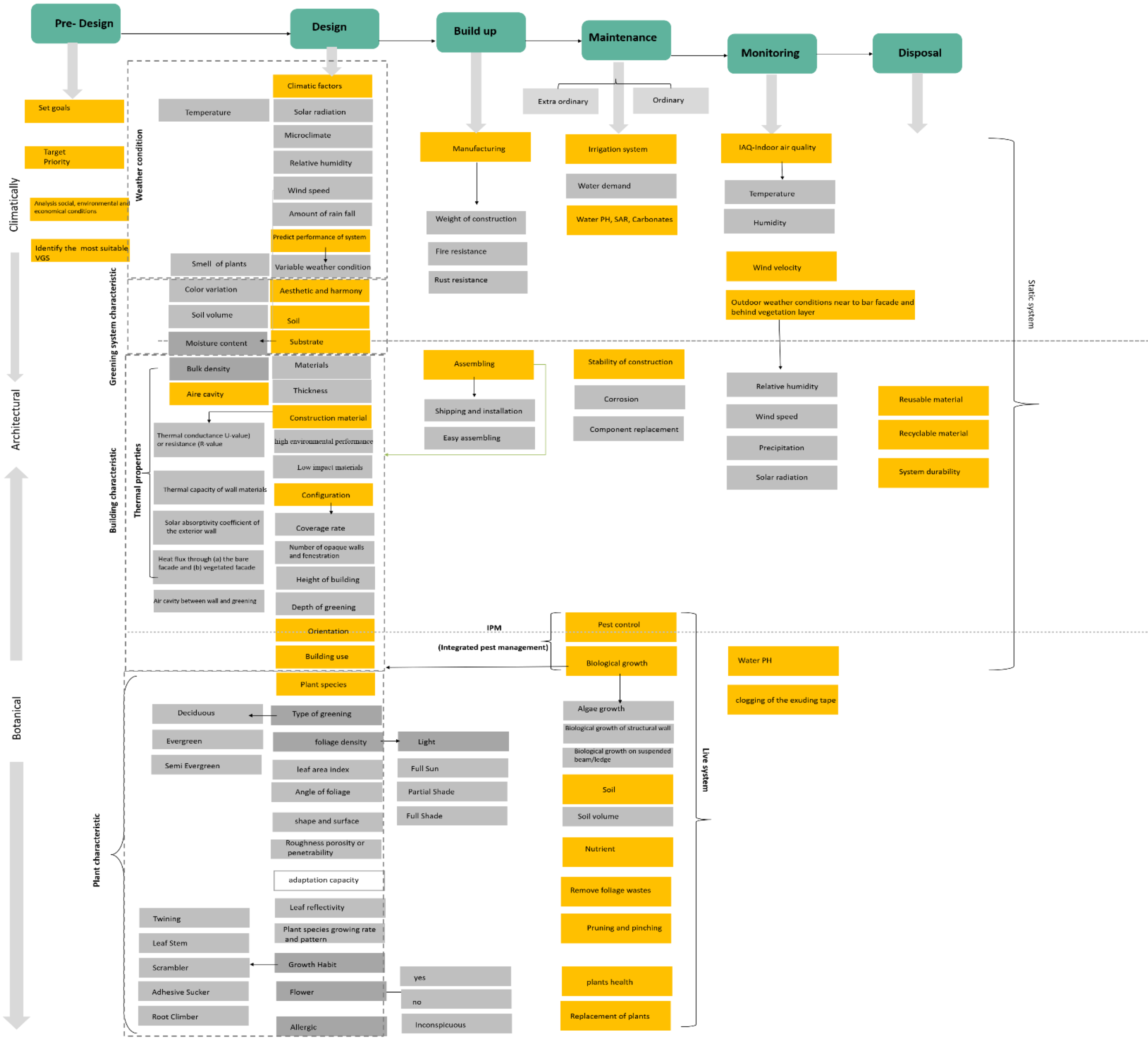


Fig 3.7 VGIS approach description by addressing phases and criterion

3.3.1 Pre-Design Phase

The pre-design phase analyzes and evaluates the objectives and prioritizes them based on examining the project's existing potentials and the project platform from an economic, social, and environmental perspective. At this stage, the critical question is to determine the purpose of the VGIS and estimate the expected results. As (Dahanayake & Chow, 2017) pointed out, appropriate plant types, taking into account fire safety, maintenance criteria, and environmental conditions, should be included in VGS based on the design objective. According to the different benefits of vertical gardens, the desired building site's expected priorities are analyzed and considered. Then assess the potential of the existing project to achieve the results and goals. Based on these studies, the most appropriate green system is selected, and the design phase starts.

Greening a building's envelope with living walls is a practical design method for new construction and retrofitting (Perini, 2012). Greening in existing and future buildings follows a different process. Landscaping of existing buildings involves a more complicated and challenging process as there are more restrictions on VGS design. On the one hand, the proper location of structures and maintenance equipment should be found. On the other hand, designers face difficulties in choosing the type of green system that applies to the building due to the size, height, orientation of facades and the proportion and the form of openings.

The choice to make the green wall type more suited for a specific project would depend not only on the design and climate factors but also on the effect of its elements on the atmosphere and the related costs over its life cycle (Manso & Castro-Gomes, 2015). Because of the pre-design process, studies and analyzes social and economic influences, which are among the most critical barriers to VGS growth today, this approach can be applied to a broader building field. Buildings of varying social class, as in general, differ in the level of technologies used in green walls. That can produce a set of patterns.

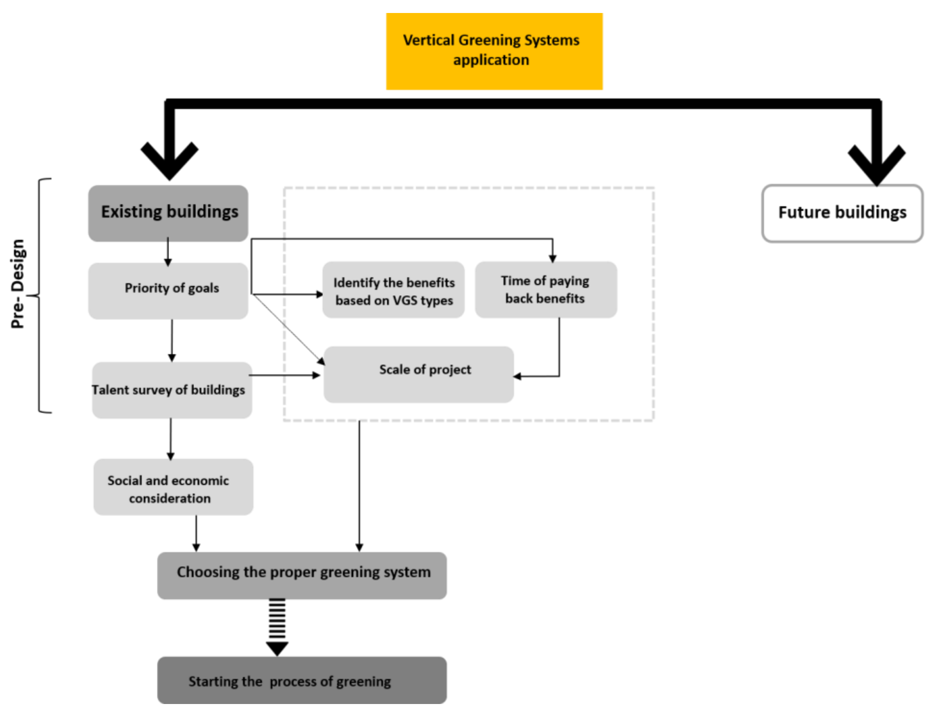


Fig 3.8 VGS application in future and existing buildings

Goal setting and prioritizing goals

The intended results of a VGS should be established, as mentioned in Chapter 2 on the advantages of VGS, which include environmental, ecological, health, economic, and the relationship between them. The advantages of VGS are basically, it's about saving energy for heating. and air conditioning, improving real estate value (or rent), and durability (Perini & Rosasco, 2013), benefits related to the larger scale include improving air quality and biodiversity and mitigating it to the Urban Heat Islands effect (Köhler, 2008; Onishi et al., 2010). Although VGS are multifunctional, each greening system (depending on the type, including the green facade and the living wall, the structure, and the types of plants used) can fulfill one of the benefits discussed. Therefore, there is one primary objective and several secondary objectives in the creation of VGS. They can be set based on the project's environmental and physical, and geometric characteristics, height, social and economic characteristics of the projected context. Accordingly, start designing and implementing the greening system considering plant selection. Separation is according to the scale of execution, determining the expected benefits on a scale, and setting project goals, and prioritizing goals accordingly. On the other hand, although one of the benefits of VGS is the reduction of noise pollution, it is usually not considered the primary purpose, especially in residential buildings, because it may be possible to solve this problem at a lower cost.

The types of ferns that grow on the living wall are investigated. However, they play an essential role in remove VOCs (Volatile organic compound) (e.g., Formaldehyde) but are not considered as good PM filters (Weerakkody et al., 2017). According to a study conducted by Perini et al., Waxy leaves such as (T. jasminoides) catch a significant level of the particle from the atmosphere. In contrast, Hairy leaves (P. fruticosa) have less effectiveness (Perini et al., 2017). As a result of selecting plants based on the principal and the primary aim of VGS, the designer can find the most proper plants and make a more efficient greening system. Besides, the Ivy plant (Hedera helix) can only be used for green facades and can absorb fine dust on its leaf surface considerably better than other plants. It can serve as an air cleaner by washing the leaves with moisture during rainy weather (Reznik & Schmidt, 2009). plants with large leaves have a lower PM capture potential than plants with smaller leaves (Beckett et al., 2000; Weerakkody et al., 2017). However, plants with higher foliage perform better in reducing cooling load by a green wall. Living walls and green roofs would reduce the town's air emissions While, Parks, street trees, and heavy green roofs are more successful (Hiemstra & Hop, 2012). Living walls as a suitable concept alone are not useful for reducing air pollution in dense urban areas. choosing the right green concept as the primary goal is achieved by recognizing these benefits. Set the goals and design based on expected results can conduct the designer in the right way. Contrary to popular belief, the presence of any greenery is not sufficient for reducing air pollution.

Specify the scale of project implementation

For proposing and designing green walls, scale is a crucial aspect. Benefits derived from VGS can be are linked to a variety of scales; their impacts on district or city scale; some function precisely on the building scale (Dunnet N, Kingsbury, 2008; Kohler, 2008; Perini & Rosasco, 2013; Wood et al., 2014). It seems that residential buildings can be considered on a specific scale due to their frequency, importance, and high energy consumption. So, with sufficient knowledge of the expected advantages that can be achieved at different scales, reasonable prioritization of green wall design goals depends on the scale of implementation. Definitely, residential scale is a subcategory of the neighborhood, and both of them are part of the urban scale. Thus, changes in the residential scale can influence urban scale.

Fig 3.9 Various scales of applying the Greening systems

Talent identification

To determine the suitability of planting, attainable soil volume, sun orientation, drainage, water availability, and limited climates, an inventory should be study before and after the project implementation. It will also help specify the right choice of plant material because plants do not respond to each of these variables equally. In order to find the talent of the existing buildings for the VGS instalation, It is important to research the environmental requirements as well as the project's potential.

Location and climate conditions are primary considerations that are used in the design process (Sudimac et al., 2019). To optimize the greenery advantages, it is advised to take deeper note of plant selection aligned with building architecture and local environment (Dahanayake & Chow, 2017). Identifying existing buildings to measure their potential for installing green walls and prioritizing goals can also help designers choose the right green wall (Radić et al., 2019), by examining the empirical and descriptive data, expresses the benefits of the green wall and links these benefits based on the VGS types included (green facade and living wall). Researchers have studied the diversity of the green walls due to structural differences. Although many studies have examined the various benefits, they are mostly descriptive and have not been measured (Loh, 2008). A small number of researches have investigated analytically and quantified (Hunter et al., 2014).

The lack of quantified studies of green wall's benefits and emphasize extra studied to evaluate the amount of influence of various plants on PM (Particulate Meter) (Ottelé et al., 2011). The previous studies have only tested the Hedera Helix (Sternberg et al., 2010). A significant lack of research in analyzing the relationship between the type and the characteristic of the VGS and its benefits concluded. However, based on these analytical and experimental studies, architects and designers can obtain more information about the kind and details (which type of support system, type of soil, and plant species) in which climate can be applied as the most suitable solution design (Radić et al., 2019). Besides, buildings with deep shad cannot provide the required light, and with low weight loading capacity usually brings more limitations. Sometimes attaching the green walls to existing buildings are not only efficient but also is expensive. For example, tall buildings with restricted access require more types of equipment to make this device more expensive. Also, considering local laws and the typology of buildings is essential. It brings new forms, methods of building, and limitations. There is no possibility of making all facades green aiming at environmental benefits, although it is possible to implement the majority of the façade green just for aesthetic pleasure.

3.3.2 Design

The design is a key stage in the life cycle of the VGS (Chew et al., 2017) because the most effective decisions are taken at this stage. As mentioned in the section on reviewing VGS classification, the first challenge is choosing the type of greening systems (green facade, living wall) and then deciding about the type of green facade or living wall. This choice can directly affect the plant type selection, water supply system, and maintenance measures.

The selection of vertical landscape design parameters is also critical in ensuring that it leads to energy savings rather than energy consumption (Carlos, 2015). The simulation study reveals that with practical design options in the subtropical climate, annual cooling energy savings will hit 25% (Stav and Lawson's, 2012).

Weather condition

In order to satisfy the local environment restrictions, climate factors must be taken into consideration in the most appropriate system selection during the design process (Pérez et al., 2014). plant-covered walls need sufficient light, oxygen, water, and soil to be alive. These criteria are affected by climatic variables, so it is essential to assess the project according them, including temperature, annual and monthly precipitation, humidity, and wind. Plants should be drought resistant and able to thrive in extreme weather conditions (Dunnett & Kingsbury, 2004). Also, to define physiological and morphological characteristics that ensure healthy plant growth, rate and water deficits should be studied (Hunter et al., 2014). Drought remains a major environmental factor in most parts of North America. According to the National Weather Forecast Center, drought in August 2012 covered more than 60 percent of the 48 neighboring states, and ¼ The United States experienced severe to exceptional drought. It creates more demand for water resources, and in these conditions, native plants and drought-resistant crops are highly recommended. environmental considerations should also consider water use needs throughout the site and the balance between use, efficiency, and protection. Opportunities for the inclusion of green facade systems in rainwater harvesting and gray water technology can be present in many projects and should be given special consideration in drought areas.

VGS characteristics

It is important to take into account the fundamental distinctions among the construction systems, especially between the living walls and the green façades, which may affect the thermal behavior of the final building (Perez et al., 2014). The number and type of improvements perceived in these variables concerning the physical features of the green wall, like the height and orientation and examining these changes during the year. The choice of materials used is calculated by considering the high environmental effect, the low amount of environmental damage, the amount of thermal transmittance (U value) or the amount of thermal conductivity, and (R-Value) amount of thermal resistance of the materials. Especially in the living walls, it is effective in improving the performance. Adequate information about the thermal capacity of materials and solar absorption in external walls can reduce energy consumption and the cooling load in summer. The green wall's construction details and the materials can change the thermal behaviore. This issue is discussed in detail in the research review section. Coverage percentage is one of the factors that influence the beauty and functionality of VGS.

The decision on this issue depends on the following factors:

1-Social issues include:

- The first and most crucial factor depends on the users' opinions because they decide about coverage percentage is due to the priority of beauty from their perspective, which has a problem with this process. After all, this decision should be based on analysis and wall simulation to achieve environmental results (this topic is discussed as an interaction between the designer and users in the systems review section).

2-Construction issues

- Based on the existing building's potential and the possibilities
- The number and the size of windows and walls: The point to be noted is the far greater success of buildings designed green from the beginning than adding greenery to existing buildings. Because from the beginning, it is based on accurate analysis and not on users' opinions. In other words, this set can work better together.
- The VGS height: Firstly, due to the choice of the green system's type. Secondly, the species of plants that can survive and grow in height and, consequently, the type of maintenance in GF, the maximum height, and growth rate. In the case of living walls in maintenance phase, explicitly watering and pruning can affect. Second, the height at which the greenery connects to the main façade results in different thermal performance. The research results showed that at the height of more than five floors, different thermal performance occurs. most buildings, with any height, can have a green facade in any climate. They can easily be fully covered and change the microclimate of the environment (Alexandri, 2008). Arguably, Hunter (2013), on the physical characteristics of the green facade, rejects this claim because, firstly, the plant's physical characteristics have been ignored. Secondly, it is a mistake to assume that this microclimate change can linearly change the microclimate on an urban scale (Jones, 2008).

  A study conducted by (Jaafar et al., 2013) in the Tropical climate of Malaysia to analyzing the performances of green facades and living walls in terms of temperature and airflow compared the effect of height of installation on thermal behavior considering temperature and air velocity of the different greening systems. Results show that thermal performance differs in the first-floor range of 29.6 °C to 30.7 °C in 5th-floor surface reduction temperature (Jaafar et al., 2013). The findings of the experimental analysis on living walls to measure the effect of height on the thermal efficiency of VGS show that air temperature reduction by the sky garden 29.0 °C and the balcony garden 30.4 °C (Taib, 2010).
- The coverage percentage: An analysis simulated building with varying greenery coverage found that the rise in coverage proportion will lead to dramatically decrease in the mean radiant and ambient temperature. The entire green coverage surface contributes to energy saving is more important 20.5 percent reduction in energy demand for cooling a building can be accomplished (Wong et al., 2009). The direct association of the green façade with plant coverage on the building façade was identified (Yin et al., 2017). Enhanced plant coverage will decrease the amount of solar radiation that reaches the soil surface and increase the moisture content at the surface (Yaghoobian & Srebric, 2015).
- VGS orintation: There is also an apparent influence of the orientation of the LW on the energy efficiency. In Brisbane's tropical climate, north-facing vegetated facades could

minimize cooling loads by 9 percent relative to west-facing façades, which decreased cooling loads by just 1 percent. In temperate climates, a difference in the energy efficiency of LW facing opposite directions is often seen. The simulation evaluation of a building in Portugal reveals that heating loads can be lowered by 6-11.2% through the use of LW on the east face, 8.2-13.3% for the west, and 24.4-28.6% for the north facade (Carlos, 2014). In the case of green facades, a simulation study shows that while all faces are fully covered by plants cooling load reductions differ based on the exterior wall configuration (Kontoleon & Eumorfopoulou, 2010). The cooling load of a building without openings is lowered by up to 20 percent, 18 percent, 8 percent, and 5 percent if the greening system is built in the west, east, south, and north (Kontoleon & Eumorfopoulou, 2010). Generally, it can be concluded that the orientation may play an important role in temperature decreases due to vegetation, only when the amounts of solar radiation received on vertical surface differ significantly.

Building characteristics

The findings demonstrate a clear impact of the form of the building envelope and the wall thickness on the heat transfer of the building on the efficiency of the LW system (Assimakopoulos et al., 2020). shifting in building geometry, orientation, and architectural features will impact solar gains (Nabil & Mardaljevic, 2006).

The orientation of the façade plays a vital role in the reduction of energy demand, which is demonstrated by the façade receiving a varying amount of solar radiation. Based on the latitude, solar direction, and height of the facades (Sosurova, 2015; Parizotto & Lamberts 2011). therefore, finding the best location for greening system installation and thermal efficiency depends on their orientation and temperature analysis. Many studies are conducted without noticing the internal loads, which greatly impact the entire heat transfer mechanism. In particular, residential buildings have an outstanding share in the energy use sector due to the frequency and period of energy consumption.

Material

Environmental sustainability is related to the energy conservation of construction materials. The development and use of energy are the roots of concern for the environment, and analysis has shown that energy production is closely linked to environmental depletion (Ding, 2013). during the construction phase, as various technical solutions and environmental problems can be implemented early in the decision-making process, the selection of materials can actually occur (Florez & Castro-Lacouture, 2013). As Sturges (1999) reported, more research was increasingly centered on the choice of materials and treated it as a significant aspect of architecture.

High energy-content materials are conventional construction materials, including steel, concrete, aluminum, and glass. During the life cycle, buildings affect the atmosphere, and the choice of materials used can affect their overall performance. They are used in several periods, from original construction to the stage of operation where the buildings are maintained and refurbished to ensure their normal working until the end of their service life. It is also an environment in which planners may provide valuable feedback if they are sufficiently advised about integrating sustainable building materials into the construction design. More focus should be paid not only to the operational energy but also to the material option. Eco-friendly materials are not inherently green materials such as asbestos, radon, and turpentine. They are natural materials because they are detrimental to the built and natural world in various materials and contexts (Thormark, 2006). However, sustainable materials are environmentally sustainable or environmentally responsible (Spiegel and Meadows, 1999; Franzoni, 2011). Thus, building materials are primarily recycled materials rather than non-renewable materials. These products do not emit contaminants or other pollution during the life cycle that affect human health and comfort.

Sustainable construction materials are connected to the following criteria.

- Availability of resources
- Energy efficiency (including original and replicated embodied energy and GHG Emissions)
- Avoidance of pollution (including indoor air quality) (Pacheco-Torgal et al., 2014)

Plant choice

The standard supporting mechanism and process for selecting plants should be considered and adaptable in extreme climate conditions (S. M. Sheweka & Mohamed, 2012). Distinctions in thermal and energy efficiency should be evaluated empirically for individual and combined species of LWs. Experimental mixed-species-based LW data can help improve energy models by showing many values relating to leaf properties, such as LAI, leaf reflectivity, and plant mix lateral root resistance (Charoenkit & Yiemwattana, 2016). It should be noted that detailed information about plants is provided in Chapter 2.

3.3. 3 Build up

Two sections, manufacturing and assembly, are part of the build-up process. The systems' significance is distinct in the building process, based on the VGS type and building characteristics. **Structure stability:** a stable structure that has good longevity and provides a supporting function for plant growth plays a vital role in double-skinned green facades. However, the features of the construction used and its resilience to extreme weather conditions, such as severe winds and floods, and appropriate resistance to rust and fire during the build-up process must be considered. It not only eliminates possible dangers during the existence of the green wall. Instead, it strengthens the green wall's helpful existence.

Besides, one of the key steps in selecting the type of green wall and the supporting framework is the weight of the additional structure, given the structural resistance of the current building and the volume of load-bearing in critical situations. The listed objects should be assessed, especially in the VGS, which typically are heavy, like the soil-based panel living walls. The transition from the factory to the execution site, depending on the safety points, preserving the amount of harm sustained during the move, and the cost of installation and transfer are base points. Clearly, for designers and consumers, simplified and lower costs are desirable.

Fire safety: Although VGS is an effective strategy but ignoring its safety in all aspects can contribute to the incidents. fire safety is a challenge that has not been adequately addressed (Chow and Chow 2003; Lau et al., 2016). Various factors influence green wall's flammability, including moisture content, physical structure, and chemical composition moisture content (MC) is the most critical factor that affects the ignitability of vegetation (Livingston and Varner, 2016). MC is usually measured by dividing the gap between the wet mass (Mspec) and dry mass (Mdry) and is expressed as a percentage. Maintenance insufficiency will cause unsuitable irrigation systems and dry plants in VGS, creating significant fire hazards (Dahanayake & Chow, 2018). Fire propagation is a possible VGS threat. The plants may be dried out by insufficient irrigation, providing a suitable situation for burning. Vegetation, though, can hardly burn if it is kept green and alive (Fire Performance of Green Roofs and Walls). by using fleshy, succulent plants, fire hazards may help discourage them. When grasses are used, they should not be allowed to dry out to minimize their flashpoint. The planters are appropriately filled with the appropriate plants, reducing the chance of plant fires (Department for Communities and Local Government London, Fire Performance of Green Roofs and Walls, 2013).

3.3.4 Maintenance

Green building is in general, and vertical gardens' management as a type of green buildings is associated with social, economic, and environmental aspects. Since nearly 50% of the construction industry's total revenue comes from investing in building maintenance (Lateef, 2009), it shows the importance of this phase. Annual maintenance is necessary to promote plant survival and growth at the facade (Köhler et al., 1993). Other factors that affect VGS' efficiency are installation methods and maintenance, including irrigation systems (Rayner & Williams, 2010). As vegetation is the critical component of greening systems, routine maintenance activities, including irrigation, fertilizer supply, pruning, and weed management, are needed to guarantee plant health. Vigorous plant growth leads to an increase in the accumulation of biomass and, at the same time, to the high productivity of green facades in carbon sequestration. While extensive green roofs are commonly known for their minimal maintenance needs, this system requires additional irrigation due to the higher use of multiple plant species. Irrigation has a significant impact on plant growth and the sustainability of green facades (Dunnett et al., 2008). To protect the integrity of construction materials, the operation of irrigation systems, and plant health, living walls must be thoroughly monitored. VGS maintenance can include special devices, such as suspended platforms or scissor lifts, depending on wall height. Green facades need less care (plant pruning and visual check), which is typically simple to do from the ground level (Dunnett, 2010). In the maintenance step, the nutrient provided should be measured as the nutrient generating process. This system generates chemical emissions and requires energy (Berndtsson et al., 2006). Although green systems have positive environmental and microclimate effects, the sustainability of the system in terms of materials used, maintenance, including sodium and water consumption (Ottelé & Perini, 2011), and toxins used to control insects are also crucial. In addition to ensuring the survival of the green system, proper maintenance systems can extend longevity and cause the stability of the whole system. In the same way, it helps increase the system's performance and ensure the safety and comfort of users.

(Chew et al., 2004) referred to building maintenance as achieving the highest building efficiency with minimal costs over the whole life cycle, requiring the inclusion of life cycle costing criteria and building performance at the start of the process. The maintenance phase consists of several sections and sub-sections, each of which can play a significant role in maintaining the survival of the green wall. Obviously, not all factors are equally important.

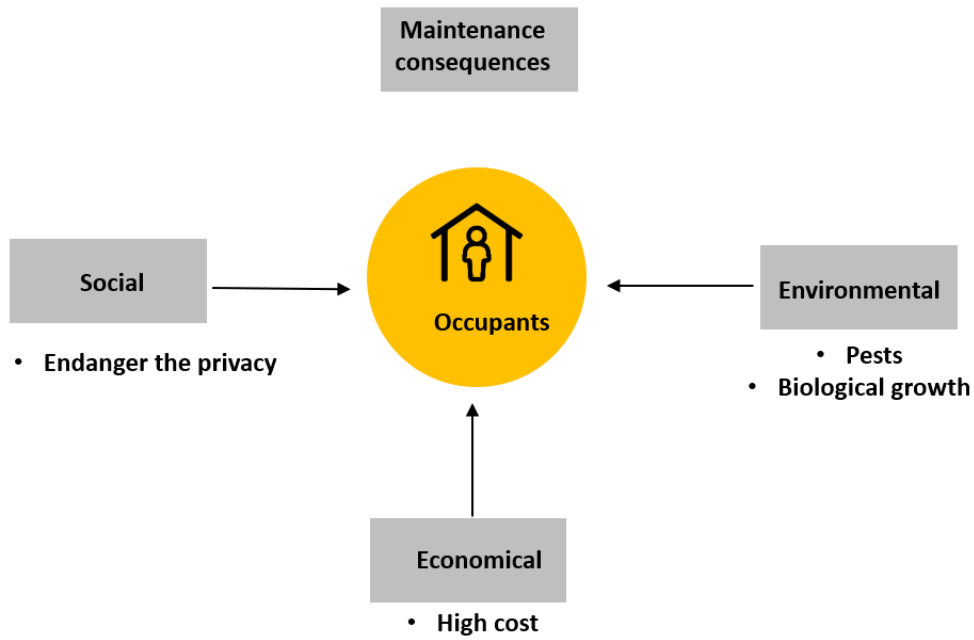


Fig 3.10 The consequences of maintenance on user's life and the benefits

The importance of the maintenance phase, especially in reducing costs, can fundamentally change public acceptance from The consumer's perspective regarding embracing the expense of machinery and repair that are important in terms of economic sustainability. Also, the restrictions on the continued existence of experts in private spaces relevant in terms of social sustainability are undeniable. The value of endangering users' privacy, particularly in residential buildings, is also factored in since qualified workers are required on a regular schedule. A device must either be updated less regularly or a system that can be maintained and controlled by consumers. The detrimental effects of the repair method can also be minimized. The superior method is a system that is easier to manage, more economical, and more efficient. Maintainability standards are - simplistic design, functional analysis, risk assessment, defect analysis, reliability-centered maintenance (RCM), and optimized O&M by scheduled maintenance programs (Chew et al., 2017). Therefore, the main factors that should be considered including:

- Reduce the number and complexity of maintenance work
- Preventive maintenance measures that users can sometimes control
- Ability to quickly replace parts and replace plants if needed
- Reduce maintenance needs and the presence of specialized personnel as much as possible
- Careful selection of irrigation system according to plants that can cause the least destructive effects of biological material growth on surfaces

In general, in designing and selecting a VGS maintenance, practical factors including environmental, physical factors, and most importantly, selected plants, climatic factors include annual and monthly rainfall are influential. Already At the design point, the maintenance of green buildings loses (Chew et al., 2017).

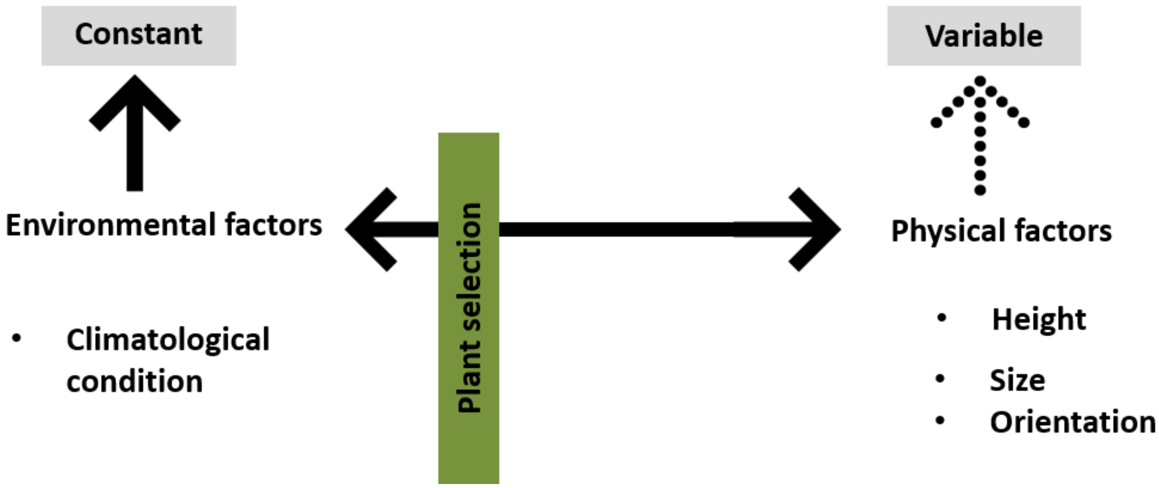


Fig 3.11 The most effective factors in maintenance

In green facades, climbers require dramatic pruning to discourage them from competing with facilities such as guttering and making their way through apertures into the house. It is unusual, though, to be a regular occurrence, at least before a wall is entirely clad; for instance, ivy will need to be pruned every two or three years by then. Old walls tend to undergo some structural maintenance, such as repointing. Each area of the wall colonized by plants should be maintained in its original state where possible to ensure continuity of interest and act as a means of recolonization for the preserved sections. Rare species of mosses, ferns, or lichens on existing walls may be damaged by construction work. Contact should be made with the nearest wildlife trust or natural history society, which should offer recommendations regarding the value of the species. The use of lime mortar, a suitable medium for supporting plants due to its inherent softness and versatility, is another argument for consideration. Lime mortar is especially ideal for VGS, while the modern mortar is typically more suitable for dwellings since plants cannot infiltrate too profoundly.

The volume of irrigation needed depends very heavily on the species used and the wall element. Plants growing on a wall facing south need much more water than those on a north or west wall. The water system for those plants embedded in the facades is likely to depend on natural sources and the moisture-retaining nature of the substrate they are developing into (Green, B. 2004, A guide to using plants on roofs, walls, and pavements). Hydroponic systems include plantings raised over a pond or water-like river body with root systems reaching into the water. There are multi-faceted issues with these processes, but each results in considerable human initiative and action. For instance, the growth of algae can be a concern and require water cleaning. Besides, if entirely underwater, many plants cannot survive, so a support system for the live matter must be built. The live matter must be added to the structural support to expand (Corradi, 2009).

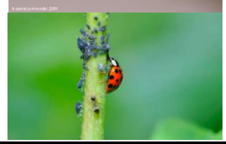
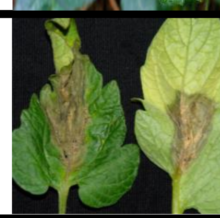
Irrigation systems

Vertical greening systems are not sustainable without irrigation. Water supply error is one of the leading causes of plant death. Irrigation systems are done by adjusting the proper water supply based on the needs of the plant type. According to the green wall specifications, such as height and location, automatic and remotely controllable irrigation systems can ease access. The irrigation needs depend on the type of greening system, plants used, and climatic conditions (Manso & Castro-Gomes, 2015). Advanced and smart systems can control the automatic operation, including the volume of irrigation delivered, its frequency, the amount of substrate moisture, the pH, and the number of nutrients in the water supply. This type of irrigation system can be primarily used in living hydroponic walls. Another influential factor is the amount of water required by plants and the number of irrigations calculated according to the type of plants and the weather conditions. Irrigation should be available as soon as the plants are installed in the wall system. The irrigation system can be enriched with nutrients and fertilizers to improve plants and keep them alive.

Pest and Disease Control (GIP)

Integrated Pest Management (IPM) is a control strategy that basically involves the rational application of a combination of biological, biotechnological, chemical, crop, or plant selection measures to minimize the use of health products.

Table 3.1 Various type of plant diseases

Woodlouse Aphid	 
White fly	
Rust	
Disease Control: OÍDIO Powdery mildew usually appears by: - Low light conditions - Excess humidity - Poor soil drainage - Poor aeration between plants	
Botrytis Maintenance Control: It is important to avoid situations with high sheet density and low ventilation. Alternate moments of water with some desiccation to dry out areas low	
RED SPIDER (symptom of dryness and / or lack of watering)	

3.3.5 Monitoring

Nowady, the VGS are recognized as an efficient method for lowering surface temperatures in urban spaces to cope with urban heat island effects. On the one hand, there is a growing trend among architects and designers to build vegetated surface facades, On the other side, there's a rising tendency among companies to broaden their product offers. Nevertheless, the primary function is often left out or concealed behind other goals. Green wall survival means the proper operation of the green wall to minimize the environment's destructive consequences. May it be said that only surviving does the green wall have a decisive role in its whole life? If the green wall's environmental function has encouraged architects and designers to use it, will it also control and measure? Do green wall manufacturers devote a step in the design to disposal processing to control performance and check its efficiency? Hundreds of green walls are being built and installed around the world today. Comparing the vertical green solutions deployed in numerous industries (Asia, Europe, and the U.S.A) and evaluating the different GW implementation methods reveals that one of the most critical steps is overlooked. The response is no since manufacturers and designers generally surviving plants and being green are perceived as good results. While green walls are commonly assumed to mean their proper operation, in reality, GW's output depends on dynamic factors.

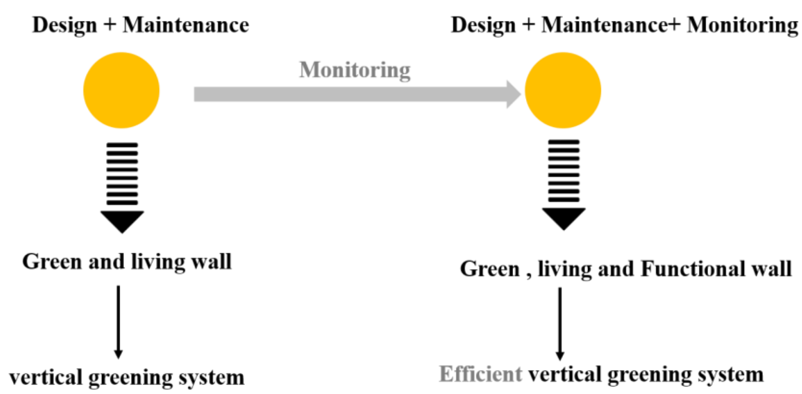


Fig 3.12 Differences between the green wall with monitoring and without

Life cycle assessment is an effective way to evaluate the sustainability of a building system, taking into account the integral balance between environmental load and expected benefits (Perini et al., 2013). Researchers can connect the actual and commercial world of VGS and the studies to strengthen their environmental advantages as it helps to achieve reliable and realistic results (Jim, 2015). The findings could optimize their design and associated environmental, social, and economic benefits. The personal benefits are mainly related to the energy savings for heating and air-conditioning (Perini & Rosasco, 2013). In general, indicators that help assess thermal performance are examined primarily by researchers and by selecting a case study, not by designers and manufacturing companies. It means a VGS does not have the feature planned for it after 30 years of life or has almost no efficiency. Monitoring during the life cycle is a reliable way to evaluate its proper performance. Monitoring relies on three dynamic factors with different level of variability and validation:

- Dynamic urban climate
- Dynamic urban features (Traffic, Buildings, land use, population, ….)
- Dynamic VGS features

The need for periodic monitoring of such improvements and maintaining adequate performance is also undeniable. Thanks to changes, the role of controlling gets more critical over time. It can be made more apparent by emphasizing the crucial aspects during the analysis processes.

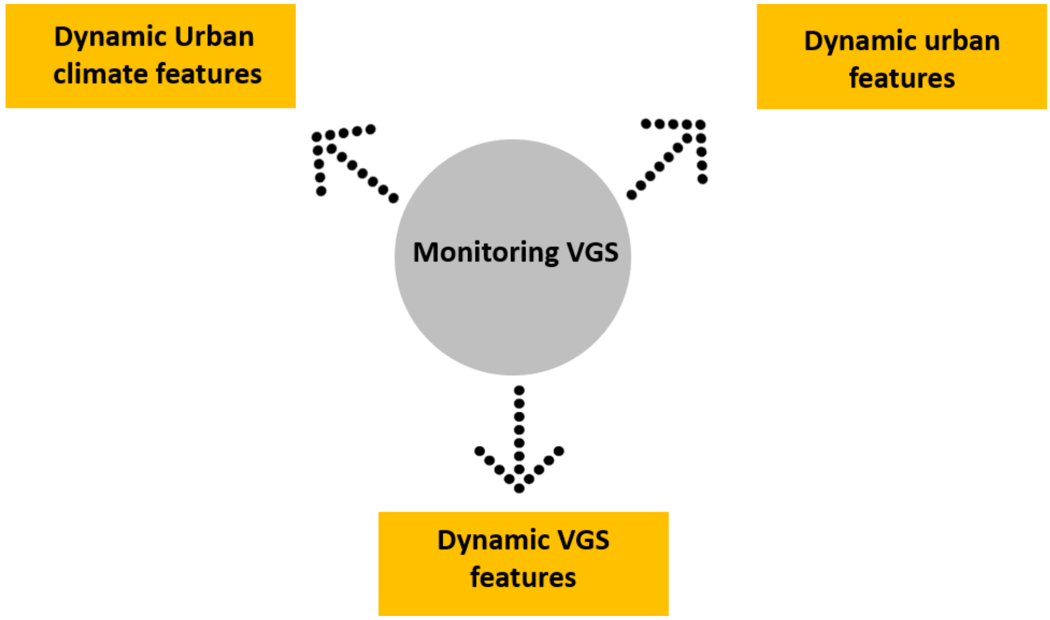


Fig 3.13 Analysis monitoring principles

Dynamic urban features (Traffic, Buildings, ….)

Microclimate variability in urban environments depends on factors related to population growth like, the new construction and thermal efficiency of building material design (Oke et al., 1991), industrial and high-density residential areas that are 5 to 7 ° C hotter relative to rural areas (Bonan, 2002), paved surface materials (Jaafar & Rasidi, 2011), street geometry (Shafaghat et al., 2016), urban reform (Hall et al., 2016) proportion of green and grey areas (Lin et al., 2008) and agricultural landscapes. Owing to changes in the number of users, urban population, and occupants' behaviors, the need for resources and anthropogenic heats (Oke,1982, Grimmond 2007); the surface characteristics (Quattrochi and Ridd, 1998; Xian and Crane 2006) can affect urban surface temperature. The city's average air temperature of 1 million or more inhabitants can be 1 to 3 ° C warmer than its surroundings (US EPA, 2008). Changing land use and urban environment contributes to altering water and soil's biophysical properties (Jankovic, 2013). There is, however, a scarcity of studies that change urban climate factors, such as air temperature, land-use humidity, and local habits (Heffernan et al., 2014). Cities build their microclimate because of their unique albedo, roughness length, and soil sealing called the urban heat island effect (Grimmond, 2006). Cr particles contribute to air pollution related to car traffic, railroad near the building's facades (200 m away) (Perini et al., 2017). When the hot, polluted, and humid metropolitan environment transmits more low thermal light to the surface of the city (Voogt, 2002), dynamic urban features lead to new urban features. Furthermore, much of the fine (b2.5-micron diameter) and ultrafine (b1 micron diameter) matter has anthropogenic origins such as automotive exhaust and emissions from manufacturing (Powe and Willis, 2004).

UHI phenomena are heavily dependent on land cover changes and energy consumption, as well as surplus energy from human activity, decreased vegetation, building materials that retain heat during daytime and move it at night (Oke 1982; Grimmond 2007). Buildings' energy efficiency would differ by 10 percent based on urban design (Ratti et al., 2005). regional geographic characteristics and weather events can affect UHI (Zhao et al., 2014). However, no experiments have examined how urban ecosystems alter air temperature and humidity across different climate zones or to what degree ordinary residential environments lead to microclimatic homogeneity. Similarly, at regional to continental dimensions, ecological theories that integrate social-ecological processes are underexplored (Heffernan et al., 2014), absolutely this dynamic factor during the life cycle of VGS accurately is unpredictable. Monitoring by setting sensors and testing them over the life cycle of VGS is the most effective tool to ensure proper performance concerning this type of complex variable.

Dynamic urban climate

The atmosphere changed by modifying the land's actual surface and producing vast amounts of heat and pollution (Jaafar & & Rasidi, 2011). Due to global climate change, significant modifications like air temperature, surface temperature, sea-level rise, and the scale and frequency of severe events in the climate (IPCC, 2007b) occur, which influence rain-dominated catchments to include higher precipitation extremes (Harmsen et al., 2009). Humans influence the environment by constructing cities, and it is activities in the production of "waste heat" because of energy use (e.g., heating, traffic). Urban surface structures, such as buildings, drastically influence local weather and air quality, and UHI depends heavily on weather conditions (Souch & Grimmond 2006).

As VGS is a plant-based solution, the selection of suitable plant species significantly influences the efficiency of VGS (Dahanayake et al., 2017), and the life of plants depends on climate conditions, as the rapidly increasing urban climate stated by (Oke 1979b) has continued and accelerating, so VGS performance should be monitored according to the environmental aspects. The thermal behavior of VGS is the product of four plant properties, including the effects of insulation, evapotranspiration, shading, and wind protection; depending on the environmental conditions, any of these can impact total efficiency. It can cause changing the layout of the vertical garden or maybe replace, add, or remove some plants.

The annual rainfall level determines the amount of evapotranspiration and the relationship with the water supply network (Liu et al., 2002). So, evapotranspiration can indicate a change in system output. In the case of air purification, rainwater's possible influence on particle adherence (Ottelé et al., 2010; Popek et al., 2013; Przybysz et al., 2014) to improve air purification (Perini et al., 2017). The particle counting of washed and non-washed P. fruticose and Hedera helix leaves shows that particles (2.5–10) cannot be washed away by rainwater since the average number of particles in 1 mm2is similar. It confirms (Ottelé et al., 2010) results, demonstrating that fine and ultrafine particles cannot be washed away from *H. helix* leaves. There is, however, a lack of research on the amounts and intensity of rainfall and its effect on the washing away of particles throughout the year that needs further study. As hunter pointed out in 2013, although the link between water use efficiency and evapotranspiration, cooling provided by the GW has been overlooked, that in the Mediterranean climate is hotter and drier is more critical. Therefore, it is essential to check green wall efficiency depending on climate change during the green wall life cycle. It can also be generalized to living walls, given the more complexity of the green facade and the more considerable divergence of the plants. Regarding the importance of the dynamic urban future, the role of wind velocity can be changed and climate change following the rate of urban change caused by construction, specifically high-rise buildings. Thus, the practical predicted outcomes of VGS should be taken into consideration about weather changes. Monitoring can help designers review features and adjust green walls to get improved functionality if necessary.

Dynamic Vertical Greening systems features

Plants are the central part of VGS, and over time (in this maximum study, the age of VGS depends on types consider 30 years), Physically, they will be changed depending on plant species and VGS type (GF or LW).

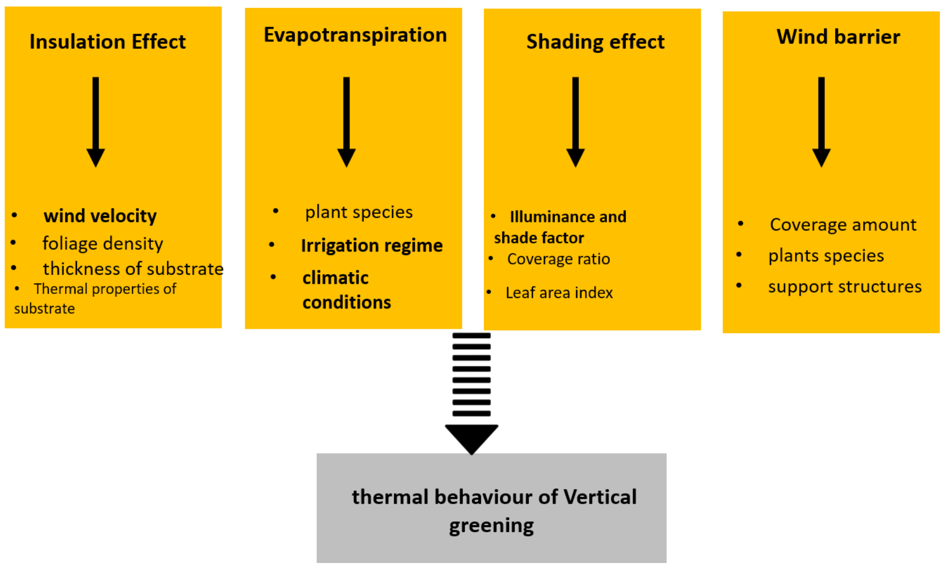


Fig 3.14 Factors influence thermal behavior of VGS

While LAI may be a significant predictor of solar radiation transmittance, it should be noted that it is not a static value. In response to fluctuations in seasonal temperature and vapor pressure deficit, light source levels, quality of soil and substrate, phenology, availability of soil nutrients, and plant maturity, LAI can alter(Whitehead and Beadle, 2004). Evergreen species retain their leaves for several years and reach a saturation point. The age of plants is also a vital factor in the VGS inflammability rate (Beckett et al., 2000). (Dahanayake & Chow, 2018) showed that fresh plants did not ignite at any heat flux stage in all three plant species tested (Hedera helix, Peperomia obtusifolia, and Aglaonema commutatum) (from 20 kW m-2 to 60 kW m-2). Vegetation height, leaf reflectivity, and leaf emissivity are other related factors contributing to thermal cooling benefits (Stav and Lawson, 2012). If the plant height changes over the life cycle of the VGS, thermal efficiency can vary. A statistical study of plant growth over 5-10 years will be suitable for analyzing green roofs and living walls' evolving efficiency over time. Further investigations using monoculture plantings may provide valuable knowledge to consider individual plant water needs, water usage efficiencies, evapotranspiration rates, and possible cooling, in addition to further understanding plant growth processes (Beecham et al., 2019).
There are six parameters that all experimental green facade studies should report as a minimum for adequate quantification of thermal performance and microclimatic benefit:1. Solar radiation in front of or away from the green facade,2. air temperature in front of or away from the green facade, and3. Wind speed in front of or away from the green facade, as well as:4. Solar radiation between the green facade and the wall,5. air temperature between the green facade and the wall,and6. Wind

speed between the green facade and the wall (Hunter et al., 2014). Using more advanced equipment and sensors achieves more accurate data, but thermal performance monitoring generally does not require measuring all factors. With more limited data, its effectiveness can be measured. Memory for 3x 60,000 measured values can also be used without software (pre-programmed 5-minute measuring interval). Automatic output as PDF file (no driver installation required), optional software download, freely adjustable storage interval from 30 seconds to 24 hours (via Log Connect software), battery life> 2 years (with measurement interval> 15 minutes), status and alarm LEDs, incl. Wall bracket and fastening screws.

Table. 3.2 The devices can measure the effective factors

Factors	Devices				
• solar radiation in front of or away from the green wall • air temperature in front of or away from the green wall • wind speed in front of or away from the green wall • solar radiation between green wall and the wall surface • wind speed between green wall and the wall surface • air temperature between green wall and the wall surface	• Peak tech Measuring range: -40... + 70 ° C, 0... 99% RH - Resolution: 0.1 ° C / 0.1% RH - Accuracy: + - 0.5 ° C (-10..40 ° C) + - 3% (40..60% RH) - Power supply: 1/2 AA size 3.6 volts - Battery life:> 2 years (with an interval> 15 min.) - Dimensions: 102 x 20 x 21 mm - Weight: 70 g - Functions: alarm LED, acoustic alarm via beeper, memory clock rate configurable from 30 seconds to 24 hours Not clear. You have to add text for explaining and comment	• Description: - 3-digit 10 mm LCD display (max. 999) - Automatic background lighting - Humidity measurement in RH% - Air temperature display in ° C or ° F - Fast response time of the sensor - Robust and handy housing design - Measured value hold function	• - Air humidity: 10% ~ 99%; 0.1; + / - 3% - air temperature ° C: -10 ° C ~ +50 ° C; 0.1; + / - 2 ° C - Air Temperature ° F: 14 ° F ~ 122 ° F; 0.1; + / - 3.6 ° F - Sampling rate: 2 x per second - Operating voltage: 9 V battery - Dimensions (WxHxD): 55 x 145 x 35 mm - Weight: 120 g (https://www.kometec.de/messgeraete/datenlogger/)	 PeakTech P 5185, temperature and humidity USB data logger	 Figure 4-10 PeakTech P 5160, temperature / humidity meter

This newly developed measuring device measures the current air humidity and the current air temperature via a permanently installed sensor for a quick and exact evaluation of the measurement results. The easy-to-read LCD monitor has an adaptive backlight that unlocks when the brightness is down, thanks to a photodiode. Moreover, this unit often has a calculated value keep feature at the click of a button, in addition to the exact measurement function. This instrument is used to measure everyday use in the building industry and determines the temperature of living spaces and greenhouses, thanks to its convenient and durable nature.

• Spring	• Class A (highest quality)	• SPA (quality A in spring)
• Summer	• Class B (Medium quality)	• SUB (quality A in summer)
• Autumn	• Class C (Low Quality)	• AUC (quality C in autumn)
• Winter		• WIB (quality B in winter)

Fig 3.15 Grading vertical greening systems regarding season functionality

In addition to the above benefits, the implementation of monitoring by designers and suppliers during the VGS life cycle reflects the efficacy of green walls' scoring. It is one of the certificates issued to clients by designers. On the one hand, this certification lets manufacturers produce goods that can be more commercially competitive by gaining more quality values from the consumers. On the other hand, costumer makes sure the level of the quality of green wall they choose. Because the efficiency of VGS varies throughout the year and because specific customers want high quality in a single season while others require high quality throughout the year, this certification category demonstrates the consistency of green walls in a given season. The grading of energy consumption reduction is composed of season +class from a reduced energy consumption perspective. For example, the SPA mark green wall (SPring, class A) means that it has the highest functionality in springtime. Also, it strengthens the VGS and takes it away from the ornamental architectural function to the realistic alternative. Companies must have enough knowledge about the various types of green systems created, as well as their production and output during different seasons of the year, to achieve this aim.

3.3.6 Disposal

The products may be recycled, reused, or landfilled in the disposal process. It is possible to reuse the steel parts, and the planter box could be recycled. Many regions, however, do not have the requisite infrastructure to pursue the process of recycling. Therefore, the worst-case should be considered, and VGS components have to be landfilled. Therefore, it is vital to develop and manufacture durable construction materials to be long-lasting and demand low maintenance over their lifespan. It is done by either planning for longevity or recovering for extended life, existing construction materials (Pacheco-Torgal et al., 2014). The use of recycled building materials during design is recognized as a core sustainable construction technique and ensures minimum material loss during the building's life cycle. They also retain arrangements for reusing and recycling building material to increase the whole process's total resource efficiency (Akadiri and Olomolaiye,2012). The steel products are considered to be disposed of in an inert content landfill, and the plastics in a landfill site, including the planter box and felt layers. It has been believed that plants and soil are naturally disposed of because they are predominantly organic. However, the transport method contributes to chemical pollution and energy usage at the disposal stage (ICOVA, 2013).

3.4 Intra-phases relations

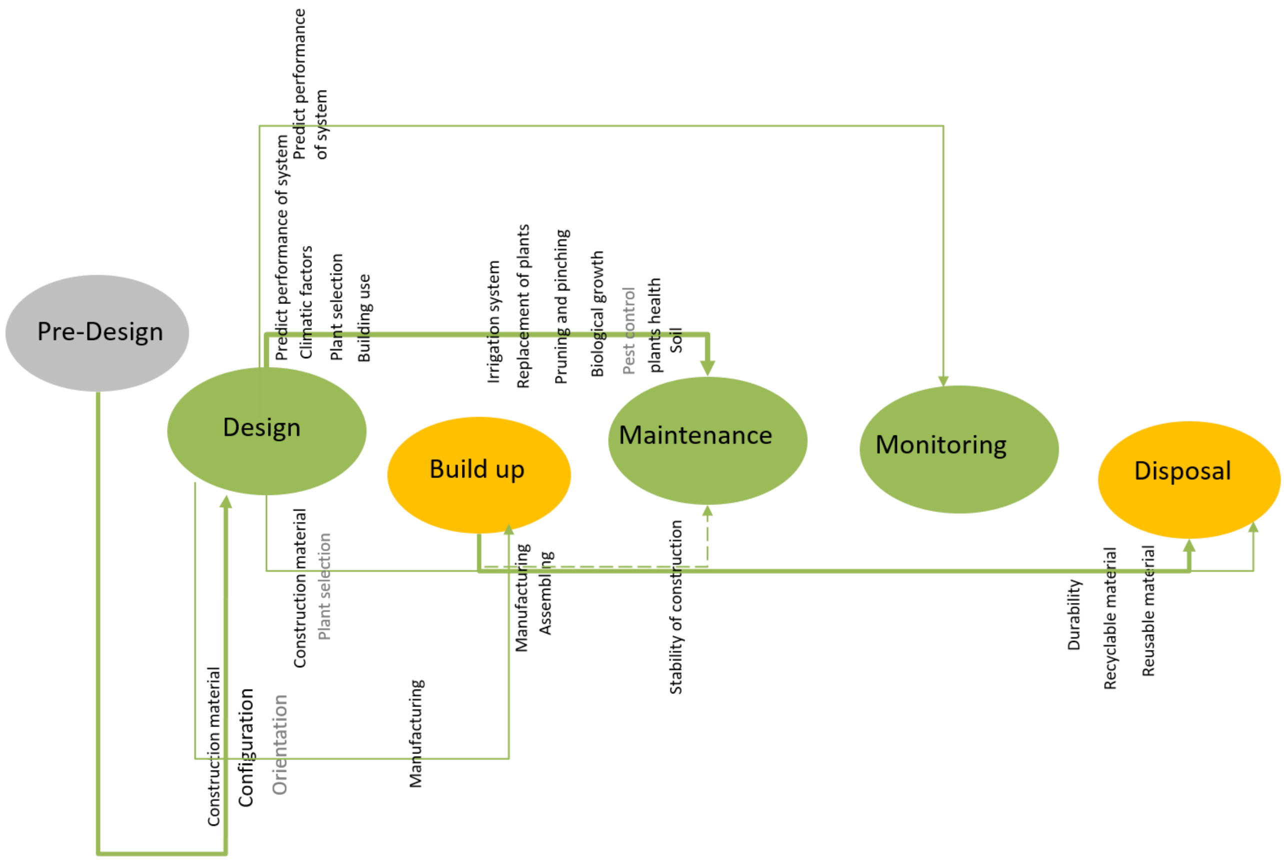


Fig 3.16 The intra-relation between different phases based on VGIS

Intra-phases relation in Pre-design –Design

The pre-design stage is where the major decisions for building a VGS are taken. The clear and rational link between the system's physical, economic, and social aspects is apparent when deciding on the best choices. In other words, understanding the construction size and evaluating the project's potentials while determining the green wall form will directly impact the design.

Intra-phases relations in Pre-design –Disposal

The type of device chosen for the VGS disposal stage is decided during the pre-design stage. Until building, the form of green wall is considered, the recyclability and recyclability of living and non-living components, the amount of environmental burden and destructive environmental impact, and the costs of collecting the device. As a result, it will have a more reliable financial forecasting order and a more suitable and environmentally friendly alternative.

Intra-phases relations in Design –Monitoring

The link between the design process and the monitoring phase is formed by ensuring that the requisite access is granted to regularly install the equipment required to track the system's output. In high-rise towers, this reinforces the partnership. In the case of irregular shapes or difficulties in reaching the facade surface, the green coverage surface should be assessed in the design phase.

Intra-phases relations in Build-up –Disposal

To ensure the system's reliability, materials can be chosen based on the disposal point. Consistency of consumables for products used in the building's facade and commitment to the collection afterlife is essential.

Intra-phases relations in Build-up –Maintenance

Since adequate equipment and functionality are considered in the build-up process, the integrity of the green wall retaining system in periodic control during the maintenance phase decreases the risk of its destruction in crucial circumstances.

Intra-phases relation in Design- Maintenance

Green maintainability defines the ability to maintain a green building as achieving the best building performance at the lowest cost throughout its life cycle, which requires integrating the building's life cycle cost and performance principles at the beginning of the project and into the design phase (Chew et al., 2004). The lack of relevance of maintenance requirements in the design phase is apparent (Zainol et al., 2014). Feeding, remove the waste foliage, and pruning is placed in the living system and are directly related to the type of plants selected in the design phase. For this reason, the relationship between the maintenance phase and the design is vital. Likewise, periodic evaluation of plant health and, if necessary, their replacement is dependent on the type of plants selected in the design phase.

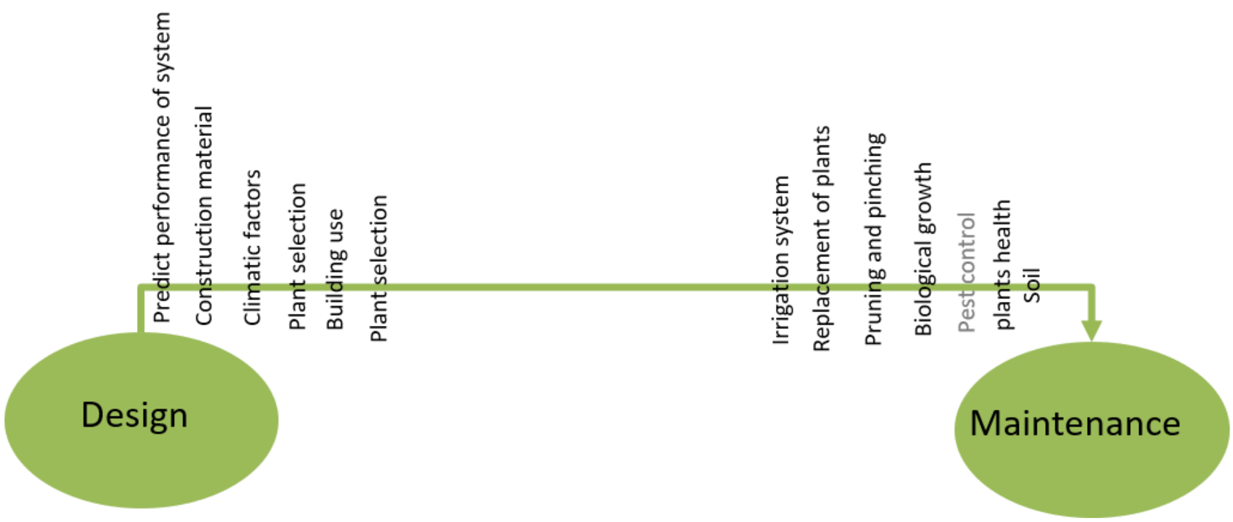


Fig 3.17 Intra-relation in the Design & Maintenance phase

The amount of water supply of plants depends on several factors, including the type of wall orientation, which means the extent to which it is exposed to sunlight, wind pattern, and rainfall (Green over Grey, 2009). Therefore, there is a direct relationship between orientation and climatic factors in the design phase with the superconducting system in the maintenance phase. Furthermore, the plant species' evergreen or deciduous leaves strengthen the design relationship with the amount of water required by the plants in the design phase. Therefore, it seems that due to the importance of maintenance, especially in living walls, and according to studies conducted by researchers such as (Chew, 2017), who emphasize the ability to maintain and the theory of green maintainability can be generalized in these green walls. Moreover, one of the essential parts of the green system's stability is the stability in the maintenance phase, which will be discussed in the maintenance section.

Intra- phases relation between Design- Build up

The mechanical stability of the VGS can be influenced by the significance of the materials used in the structure that have a supporting function and the materials chosen as the growth medium. Therefore, it is appropriate to measure and analyze the attention paid to mechanical properties and, most significantly, mechanical efficiency, thermal activity at various seasons of the year, and the coordination of thermal behavior between the maintaining material, the growth medium, and the main façade.

For example, the modular living wall collapse was triggered only by choice of light and cheap plastic and the lack of commitment to thermal expansion coordination (Irwin, 2015).

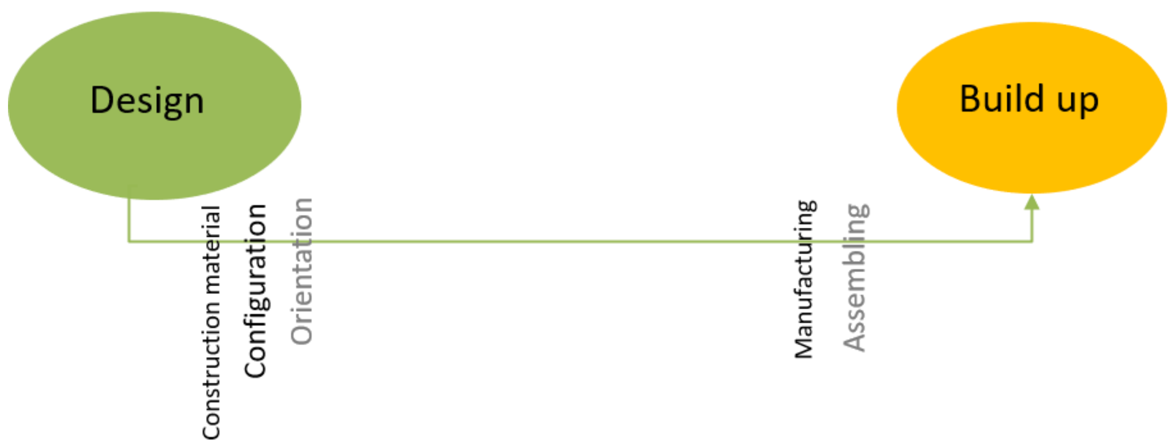


Fig 3.18 Intra-relation in the Design Build-up phase

3.5 Inter-phases relationships

Inter-phases relations in Design

Although each area's climatic conditions are recognized, buildings' form and height may influence the wind pattern. Localized winds will develop on the windward side of high-rise buildings, prompting significant street-level changes and upgrades to the upper floors (Blockenand Carmeliet, 2004). The wind speed also rises and exceeds 100 kilometers per hour, increasing the building height above 65 meters (Martilli, 2002). Thus, there is a direct relationship between climatic factors, especially wind velocity, and VGS configuration. The detail and type of configuration regarding the air cavity between the building's surface and plant-covered directly influence the system's insulation. This distance causes a change in the building's wind pattern (Ottelé et al., 2011). Different materials are used to support structure in the double-skin green facade and plant growing medium and the plate on which the plants are mounted. The materials for use as static supporters will impact the green facade's shading and cooling behavior (Price., 2010). Since the possible insulating effect of the air cavity behind the canopy is a key feature of the design, it is surprising that wind speed or convective air movement inside and behind the plant layer received little attention (Hunter, 2013).

The physical properties explain the water regime and air availability to roots, water penetration through the surface, and capillary water movement (Handreckand Black, 2002; Rayner et al., 2010). In soil-based systems, soil type, the material used in the substrate, and physical characteristics in terms of substrate thickness, type of composition layers, and physical aspects are practical. Chemical factors such as soil PH rate in soil systems and the amount of PH and other additives such as carbonates and SARs directly affect water-based systems can change growth behavior. Soil structure, air-filled porosity, water holding capacity, bulk density, and saturated hydraulic conductivity, and on the other hand, the volume of soil used to play an essential role in the relative growth of the plant, growing habit type, total LAI, and the plant health. These physical characteristics indicate the availability of climate for the roots, water filtration through the profile, and capillary moment water. Hence, it can directly change the plant's growth rate, the type of habitat, total leaf area, and plant health.
Container executive details such as volume and materials used directly and significantly affect plants' relative growth rate and evapotranspiration through root growth and water access (Mathers et al., 2007). A study on the green façade should decide which climbing plant characteristics and species, support structure arrangements, containerized systems, and irrigation regimes are most successful in reducing space cooling and heating demands over an annual period for particular climates and construction aspects. Any research yet has explored how container design (such as length, material, and elements such as geotextiles, water reservoirs, and cover plates) impacts plant growth, root-to-shoot ratios, root temperature, or accessibility of soil water, all of which have a direct effect on comparative growth rates of plants and evapotranspiration (Mathers et al., 2007). The study of plant features leads to efficient container designs.

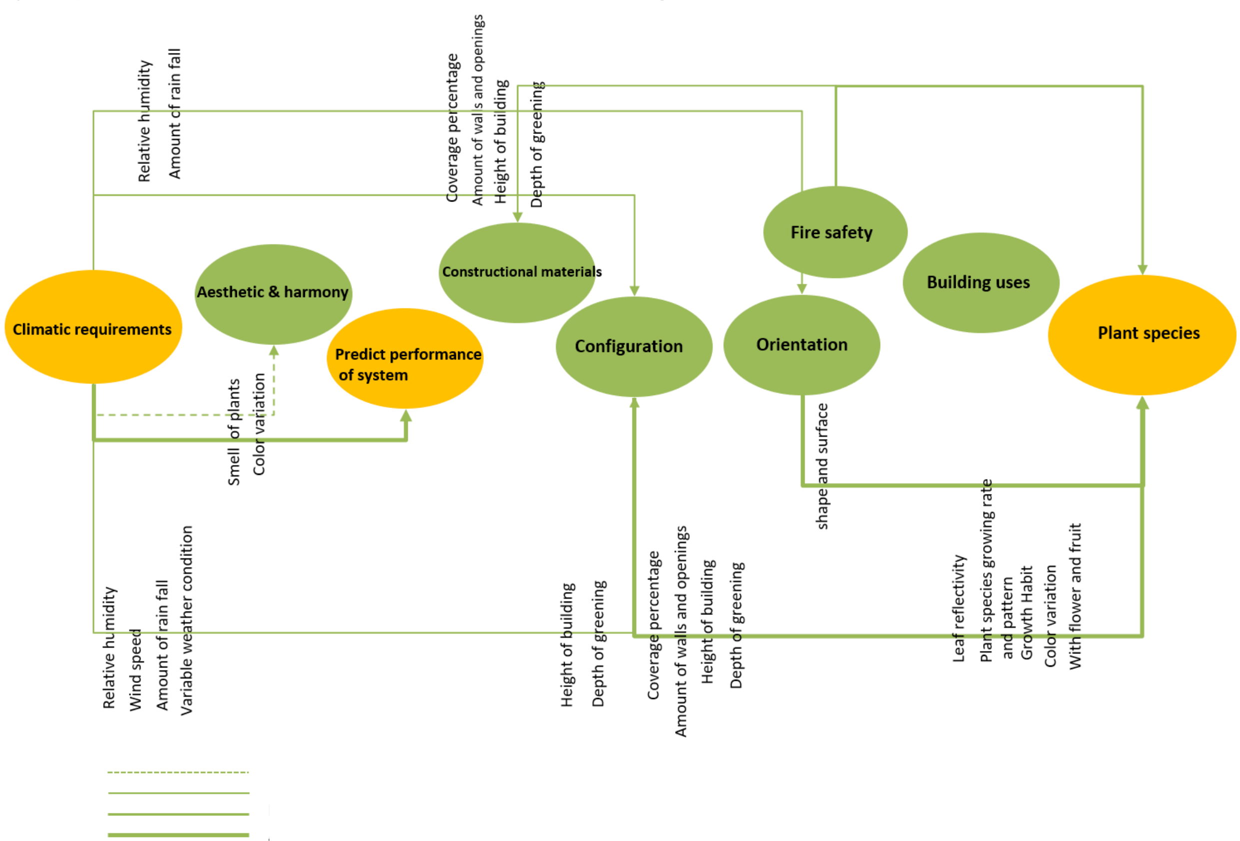


Fig 3.19 Interrelation of the Design phase

There is a strong relationship between predicting the green system's behavior in climatic conditions and the type of plants selected because of the foliage type and size of plants to withstand extreme conditions such as wind and rain to resist these conditions proportional. This connection is established for both living walls and the double-skin green façades. It becomes more critical in multi-story buildings.

Inter-phase relations in Maintenance

As described earlier, contact at four levels between practical variables is specified in the integrated approach. The relationship between different phases, there is also a relation between the factors that make up a specific phase at these four levels. It is different in each phase, while it is also vital in the design phase of communications. Since the design and maintenance phase includes several factors that play a crucial role in the VGS's performance, the intra-phase relationship in each of these two phases is analyzed. As can be seen from the diagram, most of the communication in the maintenance phase is significant, which indicates the strength of the dependence, and the irrigation system and plant health play a key role. However, the absence of other factors can cause weak green wall performance or reduce the VGS life span. Therefore, all the maintenance phase components are first extracted. The connection between the irrigation system and nutrition is strong because food reaches the roots of plants through the water supply system, which is soluble in water, and plants can feed on it. This strong connection is essential for hydroponic systems. While other types of green walls can play a lesser role, but there is a connection.
The watering system's necessity based on the amount of required water is directly related to plants' health because excessive irrigation causes root rot, and insufficient irrigation leads to plants' death which is selected based on the VGS type and plants. For instance, over-watering can cause biological growth like algae on the surface of vegetated facade elements. The stability is considered mechanically, taking into account the extra weight resulting from plants' placement, soil and irrigation supplies, and sensors, depending on the type of green system. It is imperative in high-rise buildings and rainy climates with strong winds throughout the year. Paying attention to this issue can reduce the risk to zero. Also, system maintenance and periodic inspection of the structure attached to the main external wall and control of erosion due to water supply are essential. The volume of soil used to pass the green wall can put additional pressure on the structure of the building, which indicates a strong relationship between the type in the stability of the structure and the volume and type of soil used.

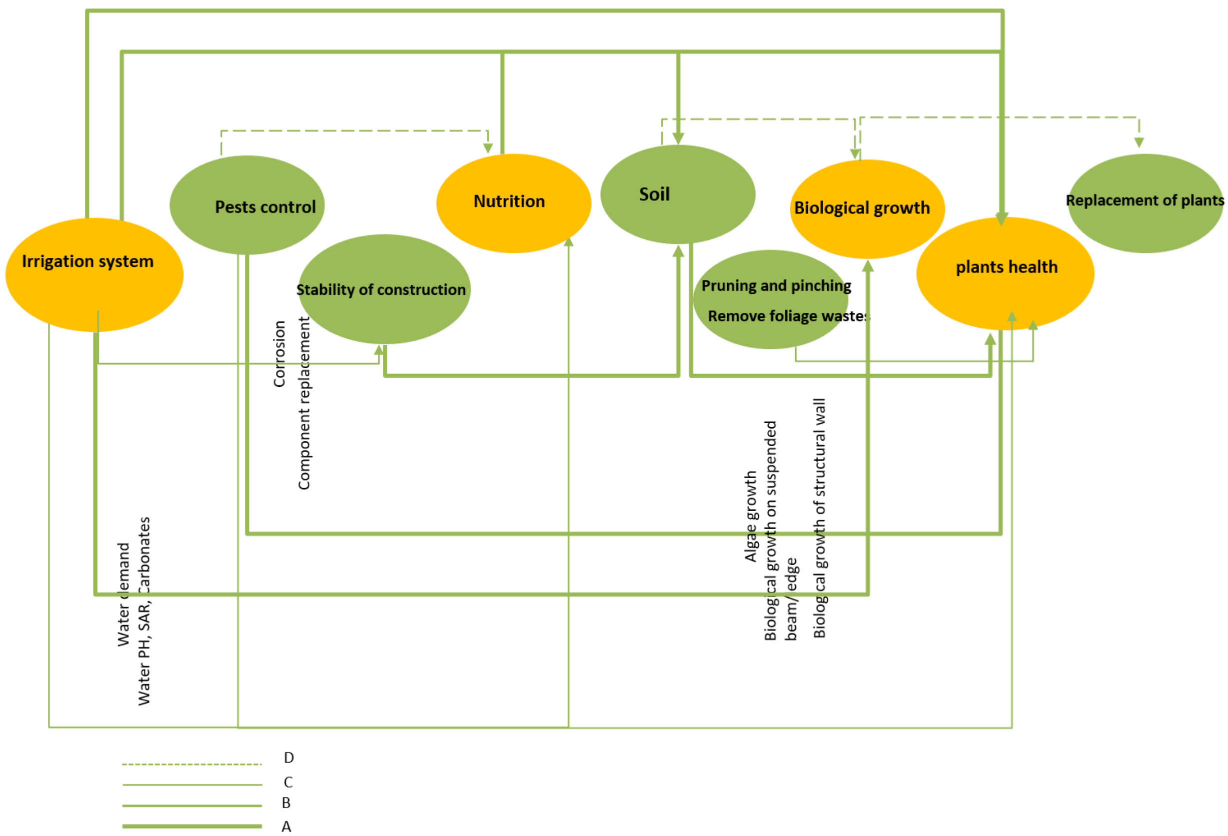


Fig 3.20 Inter-relation in the maintenance phase

Inter-phases relations in Build-up

The connection of built-up is a real correlation between manufacturing and assembly specifications. The supporting framework's weight and the vegetation planted on it must be considered during handling and construction. It is a challenge for high-rise structures, as it can be risky, causing harm to the vertical green framework in pre-planted type. Besides, one of the most critical aspects to think about is the ease of installation, which is particularly important in extreme cold and heat and buildings with difficult entry.

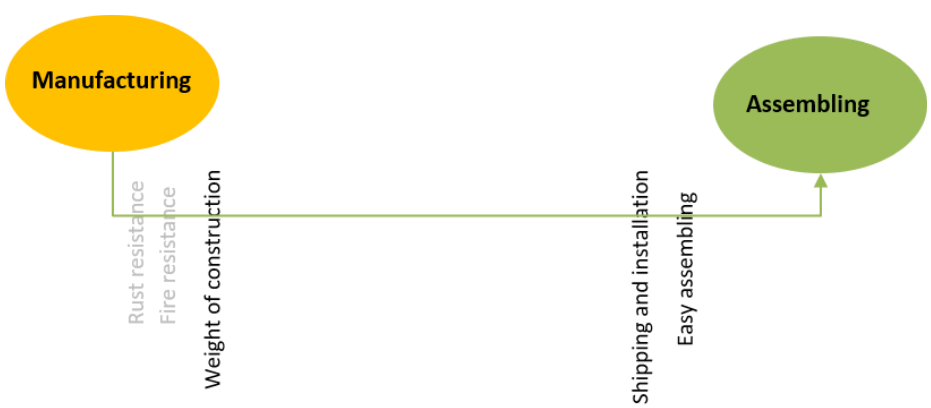


Fig 3.21 Inter-phases relations in Build-up

Inter-phases relations in Disposal

Green walls as a plant alternative can be brought closer to sustainability targets using reusable or recycled materials (Ramayah& Rahbar 2013) with a long-life period. Calculating the costs of collecting after fulfilling the purpose will help pick the best alternative for each project for both static and live content.

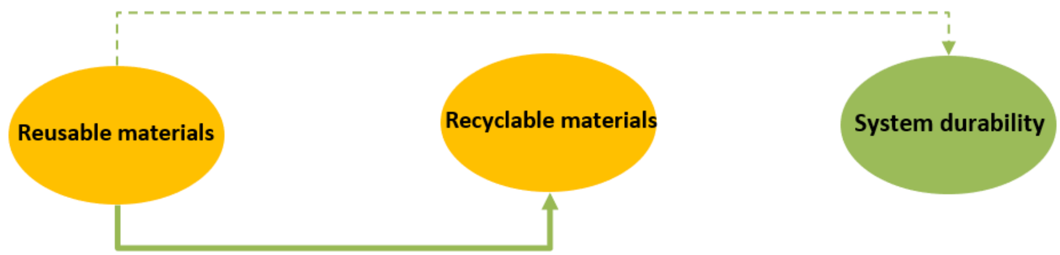


Figure 1Fig 3.22 Inter-relation in the Disposal phase

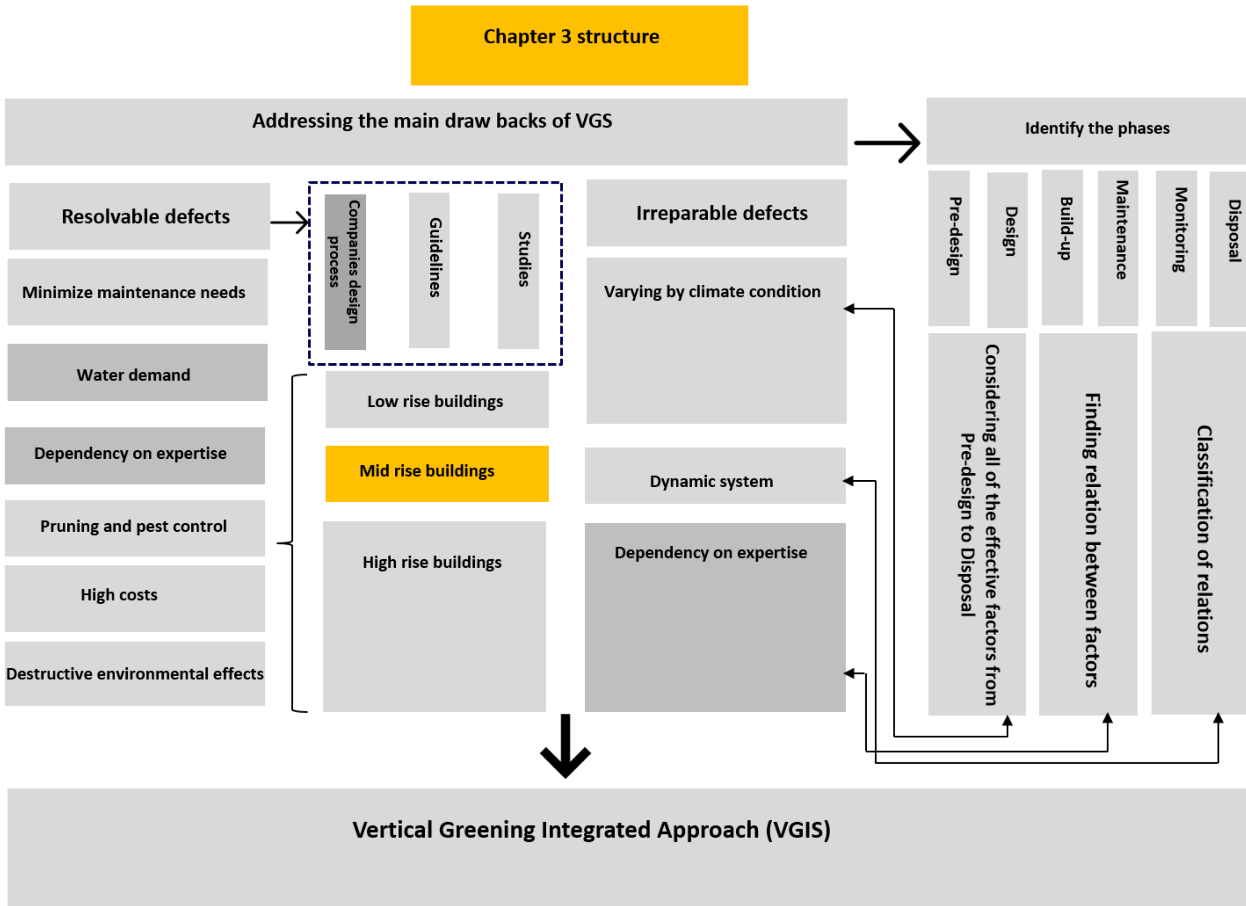


Fig 3.23 The structure of chapter 3

References

Books

Spiegel, R., & Meadows, D. (2010). *Green building materials: a guide to product selection and specification*. John Wiley & Sons.

Papers

Mazzali, U., Peron, F., Romagnoni, P., Pulselli, R. M., & Bastianoni, S. (2013). Experimental investigation on the energy performance of living walls in a temperate climate. *Building and Environment*, *64*, 57-66.

Pérez, G., Coma, J., Martorell, I., & Cabeza, L. F. (2014). Vertical Greenery Systems (VGS) for energy saving in buildings: A review. *Renewable and Sustainable Energy Reviews*, 39, 139-165.

Riley, B. (2017). The state of the art of living walls: Lessons learned. *Building and Environment*, *114*, 219-232.

Perini, K., Ottelé, M., Haas, E. M., & Raiteri, R. (2011). Greening the building envelope, façade greening and living wall systems. *Open Journal of Ecology*, *1*(01), 1.

Bustami, R. A., Belusko, M., Ward, J., & Beecham, S. (2018). Vertical greenery systems: A systematic review of research trends. Building and Environment, 146, 226-237.

Perini, K., & Rosasco, P. (2013). Cost–benefit analysis for green façades and living wall systems. *Building and Environment*, *70*, 110-121.

Hunter, A. M., Williams, N. S., Rayner, J. P., Aye, L., Hes, D., & Livesley, S. J. (2014). Quantifying the thermal performance of green façades: A critical review. *Ecological Engineering*, *63*, 102-113.

Pérez, G., Coma, J., Martorell, I., & Cabeza, L. F. (2014). Vertical Greenery Systems (VGS) for energy saving in buildings: A review. *Renewable and Sustainable Energy Reviews*, *39*, 139-165.

Alexandri, E., & 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.

CHAPTER 4. APPLICATION OF A VGS INTEGRATED APPROACH TO THE CASE STUDY OF TEHRAN, IRAN

Introduction

The rise of populations and global warming are closely linked because human activities increase greenhouse gas emissions. Temperatures rose from 0.3 to 0.6 degrees Celsius in the twentieth century. In the next 50 years, temperatures are expected to increase by 0.6 to 2.5 degrees Celsius Khasnis & Nettleman(2005). IRAN is also affected by global warming. Little research has been done on global warming and its consequences on energy consumption, buildings, and thermal comfort by researchers in Iran (Roshan et al., 2012). However, many studies have focused on climate change in Iran (Amiri et al., 2010; Ahmadinejad et al., 2013; Abbasnia et al., 2016). In the future, Iran's climate is likely to be subject to rising temperatures, mild winters, and hot summers. Heatwaves become more intense, associated with increased energy consumption for cooling in homes (Roshan et al., 2012). As a result, urban warming is enhanced by using some building materials and forms, street shapes, and urban context. The transmitted shortwave radiation is mainly stored in the building and is emitted due to the high wave heat radiation into buildings and urban microclimates. It will exacerbate the heat island and cause damage or failure to infrastructure (increased cooling demand, power shortages), thermal discomfort and low productivity and health challenges (respiratory, heart, and kidney problems), and additional mortality (Ahmadnejad et al., 2013; Li and Bou- Zeid, 2013). The effects of climate change on the human-made environment demonstrate the urgency of studying, analyzing, and implementing climate change adaptation measures at building scales.

High temperatures and lack of water are the major problems facing climate hazards in Tehran. The human concentration in this region has increased the influence of hazards. Tehran is one of the world's largest cities, currently heavily impacted by air pollution, dust, and unexpected storms. The number of toxins rises so much on certain days of the year that it is almost difficult for humans to survive. The study's value derives from the fact that currently, there are more than 200 days of air pollution in the country's capital, with a population of tens of millions of inhabitants (Saligheh,2015). The rate of rising of the average annual minimum temperature in Tehran over 40 years has been observed. The findings have shown that the temperature increase rate is 0.065 °C per year (Ranjbar saadatabadi, 2005). In Tehran (Iran), residential buildings are the most significant part of buildings and operate inaccessible mode or rely on personal heating systems. Therefore, there is a need for buildings to have adequate protection against heat and to avoid active dual systems (heating and cooling) as much as possible. Protecting occupants from climate change effects requires a review of passive and bioclimatic design strategies across the country. VGS is accepted as an effective strategy in surface temperature reduction; therefore, widespread use contributes to overcoming the urban heat island effect. Identify and correct defects to enhance this strategy, considering social, economic, and environmental benefits. Thus, this research focuses on VGS and their thermal performance in the Tehran region in summertime regarding limitations and potentials.

4.1 VGIS design methodology

Basic approach

In general, the methods used to investigate the environmental benefits of the VGIS on reducing building envelop temperatures and reducing energy consumption consequently include three categories of theoretical, simulation, and observations. This research is based on the data collected from previous qualitative and quantitative studies to extract influential factors in a high-performance and cost-effective greening system in Tehran's dry region by considering Iran's water crisis. The study resources are formed from sources such as journals index in science direct, Scopus, conference papers, books, guidelines, reports, and Ph.D. thesis.
Following the convention of other systematic review papers, Scopus and Web of Science (WoS) were chosen as the two popular indexed electronic databases for their systematic reviews. This broad review was undertaken to collect the wide range of common words used to characterize VGS. The search terms were created to locate all relevant papers on VGS, including outdoor and papers that illustrated VGS in their studies based on its thermal behavior. The following are the typical search terms entered into the two databases: "Vertical greening system*" or "Green wall*" or "Living wall*" and "Green facade*."

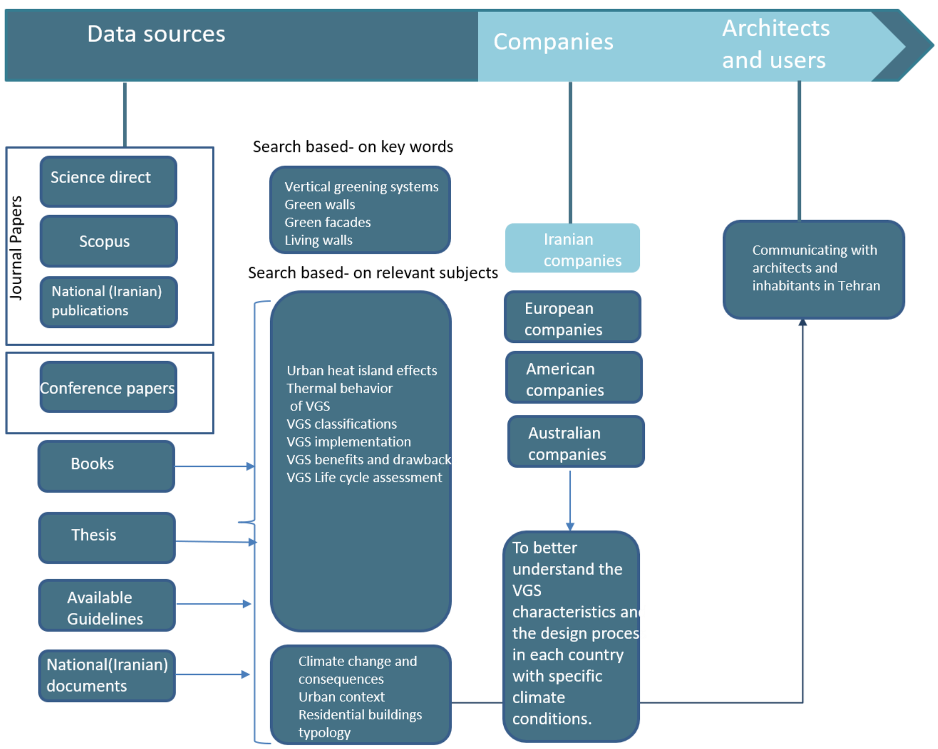


Fig 4.1 Data sources used in research

Studying and analyzing the classification performed on the green walls since 1998 and extracting the influential factors and a new division has been presented in two groups: green facades and living walls. The approach applied is primarily empirical, with the group of quantitative and qualitative data, and the benefits of the green walls are listed based on existing studies. A more

detailed analysis is performed on reducing energy consumption and the impact of green walls on reducing heat islands by referring to the studies.
Further in-depth analysis of available green systems on the market has been conducted based on the provided classification. This strategy is at the beginning of its path in developed and also developing countries like Iran. Thus, the number of active companies producing green walls in Iran is limited (Three companies producing hydroponic and one company planter-based living wall). To understand the mechanism and operation, and implementation of these systems and each of these companies' requirements from different European countries, Australia, the United States have been selected to understand systems' life cycle. The design process has been examined and concentrated on the production process in Iran due to the relevance of economic considerations and the emphasis of native plants. At this point, the drawbacks and significant barriers to deploying the green wall on a wide scale have been identified. Eventually, a new approach called an integrated approach was proposed to standardize this process, described in detail in Chapter 3. Comparisons have been made based on different phases, including pre-design, design, build-up, maintenance, monitoring, and disposal. Since two phases before design and monitoring are proposed in this new approach, but it should be noted that the monitoring phase is considered after the implementation to control the VGS's performance. The pre-design phase is also explicitly examined for the selected residential building after an initial comparison. Therefore, based on the determining factors in each phase, a comparison is made. Obviously, not all factors are equally important, so using the TOPSIS method to weighting the factors and comparison applied. The two selected green systems have been simulated by ENVI-met and analyzed to ensure proper thermal performance according to the design goal.

4.2 Basic Concept of Building Digital Simulation, ENVI-met

Computer simulation and modeling have provided an accurate and detailed appraisal of building energy design in the past decade. It is believed that building energy simulation is a powerful, analytical method for building energy research and evaluation of architectural design (Clarke 1985; Nall 1985; Seth1989; Newton, James and Bartholomew 1988; Hensen et al., 1993). Nowadays, ever-advancing technology and upgrading this simulation software's capabilities have encouraged architects to apply this technology to building design. On the one hand, awareness about new energy design tools in the market products and their abilities, considering that the variety of simulation tools and capabilities and limitations, is essential. On the other hand, practitioners should distinguish the best applications for achieving the design process's specific aim. Building energy simulation is important for the study of energy efficiency in buildings. Using modeling software like ENVI-met architect can enhance buildings' energy efficiency by predicting the system's functionality considering compelling aspects. ENVI-met gives extra meteorological simulations to replicate the area and take influential variables such as climate, materials, and atmospheric processes. Include wind flow, temperature, humidity, air turbulence, radiation, soil model, plant model, soil surfaces, building surfaces, and gases. Also, particles, initialization, boundary conditions, thermal comfort indexes, mean radiant temperature measurement, BOT world-dynamic comfort index calculation (e.g., Ali-Toudert and Mayer, 2004).
ENVI-met delivers a high-resolution simulation of the flow of heat and humidity to the building's façade and a projected measurement of the wall and indoor temperatures. Also, "urbanized" weather information can be created by ENVI-met to be used for building energy simulation tools.

It also offers a sophisticated plant model based on the plant's photosynthetic rate to simulate evapotranspiration, CO2 uptake, and leaf temperature.
The effects of various rising media and staging methods for the plants, vegetated walls, and roof structures can be simulated (Envi-met.com). Additionally, urban planners and architects looking at the microclimate would benefit from accurate modeling of the energy exchange between facades and the atmosphere: it also helps architects and building engineers better assess the energy needs for cooling and heating and monitoring the feedback between the building and its vicinity. ENVI-met is a prognostic three-dimensional climate model. The main difference between ENVI-met and large-scale atmospheric models used to predict the daily weather or future climate conditions is the temporal and spatial model resolution. With a typical spatial resolution between 0.5m and 10m and the time steps of ≤10s, ENVI-met simulates the interactions between the atmosphere, soil, vegetation, and buildings on a microscale level. Every single plant and urban structure can explicitly be simulated. ENVI-met is an ideal instrument for urban planners, engineers, and urban climatologists to model the urban environment's climatological elements (Huttner, 2012). Usually, the modeling target provides comfortable indoor conditions while maintaining acceptable fuel consumption levels, optimizing the system performance, or comparing different design options based on their life cycle costs. An additional module is required for the economic analysis (Hui, 1998).

4.3 Fuzzy TOPSIS method

Hwang and Yoon suggested the TOPSIS approach, which is a methodology for order choice dependent on similarities to an optimal solution (1981). In fact, TOPSIS can be compared the qualitative and quantitative data to compare and decide to choose the best alternative. This approach's fundamental theory is that the alternative should be closest to the positive ideal solution and furthest away from the negative solution (Chen,2000). In this method, quantitative and qualitative criteria are involved in the evaluation simultaneously while a significant number of criteria are considered.

Step 1: Create a decision matrix

Each column represents a measurement index, and each row represents an option. Xij indicates the quantity of option I under the j criterion. Also, the sub-criteria may be negative or positive depending on the effect on the options. Xij values can be decided based on a fuzzy spectrum entered into the matrix. To complete the fuzzy decision matrix, it can use the following range of 5, from the phrase "very low" to "very high."

$$\tilde{A} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \dots & \dots & \dots & \dots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix}$$

If fuzzy triangular numbers are used for analysis in this technique, its function will be

$\tilde{x}_{ij}\ (, c_{ij} , b_{ij}\ a_{ij})\ =$

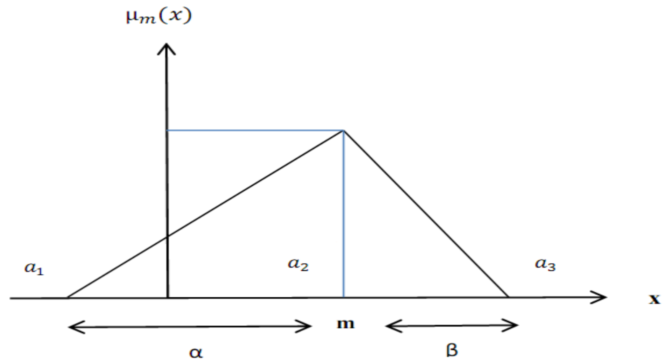


Fig 4.2 The membership function of triangular numbers in a fuzzy environment

Step 2: In this model, determining the weight matrix of criteria will be that the following equations are used to achieve this

$$w_{j1} = min_k\{w_{jk1}\}$$

$$w_{j2} = \frac{\sum_{k=1}^{k} w_{jk2}}{k}$$

$$w_{j3} = max_k\{c_{jk1}\}$$

Step 3: De-scaling of the matrix is a fuzzy decision, which is done according to the following equations

$$\tilde{r}_{ij} = \left[\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right]$$

$$\tilde{r}_{ij} = \left[\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{c_{ij}}\right]$$

In the above relations, $c_j^* = max_{i^*}\ c_{ij}$ and also $a_j^- = min_i a_{ij}$ will be. Due to the above relations, a fuzzy unbalanced matrix (R˜) will be obtained, which is formed by using the following equation.

$\tilde{R} = \tilde{r}_{ij})_{m\times n}$ I=1, 2..., m

Step 4: Among the calculated indices, there are indicators with a positive aspect and indicators with a negative aspect.

$$\tilde{v}_{ij} = \tilde{r}_{ij}.\tilde{w}_{ij} = \left\{\frac{a_{ij}}{c_i^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right\}.(w_{j1}, w_{j2}, w_{j3}) = \left\{\frac{a_{ij}}{c_j^*}.w_{i1}\,\frac{b_{ij}}{c_j^*}.w_{i2}\,\frac{c_{ij}}{c_j^*}.w_{i3}\right\}$$

$$\tilde{w}_{ij} = \left\{\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right\} w_{j1}, w_{j2}, w_{j3}) = \left\{\frac{a_j^-}{c_{ij}}.w_{i1}\,\frac{a_j^-}{b_j^*}.w_{i2}\,\frac{a_j^-}{a_{ij}}.w_{i3}\right\} \tilde{v}_{ij} = \tilde{r}_{ij}$$

Step 5: In this model, the calculation is close to fuzzy ideal and anti-fuzzy ideal. These states are calculated using the following equations, respectively.

$$A^* = [\tilde{v}_1^*, \tilde{v}_2^*, \dots \tilde{v}_n^*]$$
$$A^- = [\tilde{v}_1^-, \tilde{v}_2^-, \dots \tilde{v}_n^-]$$

In these relations, $\tilde{v}_i^*$ will indicate' best values and $\tilde{v}_i^-$ the worst value for the indicated.

Step 6: The distance calculation from the ideal will be positive and negative, for which the following equations have been used, respectively.

$$S_i^* = \sum_{j=1}^{n} d = (\tilde{v}_{ij}, v_j^*)$$

$$S_i^- = \sum_{j=1}^{n} d = (\tilde{v}_{ij}, v_j^-)$$

Step 7: The last step in this model will be to calculate the similarity index using the following equation.

$$cc_i = \frac{S_i^-}{S_i^* + S_i^-}$$

Based on the descending order of CCi, the available options of the assumed problem can be ranked.

4.5 Life cycle assessment of various VGS

Based on the proposed integrated approach that consists of six phases, all of the applicable criteria in each phase are introduced and available VGS compared to these criteria. Data extracted from previous studies communicating with companies and also guidelines.

Table 4.1 Life cycle assessment of Living walls in Design phase

Design	Climate Limitation	Material	Components	Stability of construction	Fire safety	Flexibility in Design	Aesthetic value
				Resistance in harsh weather	Rust resistance		
Continuous LW	High water demand, protection in extreme freezing temperatures	Minerals (arlite / vermiculite / perlite / sand): usually use to improve some of the main features of substrates such as aeration, moisture retention, structure, etc)	• 1. Universal substrate • 2. sphagnum moss • 3. Blonde peat • 4. Black peat • 5. Coconut fiber • 6. Minerals (arlite / vermiculite / perlite / sand) Fabric layer or porous screen • Waterproof membrane • Structural framework (optional) • Mesh lattice at the outer layer to hold a fabric layer against • wind (optional) • Irrigation system	Medium	Low	high	high
Geotextile felt system(continuous) Hydroponic system				Low	High		
Modular LW		Geotextile, felt and PVC foam sheet, ,PP	• Substrate • Drainage system • Waterproof membrane • Structural framework made of wood or metal • Irrigation system	Medium	low	High	High
Modular Soil-based Pocket			Modular components made of plastic, metal, or ceramic Substrate Drainage system Waterproof membrane Structural framework made of wood or metal Irrigation system	Medium	High		
Panel-based	Wind resistance to 140 mph	Recycled Water Bottles • Modular components made of plastic, metal, or ceramic • recycled polypropylene	• Waterproof membrane • Fixing rail • Living wall module • Vertical irrigation pipe • Mineral wools or other fibers as a growing medium	High	High	High	High
				High	High		
Planter boxes		UV-stabilized recycled polypropylene plastics. Stainless Steel, Aluminum	rails are extruded from 6063-T6 aluminum-Slot Rail (H-Rail)-Rain Rail-Rear Irrigation Feed ½" Female Thread) Soil, Irrigation Piping	High	780º F flashpoint and burn at 450º F	Low	High
				High	High		
Modular boxes		PP UV-stabilized recycled polypropylene recycled plastics. Stainless Steel, Aluminum	Soil, Irrigation Piping,	High	High	High	High
Pocket- based Hydroponic		Light metal frame, PVC, recycled polystyrene panel, Fabric (or felt	Pockets, substrate, drip line water, substrate	Medium	Medium	High	High

Table 4.2 Life cycle assessment of Living walls in Maintenance phase

Maintenance	Maintenance Cost	Maintenance frequency	Irrigating system service life / Irrigation check	Pipe replacement Main component replacement	Water demand	Fertilizer	The frequency of the pruning	The frequency of the Plant replacement
Continuous LW	270-380 euro/m2	Every 2 weeks	7.5 years	Every 7.5 years	Medium	1 per week	Every 2 years	Every 3.5 years
Geotextile Felt system			Monthly					
Modular LW	200-370 euro/m2	Monthly	7.5 years	Every 7.5 years		1 per week	annual	Every 2 years
Pocket- based modular LW			Monthly		High			
Panel-based	230-410 euro/m2	Monthly	7.5 years	Every 7.5 years	High	1 per week	annual	Every 3.5 years
			Monthly					
Planter boxes	220-310 euro/m2	Every 1 to 2 weeks-	7.5 years	Every 7.5 years	Every 14 days	1 per week	annual	Every 10 years
			Monthly					

Table 4.3 Life cycle assessment of Green facades in Design phase

Design	Climate Limitation / Harsh weather	Material	Components	Stability of construction / Resistance in harsh weather	Fire safety / Rust resistance	Maintenance frequency	Flexibility in Design	Aesthetic value
Cable wire system Two-dimensional system	Wind and hurricane, harsh rain	stainless steel	vertical cables, horizontal cables, rods, grids, or nets Galvanized	High 30 years	High	Every 3 months	Low	Medium
				high	Medium			
Trellis panel Three-dimensional Panels	Wind and hurricane, harsh rain	stainless steel	Galvanized connectors , galvanized coating bleed 3D panels , thin gauge steel wire	Very high	High	Every 2 months	Low	Medium
					Medium			
Grid system	Wind and hurricane, harsh rain	stainless steel	steel wires	Medium	High	Every 3 months	High	Medium
					Medium			
Premier flowerpot	Wind and hurricane, harsh rain	PP, wood	Water reservoir Hanger Substrate	High	High	Every 2 months	Medium	Medium
				High	High			

Table 4.4 Life cycle assessment of Green facades in Maintenance phase

Maintenance	Maintenance Cost	Maintenance frequency	Pipe replacement	Water demand	Fertilizer	Biological growth	The frequency of the pruning	The frequency of the Plant replacement
		The frequency of the pruning		Irrigating system control				
Cable wire system Two- dimensional system	6.65 euro/m2	annually	Every 10 years	Medium	Twice a year	Low	Annual	No need
		annually		Annually				
Trellis panel systems Three-dimensional Panels	1.50 to 1.80 euro/m2	annually	Every 10 years	Medium	Twice a year	Low	Annual	No need
		annually		Annually				
Mesh	1.50 to 1.80 euro/m2	annually	Every 10 years	Medium	Twice a year	Low	Annual	No need
		annually		Annually				
Grid system	1.50-1.80 euro/m2	annually	Every 10 years	Medium	Twice a year	Low	Annual	No need
		annually		Annually				
Flowerpot	2-3 euro/m2	annually	Every 12 years	High	Seasonally	Low	Monthly	Every 5 years
				Annually				
Direct Green facades	1 euro/m2	Every two years	No need	Low	No need	Low	After five years	No need
				No need				

Table 4.5. Life cycle assessment of Living walls in Build-up & disposal phases

Build up & Disposal	Manufacturing	Reusable material	Recyclable material	Longevity	Fire resistance	Disposal cost	Initial price
	Weight of construction				Rust resistance		Installation, supporting system & transportation
Geotextile Felt. Hydroponic system	20 kg	None reusable	None recyclable	10-15 years	Medium	25 euro/m2	400 euro/m2 - 750 euro/m2
					High		
Pocket-based	20 kg	None reusable	Recyclable	10-15 years	Medium	23 euro/m2	280 – 400 euro/m2 72 euro For implementing 4 pockets
					High		
Panel-based	30 kg	None reusable	recyclable	40 years	High	40 euro/m2	300 – 550 euro/m2
plastic					High		
Planter boxes	70 kg	Non reusable	Recyclable	50 years	High	28 euro/m2	120 euro/m2
					High		

Table 4.6. Life cycle assessment of green facades in Build-up & disposal phases

Build up & Disposal	Manufacturing Weight of construction	Reusable material	Recyclable material	Longevity	Fire resistance Rust resistance	Disposal costs	Initial price
Cable wire system	15 kg	Reusable	Recyclable	High 50 years	High High	15 euro/m2	123 -210 euro/m2
Trellis system	40 kg	Reusable	Recyclable	50 years	High High	20 euro/m2	170-320 euro/m2
Premier flowerpot	15 kg	nonreusable	Recyclable	20 years	Medium High	10 euro/m2	180-230 euro/m2
Grid system	20 kg	Reusable	Recyclable	50 years	High	15 euro/m2	130-180 euro/m2
Direct Green facades	7.00	No material	No material	50 years and more	High	6.00 euro/m2	20-35euro/m2

Curency € / m2

The green walls are compared according to the classification performed in Chapter 2 and considering the parameters derived in Chapter 3, described in the context of the Vertical Greening Integrated (VGIS) approach. It is evident that each system has its disadvantages and advantages**.** The current project's capacity and coordination with the form of the green wall chosen are critical considerations in the design procedure.

4.6 Case study description

Tehran was made up of a smattering of small villages surrounded by vast expanses of gardens, forests, and meadows. It is now a massive, sprawling metropolis with exponential development since 1970 and a lack of systematic green space planning as a coordinated structure. Some parts of Tehran have restricted facilities due to rapid population increase and subsequent sprawl public space areas for the different populations. Rapid rural-urban migration and urban population development have had a significant impact on the urban fabric. As a result, greenspace has become exceedingly scarce in recent years, and land use reform occurs on a wide scale in these regions (Saeifar and Mohammadnia, 2015). It will be the source of social issues among residents and negative environmental implications.

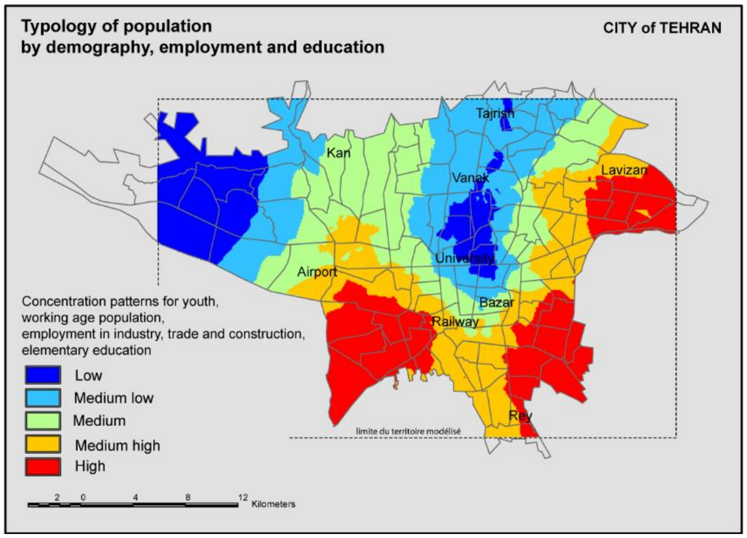


Fig 4.3 Tehran population typology focused on demography, jobs, and education, atlas of Tehran metropolis (2005)

Tehran's three main vegetation zones equate to the three major topographic zones in the region: forest, mountain-slope, and desert (Atlas of Tehran metropolis, 2005).

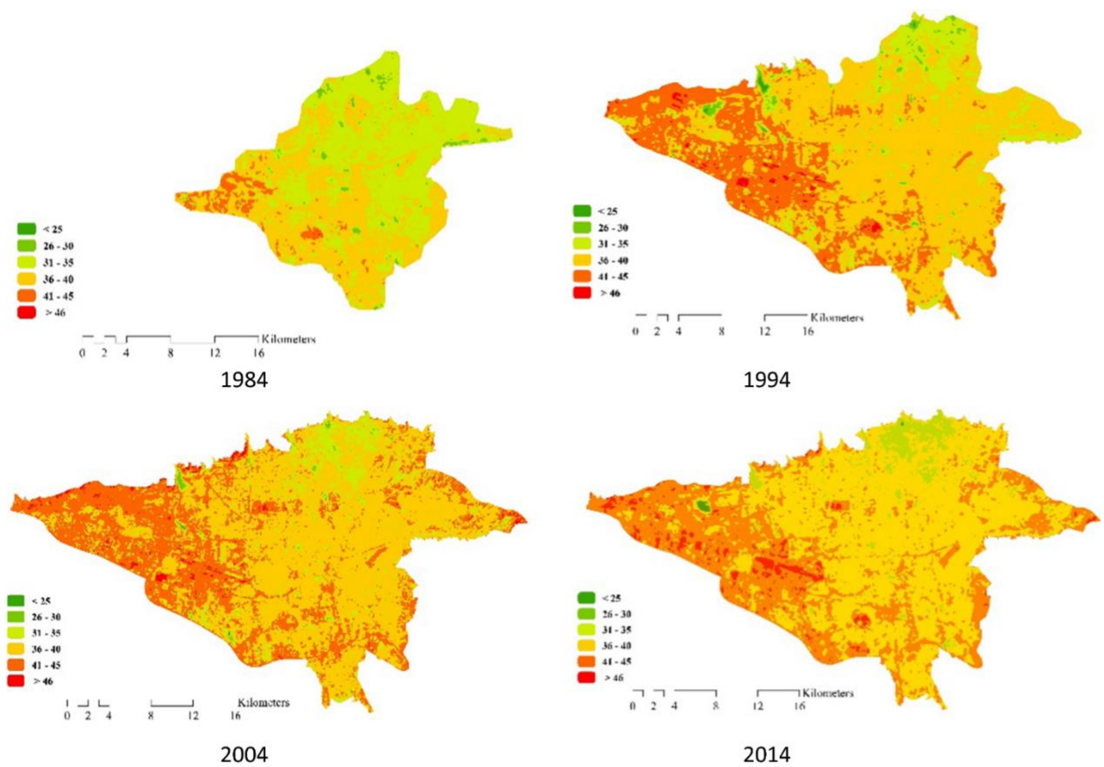


Fig 4.4 Maps of surface temperature in Tehran during the four study periods (numbers are in °C), (Tayebi et al., 2019)

4.6.1 Climatic condition

Tehran (35_400N, 51_190E,1191 m) is the largest city of Iran and the third-largest in the Middle East. According to the Koppen- Geiger classification, it features a mid-latitude steppe and cool semi-arid climate, known as Bsk. The air temperature is based on a minimum of 18 °C and a maximum of 25 °C as recorded in the Mehrabad synoptic station (Keyhani et al., 2010). Characterization of the climate can be found in Fig. 4.5 (Tehran Typical Meteorological Year data).

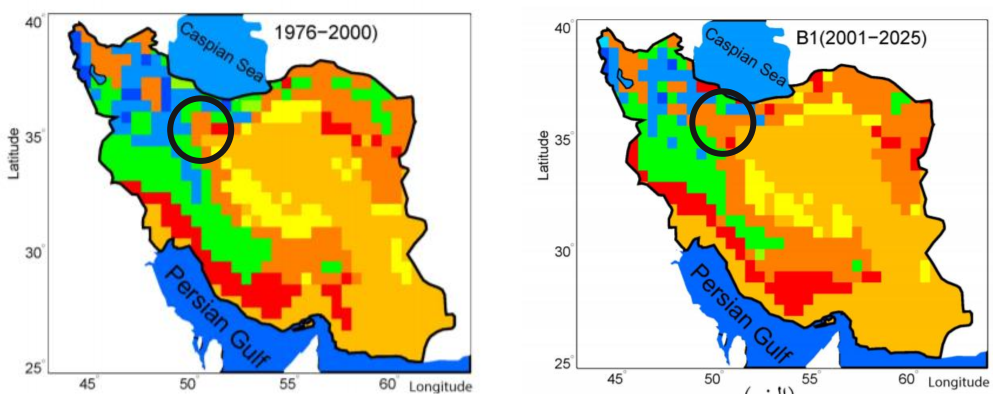


Fig 4.5 Iran climate condition based on Koppen- Geiger classification, from 1976-2000, prediction to 2025 respectively (Raziei, 2017)

- Tehran is geographically located at 51 degrees, 17 minutes to 51 degrees, 33 minutes east and 35 degrees, 36 minutes to 35 degrees, and 44 minutes north latitude. Tehran's current altitude varies from 900 to 1800 meters, although north-eastern Tehran has reached 2000 meters in some areas. Tehran is warm and dry (except its northern mountainous regions, which are slightly moist and mild). The maximum monthly temperature in Tehran 29 and at least 0.1 degrees Celsius. The average amount of rainfall in the city of Tehran is low, and the average in the last thirty years is about 220 mm during the year, and the number of frosty days is recorded 36 days a year (Khosravi et al., 2018).
- Teheran has a mid-latitude steppe/ semi-arid cool climate (Köppen-Geiger classification: BSk).
- According to the Holdridge life zones system of bioclimatic classification Teheran is situated near the warm temperate thorn steppe biome.
- The mean temperature is 17 degrees Celsius (62.6 degrees Fahrenheit).
- Average monthly temperatures vary by 28.3 °C (50.9°F).

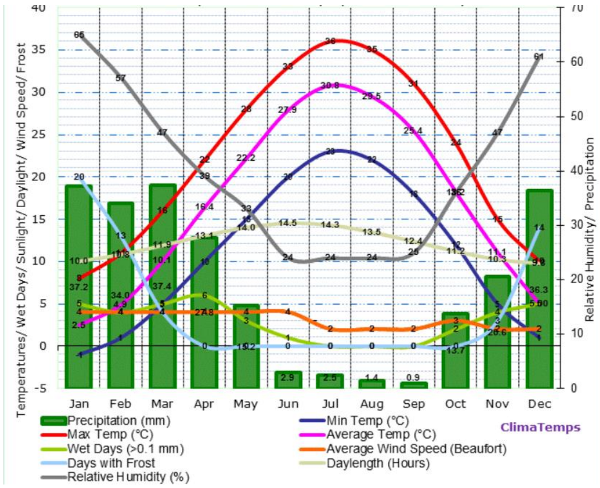


Fig 4.6 Tehran, Iran Climate graph, http://www.tehran.climatemps.com/

- Total annual Precipitation averages 229.9 mm (9.1 inches), equivalent to 229.9 Litres/m² (5.64 Gallons/ft²).

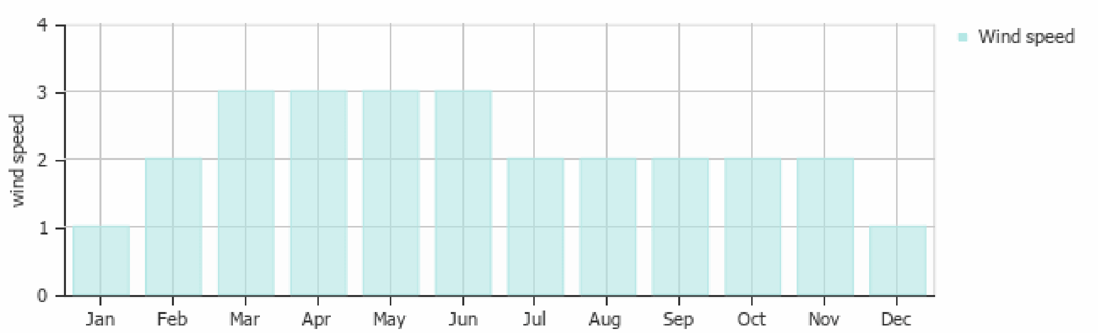


Fig 4.7 Average wind speed in Tehran, Iran www.weather-and climate.com

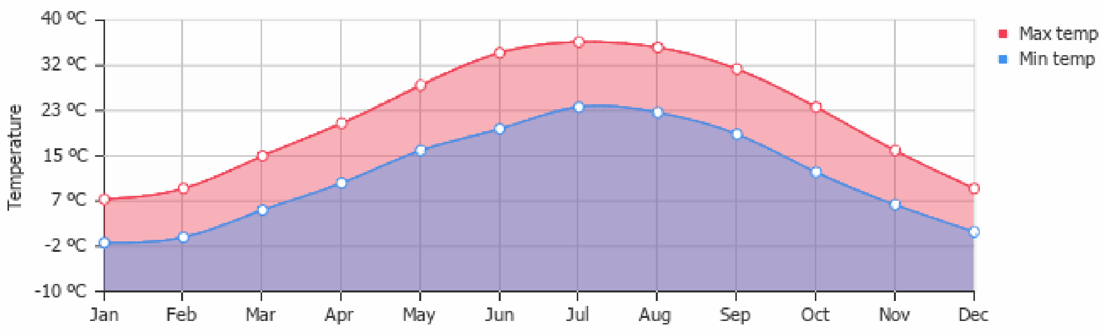


Fig 4.8 Tehran, Iran, Average minimum and maximum temperature over the year

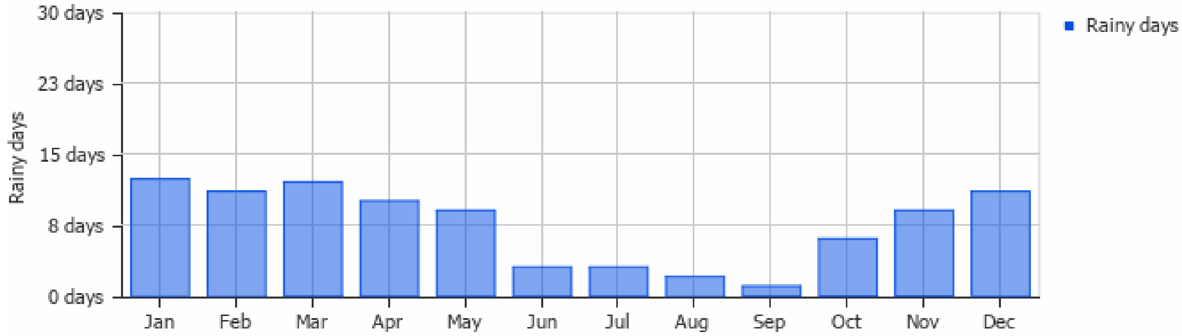


Fig 4.9 Average rainy days in Tehran, Iran www.weather-and climate.com

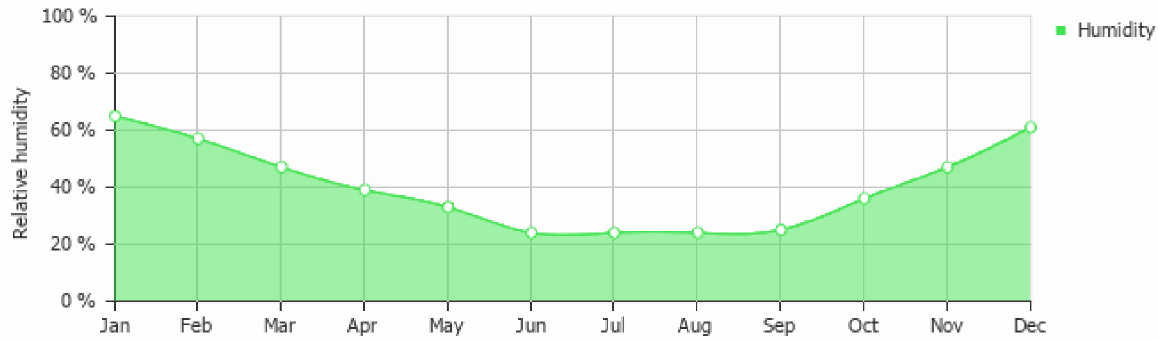


Fig 4.10 Average relative humidity in Tehran, Iran www.weather-and climate.com

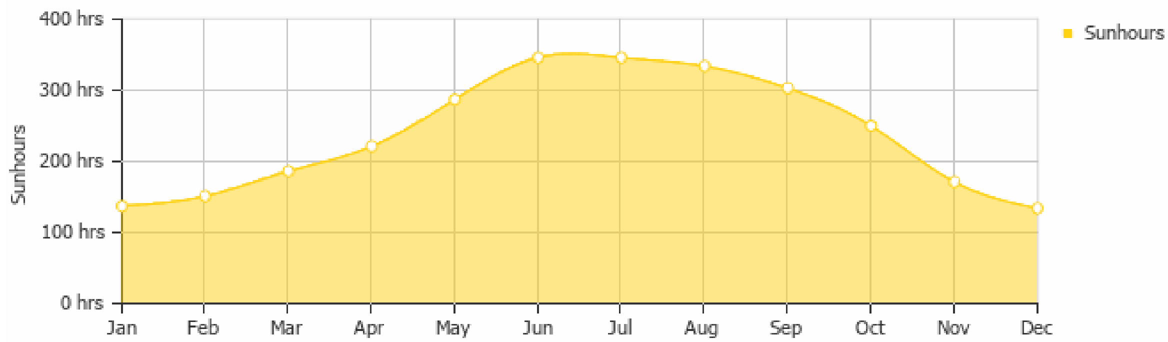


Fig 4.11 Average monthly sun hours in Tehran, Iran www.weather-and climate.com

The building in question is located in the north of Tehran. Most of the buildings in this area are residential, and there are some commercial buildings. In 2012, the building won the architect award in the residential sector. These are typical residential buildings in Tehran due to their height, material applied, and cubic form. The surface is made of brick materials and in some parts of granite. The hottest day of the year in Tehran was in July, according to weather data graphs. So, 14 July from 13 to 15 that are choosing to simulate. July is also one of the months with the least rainfall, and the water supply system study is also considered this month.

Fig 4.12 Site analysis of Cedar residential building

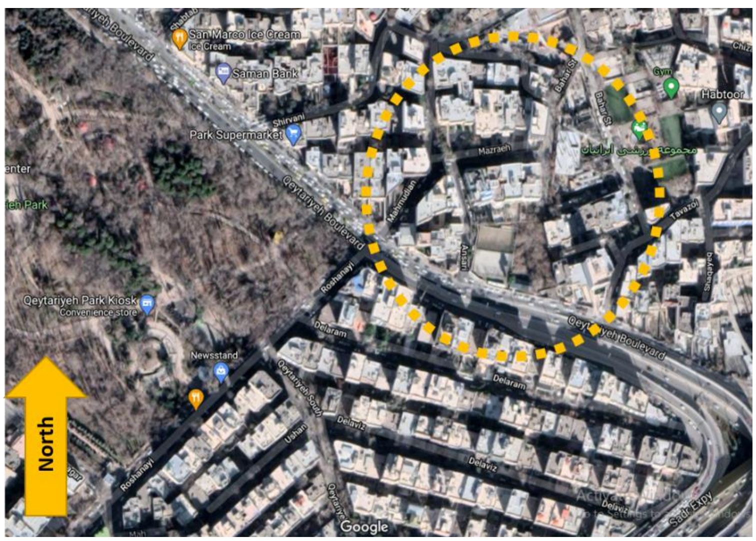


Fig 4.13 Site analysis of Cedar residential building

Fig 4.14 South-east face of Cedar residential building, cedarstudio.io

4.7 Design based on integrated approach

Pre-design phase

The first step in designing an effective VGS is deciding on a suitable greening system, as outlined in detail in Chapter 3. the most critical part is defining and prioritizing the green wall's goals. To choose the green wall type, analyzing the case study's potentials geometrically and physically is necessary. Some types are left out at this stage due to the impossibility of implementation. For example, the perimeter flowerpot alternative is removed in the studied building due to the smoothness and uniformity of the desired wall's outer surface without opening. Furthermore, according to the green wall's ultimate goal of lowering the surface's external temperature, it will not perform satisfactorily. Next, take the desired building's life span and calculate the green wall's pay-back time. As the life span of residential buildings in Iran is a maximum of 30 years, and the pay-back period of indirect green facades is typically 50 years, this alternative does not appear to be a good solution for this residential building. Due to the significant role of social and economic factors in determining the type of green system, residents prefer the green system that requires less maintenance, Particularly the presence of specialists in SEDAR residential buildings with Muslim inhabitants (Tehran) and their cultural traditions (defining the concept of privacy, especially for women). When choosing plants that need minor pruning, this point should be considered, as the green wall requires constant maintenance. Also, due to its height of 25 meters, pruning costs must be noted. Finally, the right one can be selected from the modular and continuous living walls and the direct green façade. According to criteria in other phases identified (Fuzzy TOPSIS method), these greening systems compare, and two alternatives will be chosen to simulate.

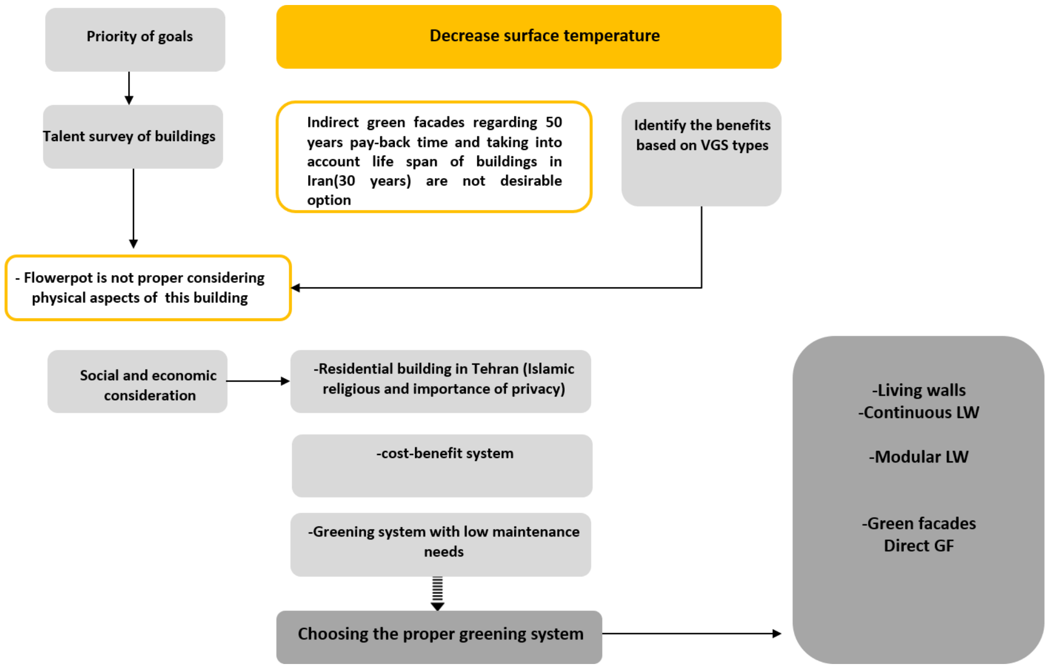


Fig 4.15 Pre-design phase analysis for the case study to choosing proper greening system

4.8 Comparison of various VGS based on Fuzzy TOPSIS method

This part compares current VGS based on the parameters derived and their relationship based on the integrated approach. It should be remembered that the various types of these structures that are in production and design in different countries have been researched, with the main aim of studying the change in various areas with different climatic characteristics and seeking existing gaps. However, according to Tehran's selected case study, the review of green building systems in Iran is essential. So, the tables provided display the green building systems in Iran.

It should be noted that two green systems (trellis panel and wire-rope net system) are not accessible in Tehran right now. Therefore, it is assumed that the systems produce in Iran and the costs of moving from Europe to Iran are not included. Since manufacturing companies are expanding and rising in developing countries like Iran, this sector is still in its early stages. As a result, they will launch their activities in the coming years. Moreover, in order to match the results, costs have also been entered in euros. The plants chosen were based on research undertaken by Iranian companies.

A variety of active examples of green hydroponic systems have been picked by analyzing one of the best examples of plants introduced in Tehran by Patrick Blanc, which consists of 120 plants and is compliant with the current situation. In the case of direct green façade, *Hedera helix* examined which is accessible and proper for planting in Tehran climate condition. The plants used are also based on botanical studies and selected by identifying the plant characteristics, growth habits, and rate. VG's most significant drawbacks are their high cost (Riley, 2017), so selecting a cost-effective VGS is helpful.

The operations and Maintenance stage has the most significant effect on a VGS's LCC (73.7-83.9%). In contrast, plant-related parameters, such as plant replacement rate and price, had an enormous effect on LCC variances (Huang et al., 2019). The difficulty of long-term maintenance requirements is one of the most critical challenges to establishing VGS in various parts of society (Perez et al., 2014). there is a need to design water supply systems for each building, taking into account all the aspects.

Depending on climate zone irrigation has been described as one of the cost contributors (Natarajan et al., 2014). Pruning and annual plant replacement, which can cost up to 50% in some situations, are examples of maintenance costs (Pe'rez-Urrestarazu and friends, 2015). However, 10 to 15% of plants must be replaced in living walls. Pipe degradation and replacement, if necessary, has hit 15%. Shipping costs would account for 6% to 10% of total costs (Rosasco, 2018).

Furthermore, the cost of disposal of living walls at the end of the green wall's lifetime is almost half of the installation costs, which is a significant sum (Rosasco, 2018). Thus, it should be taken into account in the design process. If optimally designed to prevent over-watering of plants, it can be augmented further with drip irrigation, drought-tolerant plants, a rainwater collection system, and irrigation without a pumping system, the energy payback-time carbon footprint may be reduced (Natarajan et al., 2014).

Also, due to the water crisis in Tehran, the amount of water demand is an essential factor that should be considered. Also, in February, there are harsh windy days chosen greening system must be resisted on this weather condition. In this study, the process of ranking in the TOPSIS method according to data extracted from previous studies, companies information, and analyzing the case study situation the grading of criteria to perform six greening systems and 18 criteria. In this regard, the collected opinions according to table 5 were converted into fuzzy numbers to enter the model and prioritize the criteria.

Table 4.7 Fuzzy number and linguistic options

Fuzzy number	linguistic options
(1 ، 1 ، 3)	Very low
(1 ، 3 ، 5)	Low
(3 ، 5 ، 7)	Medium
(5 ، 7 ، 9)	High
(7 ، 9 ، 9)	Very high

Next, an attempt was made to form a fuzzy scaleless matrix and a fuzzy weighted matrix for resilience components for 18 criteria in all six greening systems.

Table 4.8. Fuzzy weighted normalized matrix for 18 criteria in Modular soil-based pocket system

Indicators	Fuzzy min	Fuzzy mean	Fuzzy max
Disposal cost	0.277778	0.544444	0.9
Weight	0.055556	0.077778	0.3
Pay-back time	0.277778	0.544444	0.9
Flexibility in Design	0.055556	0.233333	0.5
Fire safety	0.277778	0.544444	0.9
Stability in harsh weather	0.277778	0.544444	0.9
Maintenance cost	0.166667	0.388889	0.7

Initial cost	0.277778	0.544444	0.9
Rust resistance	0.166667	0.388889	0.7
Longevity	0.277778	0.544444	0.9
Recyclable materials	0.055556	0.233333	0.5
Reusable materials	0.166667	0.388889	0.7
Maintenance frequency	0.166667	0.388889	0.7
Pruning frequency	0.055556	0.233333	0.5
Water demand	0.055556	0.233333	0.5
The frequency of the Plant replacement	0.166667	0.388889	0.7
Frequency of irrigation check	0.166667	0.388889	0.7
Irrigation system service life	0.277778	0.544444	0.9

Table 4.9 Fuzzy weighted normalized matrix for 18 criteria in Geotextile Felt system (continuous)

Indicators	Fuzzy min	Fuzzy mean	Fuzzy max
Disposal cost	0.277778	0.544444	0.9
Weight	0.277778	0.544444	0.9
Pay-back time	0.277778	0.544444	0.9
Flexibility in Design	0.388889	0.7	0.9
Fire safety	0.055556	0.233333	0.5
Stability in harsh weather	0.055556	0.233333	0.5
Maintenance cost	0.055556	0.233333	0.5
Initial cost	0.166667	0.388889	0.7
Rust resistance	0.277778	0.544444	0.9
Longevity	0.166667	0.388889	0.7
Recyclable materials	0.055556	0.233333	0.5
Reusable materials	0.055556	0.233333	0.5
Maintenance frequency	0.055556	0.233333	0.5
Pruning frequency	0.166667	0.388889	0.7
Water demand	0.166667	0.388889	0.7
The frequency of the Plant replacement	0.166667	0.388889	0.7
Frequency of irrigation check	0.055556	0.233333	0.5
Irrigation system service life	0.166667	0.388889	0.7

Table 4.10 Fuzzy weighted normalized matrix for 18 criteria in Panel-based

Indicators	Fuzzy min	Fuzzy mean	Fuzzy max
Disposal cost	0.055556	0.233333	0.5
Weight	0.055556	0.233333	0.5
Pay-back time	0.277778	0.544444	0.9

Flexibility in Design	0.055556	0.233333	0.5
Fire safety	0.277778	0.544444	0.9
Stability in harsh weather	0.277778	0.544444	0.9
Maintenance cost	0.055556	0.233333	0.5
Initial cost	0.166667	0.388889	0.7
Rust resistance	0.277778	0.544444	0.9
Longevity	0.277778	0.544444	0.9
Recyclable materials	0.166667	0.388889	0.7
Reusable materials	0.166667	0.388889	0.7
Maintenance frequency	0.055556	0.233333	0.5
Pruning frequency	0.166667	0.388889	0.7
Water demand	0.055556	0.233333	0.5
The frequency of the Plant replacement	0.166667	0.388889	0.7
Frequency of irrigation check	0.166667	0.388889	0.7
Irrigation system service life	0.166667	0.388889	0.7

Table 4.11 Fuzzy weighted normalized matrix for 18 criteria in Planter boxes

Indicators	Fuzzy min	Fuzzy mean	Fuzzy max
Disposal cost	0.166667	0.388889	0.7
Weight	0.277778	0.544444	0.9
Pay-back time	0.277778	0.544444	0.9
Flexibility in Design	0.055556	0.233333	0.5
Fire safety	0.277778	0.544444	0.9
Stability in harsh weather	0.277778	0.544444	0.9
Maintenance cost	0.277778	0.544444	0.9
Initial cost	0.166667	0.388889	0.7
Rust resistance	0.277778	0.544444	0.9
Longevity	0.277778	0.544444	0.9
Recyclable materials	0.277778	0.544444	0.9
Reusable materials	0.166667	0.388889	0.7
Maintenance frequency	0.055556	0.233333	0.5
Pruning frequency	0.166667	0.388889	0.7
Water demand	0.055556	0.233333	0.5
The frequency of the Plant replacement	0.166667	0.388889	0.7
Frequency of irrigation check	0.166667	0.388889	0.7
Irrigation system service life	0.166667	0.388889	0.7

Table 4. 12 Fuzzy weighted normalized matrixes for 18 criteria in Pocket- based Hydroponic

Indicators	Fuzzy min	Fuzzy mean	Fuzzy max
Disposal cost	0.166667	0.388889	0.7
Weight	0.388889	0.7	0.9
Pay-back time	0.277778	0.544444	0.9
Flexibility in Design	0.277778	0.544444	0.9
Fire safety	0.055556	0.233333	0.5
Stability in harsh weather	0.166667	0.388889	0.7
Maintenance cost	0.166667	0.388889	0.7
Initial cost	0.055556	0.233333	0.5
Rust resistance	0.277778	0.544444	0.9
Longevity	0.166667	0.388889	0.7
Recyclable materials	0.166667	0.388889	0.7
Reusable materials	0.055556	0.077778	0.3
Maintenance frequency	0.055556	0.233333	0.5
Pruning frequency	0.166667	0.388889	0.7
Water demand	0.166667	0.388889	0.7
The frequency of the Plant replacement	0.166667	0.388889	0.7
Frequency of irrigation check	0.166667	0.388889	0.7
Irrigation system service life	0.166667	0.388889	0.7

Table 4.13 Fuzzy weighted normalized matrix for 18 criteria in Direct green facades

Indicators	Fuzzy min	Fuzzy mean	Fuzzy max
Disposal cost	0.277778	0.544444	0.9
Weight	0.277778	0.544444	0.9
Pay-back time	0.055556	0.233333	0.5
Flexibility in Design	0.277778	0.544444	0.9
Fire safety	0.277778	0.544444	0.9
Stability in harsh weather	0.277778	0.544444	0.9
Maintenance cost	0.388889	0.7	0.9
Initial cost	0.277778	0.544444	0.9
Rust resistance	0.388889	0.7	0.9
Longevity	0.388889	0.7	0.9
Recyclable materials	0.388889	0.7	0.9
Reusable materials	0.388889	0.7	0.9
Maintenance frequency	0.388889	0.7	0.9
Pruning frequency	0.277778	0.388889	0.9
Water demand	0.388889	0.7	0.9
The frequency of the Plant replacement	0.388889	0.7	0.9

Frequency of irrigation check	0.388889	0.7	0.9
Irrigation system service life	0.388889	0.7	0.9

After calculating the fuzzy scale matrix for 18 criteria in all six systems, an attempt was made to calculate the distance index from the positive ideal, the distance from the negative ideal, and the final fuzzy similarity index, to determine the priority of criteria and systems. This process is described in the table below for all three areas. The design and construction of the green wall are split into 6 phases according to the Integrated approach and process separation. Each phase contains criteria that influence the whole process, and each has its value, so the weight of each must be considered. These criteria have been ranked and rated for each type of green wall, as seen in (tables 7-13). However, it should be noted that only 18 of the most relevant criteria have been chosen and scored for the final comparison of greening systems. For example, the disposal cost criterion has the highest weight in soil-based modular living walls. Also, fire resistance and life span, and resistance to harsh weather conditions have gained the same weight, which can be said that these factors are considered the advantages of this green wall. Simultaneously, the weight criterion takes the least weight, which is one of the disadvantages of this living wall. In various kinds of vertical green systems, the majority of the criteria were weighted in the same way.

Table 4.14 Fuzzy calculation and final weight and rank of 18 criteria in Modular soil-based pocket system

Indicators	S^+	S^-	CC_i	Rank
Disposal cost	0.504165	0.676958	0.573147	1
Weight	0.262871	0.245452	0.482867	5
Pay-back time	0.504165	0.676958	0.573147	1
Flexibility in Design	0.369183	0.478681	0.564573	4
Fire safety	0.504165	0.676958	0.573147	1
Stability in harsh weather	0.504165	0.676958	0.573147	1
Maintenance cost	0.436643	0.577778	0.569564	2
Initial cost	0.504165	0.676958	0.573147	1
Rust resistance	0.436643	0.577778	0.569564	2
Longevity	0.504165	0.676958	0.573147	1
Recyclable materials	0.369183	0.478681	0.564573	3
Reusable materials	0.436643	0.577778	0.569564	2
Maintenance frequency	0.436643	0.577778	0.569564	2
Pruning frequency	0.369183	0.478681	0.564573	3
Water demand	0.369183	0.478681	0.564573	3
The frequency of the Plant replacement	0.436643	0.577778	0.569564	2
Frequency of irrigation check	0.436643	0.577778	0.569564	2
Irrigation system service life	0.504165	0.676958	0.573147	1

Table 4.15 Fuzzy calculation and final weight and rank of 18 criteria in Geotextile Felt system(continuous)

Indicators	S^{+}	S^{-}	CC_i	Rank
Disposal cost	0.504165	0.676958	0.573147	2
Weight	0.504165	0.676958	0.573147	2
Pay-back time	0.504165	0.676958	0.573147	2
Flexibility in Design	0.355257	0.598352	0.627461	1
Fire safety	0.369183	0.478681	0.564573	4
Stability in harsh weather	0.369183	0.478681	0.564573	4
Maintenance cost	0.369183	0.478681	0.564573	4
Initial cost	0.436643	0.577778	0.569564	3
Rust resistance	0.504165	0.676958	0.573147	2
Longevity	0.436643	0.577778	0.569564	3
Recyclable materials	0.369183	0.478681	0.564573	4
Reusable materials	0.369183	0.478681	0.564573	4
Maintenance frequency	0.369183	0.478681	0.564573	4
Pruning frequency	0.436643	0.577778	0.569564	3
Water demand	0.436643	0.577778	0.569564	3
The frequency of the Plant replacement	0.436643	0.577778	0.569564	3
Frequency of irrigation check	0.369183	0.478681	0.564573	4
Irrigation system service life	0.436643	0.577778	0.569564	3

Table 4. 16 Fuzzy calculation and final weight and rank of 18 criteria in Panel-based

Indicators	S^{+}	S^{-}	CC_i	Rank
Disposal cost	0.369183	0.478681	0.564573	3
Weight	0.369183	0.478681	0.564573	3
Pay-back time	0.504165	0.676958	0.573147	1
Flexibility in Design	0.369183	0.478681	0.564573	3
Fire safety	0.504165	0.676958	0.573147	1
Stability in harsh weather	0.504165	0.676958	0.573147	1
Maintenance cost	0.369183	0.478681	0.564573	3
Initial cost	0.436643	0.577778	0.569564	2
Rust resistance	0.504165	0.676958	0.573147	1
Longevity	0.504165	0.676958	0.573147	1
Recyclable materials	0.436643	0.577778	0.569564	2
Reusable materials	0.436643	0.577778	0.569564	2
Maintenance frequency	0.369183	0.478681	0.564573	3
Pruning frequency	0.436643	0.577778	0.569564	2
Water demand	0.369183	0.478681	0.564573	3
The frequency of the Plant replacement	0.436643	0.577778	0.569564	2
Frequency of irrigation check	0.436643	0.577778	0.569564	2

Irrigation system service life	0.436643	0.577778	0.569564	2

Table 4.17 Fuzzy calculation and final weight and rank of 18 criteria in Planter boxes

Indicators	S^{+}	S^{-}	CC_i	**Rank**
Disposal cost	0.436643	0.577778	0.569564	2
Weight	0.504165	0.676958	0.573147	1
Pay-back time	0.504165	0.676958	0.573147	1
Flexibility in Design	0.369183	0.478681	0.564573	3
Fire safety	0.504165	0.676958	0.573147	1
Stability in harsh weather	0.504165	0.676958	0.573147	1
Maintenance cost	0.504165	0.676958	0.573147	1
Initial cost	0.436643	0.577778	0.569564	2
Rust resistance	0.504165	0.676958	0.573147	1
Longevity	0.504165	0.676958	0.573147	1
Recyclable materials	0.504165	0.676958	0.573147	1
Reusable materials	0.436643	0.577778	0.569564	2
Maintenance frequency	0.369183	0.478681	0.564573	3
Pruning frequency	0.436643	0.577778	0.569564	2
Water demand	0.369183	0.478681	0.564573	3
The frequency of the Plant replacement	0.436643	0.577778	0.569564	2
Frequency of irrigation check	0.436643	0.577778	0.569564	2
Irrigation system service life	0.436643	0.577778	0.569564	2

Table 4.18 Fuzzy calculation and final weight and rank of 18 criteria in Pocket- based Hydroponic

Indicators	S^{+}	S^{-}	CC_i	**Rank**
Disposal cost	0.436643	0.577778	0.569564	3
Weight	0.355257	0.598352	0.627461	1
Pay-back time	0.504165	0.676958	0.573147	2
Flexibility in Design	0.504165	0.676958	0.573147	2
Fire safety	0.369183	0.478681	0.564573	4
Stability in harsh weather	0.436643	0.577778	0.569564	3
Maintenance cost	0.436643	0.577778	0.569564	3
Initial cost	0.369183	0.478681	0.564573	4
Rust resistance	0.504165	0.676958	0.573147	2
Longevity	0.436643	0.577778	0.569564	3
Recyclable materials	0.436643	0.577778	0.569564	3
Reusable materials	0.262871	0.245452	0.482867	5
Maintenance frequency	0.369183	0.478681	0.564573	4
Pruning frequency	0.436643	0.577778	0.569564	3
Water demand	0.436643	0.577778	0.569564	3

The frequency of the Plant replacement	0.436643	0.577778	0.569564	3
Frequency of irrigation check	0.436643	0.577778	0.569564	3
Irrigation system service life	0.436643	0.577778	0.569564	3

Table 4. 19 Fuzzy calculation and final weight and rank of 18 criteria in Direct green facade

Indicators	S^{+}	S^{-}	CC_i	Rank
Disposal cost	0.504165	0.676958	0.573147	2
Weight	0.504165	0.676958	0.573147	2
Pay-back time	0.369183	0.478681	0.564573	3
Flexibility in Design	0.504165	0.676958	0.573147	2
Fire safety	0.504165	0.676958	0.573147	2
Stability in harsh weather	0.504165	0.676958	0.573147	2
Maintenance cost	0.355257	0.598352	0.627461	1
Initial cost	0.504165	0.676958	0.573147	2
Rust resistance	0.355257	0.598352	0.627461	1
Longevity	0.355257	0.598352	0.627461	1
Recyclable materials	0.355257	0.598352	0.627461	1
Reusable materials	0.355257	0.598352	0.627461	1
Maintenance frequency	0.355257	0.598352	0.627461	1
Pruning frequency	0.623697	0.632065	0.503332	4
Water demand	0.355257	0.598352	0.627461	1
The frequency of the Plant replacement	0.355257	0.598352	0.627461	1
Frequency of irrigation check	0.355257	0.598352	0.627461	1
Irrigation system service life	0.355257	0.598352	0.627461	1

Finally, by combining the obtained weights, the six systems were weighted and prioritized using a fuzzy model described in Table 4.13.

Table 4.20 Final weight and prioritization of the six systems

Systems	S^{+}	S^{-}	CC_i	Rank
Direct green facade	7.57044	11.15601	0.595735	1
Geotextile Felt system	7.576057	10.12362	0.571966	2
Planter boxes	8.197371	10.89615	0.570673	3
Pocket- based Hydroponic	7.6046	10.0885	0.570194	4
Panel-based	7.792425	10.30132	0.56933	5
Modular soil-based pocket	7.224842	9.535708	0.568938	6

As shown in (Table 4.25) the direct green facade has the highest ranking, and the soil-based living wall has the lowest. The continuous living wall made of felt is ranked second. It is worth noting that the distance between the positive and negative values in the felt-based living wall and the planter box is not especially big. Even with a gap of 0.2 from the continuous living wall, the pocket-based living wall is in the fourth position. As a result, two alternatives, a direct green facade and a felt-based living wall, are chosen and simulated on the targeted residential building in order to measure and assess their success in lowering the temperature of the facade's exterior surface.

4.9 Examined scenarios

After comparing all of eight greening systems (based on classification and description in chapter 2, two VGSs chose and simulated in the case study in three scenarios as follows:

-First scenario

The southeast facade, which is actually covered with Granite materials, was subjected to a simulation analysis with dimensions of 5 * 25 m2 (20% ratio) and a thickness of 20 cm. The surface of this section of the exterior is flat, and there are no openings. The first scenario is a facade that is not greened in order to isolate the thermal activity of chosen green walls.

-Second scenario

A direct green facade is a chosen option after comparing. *Hedera helix*, a climbing plant directly attached to the facade's surface, covers the green facade. Although same as indirect green facade pay-back time of direct green facade is about 50 years and considering the life span of a residential building in Iran. It is not reasonable, but because of low maintenance needs and a cost-effective greening system, this option simulates a better understanding of thermal behavior. If it has acceptable efficiency, it could be suggested as a VGS for future buildings in Tehran. As the most famous facade vine, *English ivy (Hedera helix)*, has an LAI of 2.6–7.7 Ottele(2011) 5.00 is an LAI of the *Hedera helix* in this study.

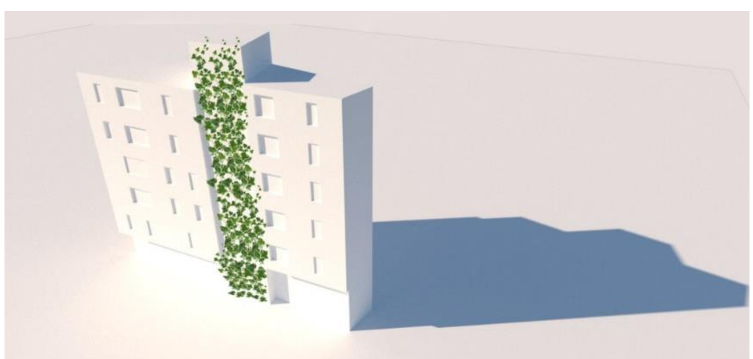


Fig 4.16 Second scenario, greening by Hedera helix (Direct green facade)

-Third Scenario

The ideal exterior is covered by a hydroponic living wall (felt-based) in the third example. Aluminum structure, substrate, insulation layer, anti-root plate and felt layer, and vegetation are the execution layers, respectively.

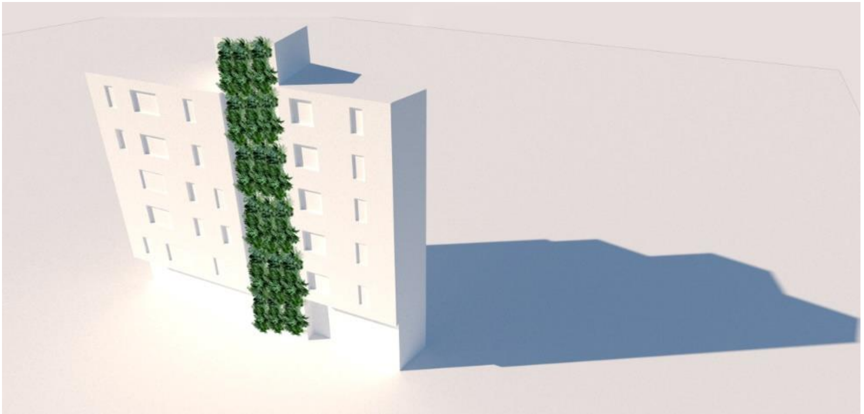


Fig 4.17 Third scenario, greening by Felt-based living wall

Plant selection

According to the green wall, the purpose is to lower the surface temperature plants selected. The creeping Hedera Helix was chosen as the test plant since the second scenario involves a direct green facade and climbing plants that may be utilized in this type of wall. It takes minimal maintenance and can be cultivated in Tehran. Previous tests have also confirmed this plant's adequate thermal efficiency (Holm, 1989; Stec et al., 2005; Perini et al., 2011; Perez et al., 2011b). Because of the variety of the selection, the plant selection procedure is based on what is shown in (figure 4.15) Searching for native plants that can thrive in Tehran's environment and are also ideal for planting in the southeast, which receives much sun, especially in the summer. By compiling plant lists used in green walls by companies and considering Patric Blanc's best practice in Tehran, comprehensive lists were created and chosen depending on the goal and conditions. Plants that require less water and require little maintenance are favored. Plant shade improves a facade's thermal efficiency when exposed to the sun (Susorova, 2014). *Hedera helix,* for example, cooled wall surface through shading effect. The cooling effects on hot summer days mainly depended on shading (Hoelscher et al., 2016). Also, Plant evapotranspiration can improve facade thermal efficiency by reducing heat conduction through external walls, lowering building cooling loads, and energy demand for space cooling (Susorova, 2015). Because shade and evapotranspiration are critical for surface cooling, plants with a high LAI and broadleaf are ideal.

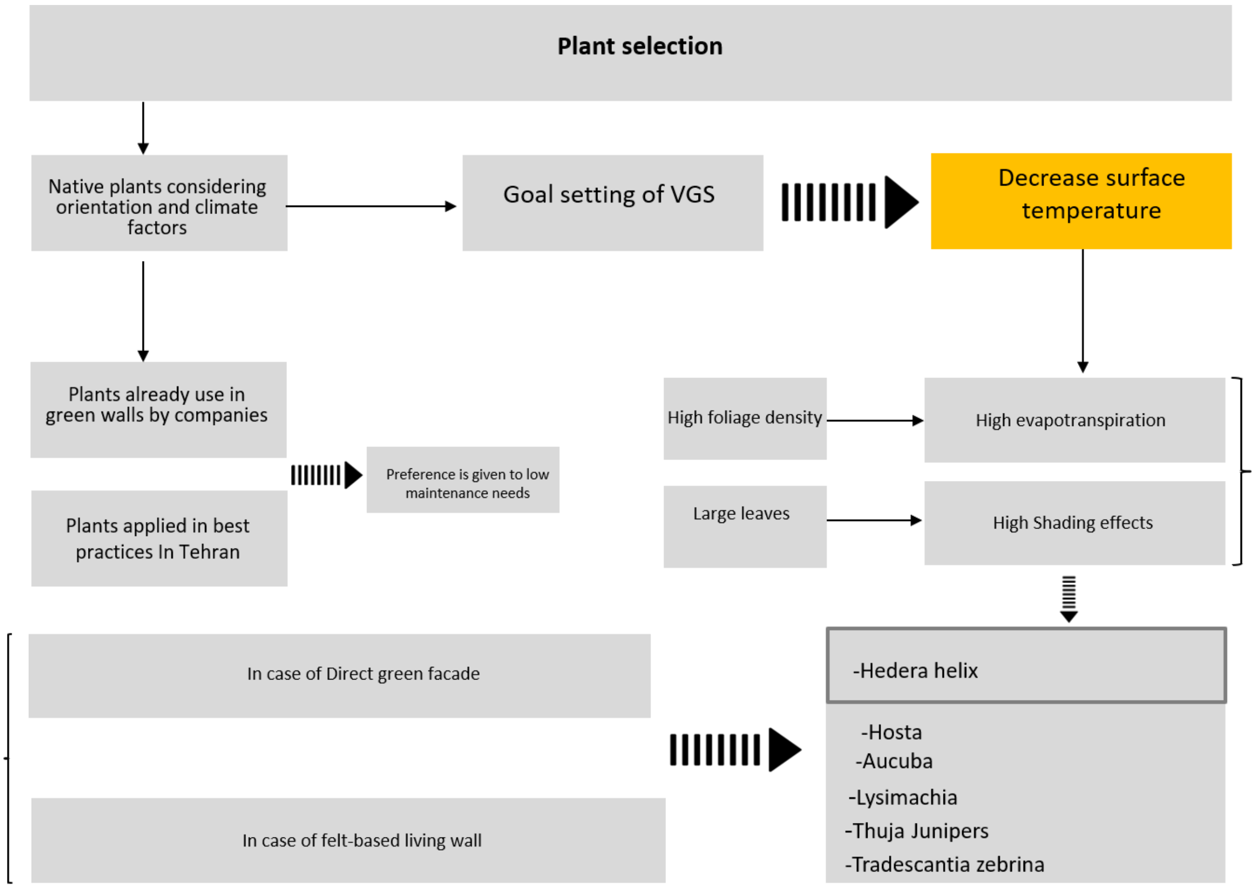


Fig 4.18 Process of plant selection

Table 4.21 Comparison of examined scenario

Criteria			
Climatic condition Bsk, cold semi aired Dry temperature summertime: 100 C° Humidity temperature summertime: 74 C° Daily temperature summertime: 27 C° Dry temperature wintertime: 22 C° Longitude: 51.38 ° E Latitude: 35.68 ° N Humidity RH%: 78 Average wind speed: 5.4 mph Amount of rainfal : 0.1- 0.5 inches Maximum air temperature: July (42.2 C°) Minimum air temperature: January (-12.8 C°) Maximum rainfall: January (43 mm) Minimum rainfall: Jun- July (2 mm) Maximum wind speed: 70 km/h		**Predict performance of the VGS** Hot weather in summer Low precipitation in Jun Windy days in March **Orientation:**South-east **Building ues:**Residential **Configuration** Coverage rate: 20% Number of fenestrations: 0.00 Height of building :25 m **Materials Chatachteristics** External wall U value: 1.3 W/m2K) Heat transfer coefficient: Granit: 1.6 to 7.7 W/mK Clay block: 0.51 W/m.K Cement mad: 1.50 W/m.K Gypsum: 0.09 W/m.K Insulation layer: 0.02 W/m.K	
	First scenario (without greening	**Second Scenario (Direct green faacd)**	**Third Scenario (Felt-based living wall)**
Aesthetic harmoony			
Color variation	❖	Green	Green, yellow, light green
Smell of plants	❖	No specific smell	Good smell of one speices another with no specifi smell
Substrate			
Type	❖	Soil PH : Acidic	Peat moss
Thikcness	❖	0.03 m	0.08 m
Moisture content percentage	15%		50-60%

Plant species		Hedera helix	Atriplex halimus LAI: 3.00 Tradescantia zebrina LAI 4.00 Lysimachia LAI 3.00 Aucuba LAI: 6.00 Achillea millefolium LAI:2.00
Leaf Area Index	❖	LAI 5.00	
Plant Average thickness	❖	0.20 m	0.30
Air gap	❖	0.00	0.07

Creating a space between vegetation and wall surfaces improves the effectiveness of living walls. The desire airgap was estimated to be 30 cm in Malaysian research (Saffikhani & Bahrvand, 2017). The number of studies on efficiency air gap is limited, and this study accounted for 0.07 m through talking with companies and evaluating researches. In Tehran, the average annual precipitation is 9.3 inches (236.2 mm), and January had the most precipitation on average, with 1.7 inches. "Precipitation totaled 43.2 mm, and June has the least precipitation on average, with an average of 0.1 inches " (2.5 mm) (https://www.weatherbase.com) and for design it regarded.
The exterior wall of the building consists of gypsum, clay block, insulation layer, clay block, cement sand mortar, and granite, respectively, from inside to outside. The Southeast façade chose to simulate various greening systems due to the highest sun exposure with a 20 cm thickness (detail of the outer wall figure.4.16).

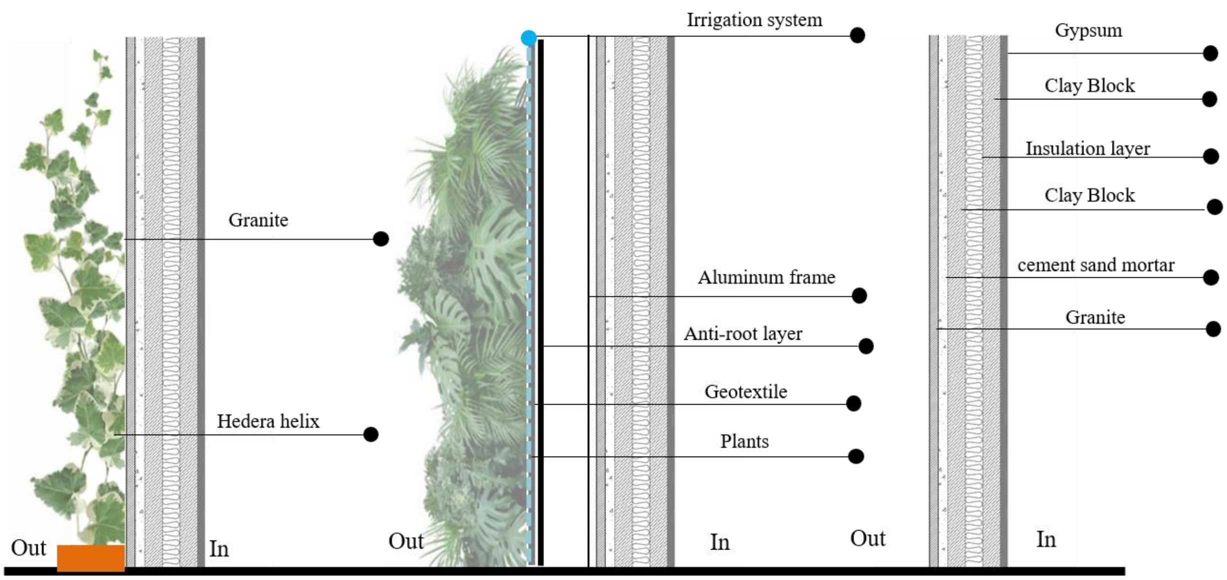


Fig 4.19 Details of reference and examined scenarios wall layers and thickness (outer to inner)

Table 4.22 Detailed description of facade in three scenarios

Layer number	First scenario		Second scenario		Second scenario	
	Layer name	Thikcness (m)	Layer name	Thikcness (m)	Layer name	Thikcness (m)
1	Clay Block	0.05	Clay Block	0.05	Clay Block	**0.05**
2	Insulation layer	0.05	Insulation layer	0.05	Insulation layer	**0.05**
3	Clay Block	0.05	Clay Block	0.05	Clay Block	**0.05**
4	Cement sand mortar	0.03	Cement sand mortar	0.03	Cement sand mortar	**0.03**
5	Granite	0.02	Granite	0.02	Granite	**0.02**
6			Plant layer	0.05	Aluminium frame	**0.04**
7					Anti root layer	**0.02**
8					Geotextile	**0.02**
9					Plant layer	0.35

Table 4.23 Build-up phase in three scenarios

Build- up advice	First senario	Second senario	Third senario
Manufacturing **Weight of construction** **Fire resistance** **Rust resistance**	❖	5 kg per mm2 No need to enhance No need to enhance	40 kg per mm2 -Adding material to enhance fire resistancee - No need to enhance
Assembling **Shipping** : wall tracking Installation Assembling	❖	Planting in place	Plantig in place

Table 4.24 Maintenance in three scenarios

Maintenance advice	First senario	Second senario	Third scenario
Irrigation system Water demand Water PH **Corrosion control** **Component replacement**	❖ ❖ ❖	1-3 12-30 liter/m2 depending on season Every three years ❖	12-30 liter/m2 depending on season ❖ Annually
Stability of construction	❖	Every three years	Annually
Pest control	❖	Annually	Seasonally check
Biological growth	❖	Annually	Seasonally check
Soil or substrate	❖	Every two years	Annually
Nutrient	❖	No need	Monthly
Remove foliage waste	❖	Annually	Twice a year
Prunning and pinching	❖	Annually	Twice a year

Table 4.25 Monitoring phase in three scenarios

Monitoring advice	Ceriteria	First senario	Second senario	Third senario
Outdoor weather conditions near to bar facade and behind vegetation layer	Temprature Humidity Wind velocity Precipitation	❖	Measuring by peack tech	

References

Papers

Saligheh, Mohammad, 2015, Climate change and hazards in Tehran, Spatial analysis environmental hazards, second year, number3, 15-32 pp
Ranjbar Saadatabadi, Abbas, 2005, Study of changes in wind and temperature fields in the metropolis of Tehran due to urban development, Geographical Research Quarterly 188-171

Chen, C. T. (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy sets and systems*, *114*(1), 1-9.
Hoelscher, M. T., Nehls, T., Jänicke, B., & Wessolek, G. (2016). Quantifying cooling effects of facade greening: Shading, transpiration and insulation. *Energy and Buildings*, *114*, 283-290.

Roshan, G. R., Orosa, J. A., & Nasrabadi, T. (2012). Simulation of climate change impact on energy consumption in buildings, case study of Iran. *Energy Policy*, *49*, 731-739.

Susorova, I. (2015). Green facades and living walls: vertical vegetation as a construction material to reduce building cooling loads. In *Eco-Efficient Materials for Mitigating Building Cooling Needs* (pp. 127-153). Woodhead Publishing.

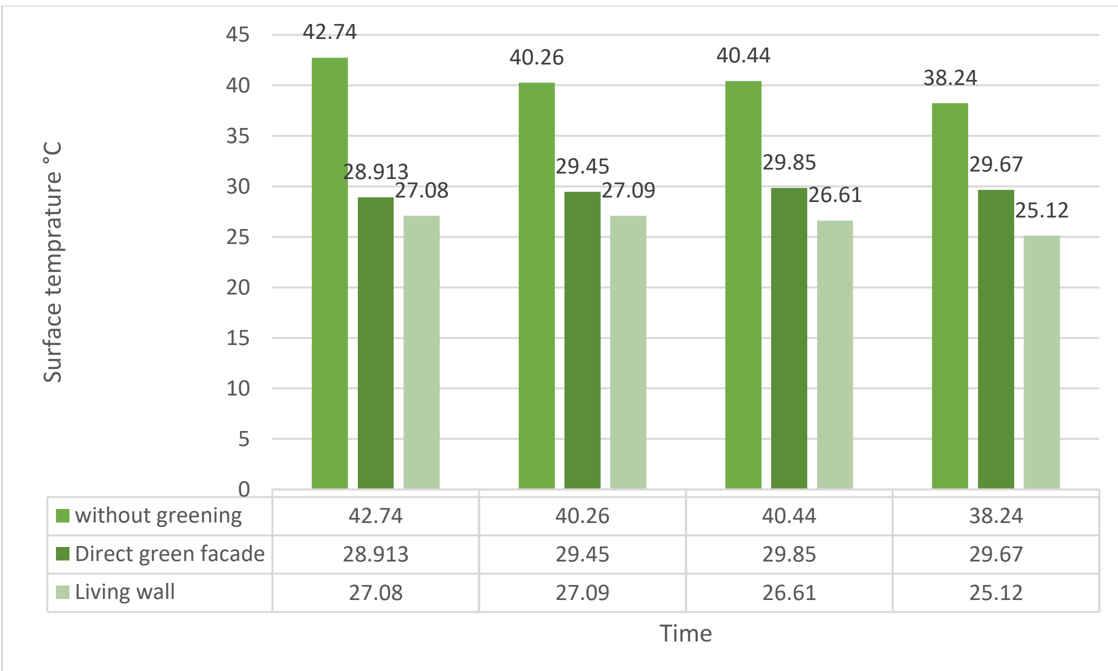
Website

(https://www.weatherbase.com)

CHAPTER5. RESULTS DISCUSSION AND PERSPECTIVE FOR FURTHER STUDIES

5.1 Results and discussion of the case study simulation

Outdoor simulations were carried out on the southeast exterior of a residential building in Tehran, Iran, during the hot summer day. To better understanding, the thermal action and climatic study periods for each scenario were defined. Surface temperatures of greened and bare walls with climbing plants like *Hedera helix* in the case of a direct green facade and the case of a living wall *Atriplex halimus, Aucuba, Lysimachia, Achillea millefolium, Tradescantia zebrina* were investigated. Because of the importance of solar radiation as an environment influencing force that affects the VGIS behavior, days with the maximum solar radiation intruding on the walls were chosen. The action of the most significant meteorological factors will be examined in the following parts during the reference days. It should be noted that the southern directions up to 30 degrees east are the most appropriate orientation for collecting solar energy during the year in Tehran.



without greening	42.74	40.26	40.44	38.24
Direct green facade	28.913	29.45	29.85	29.67
Living wall	27.08	27.09	26.61	25.12

Fig 5.1 Average surface temperature analysis of three scenarios

Without greening, exterior walls' surface temperatures reach a high of 42.74°C and a minimum of 38.24°C. When contrasting facades covered by *Hedera Helix,* temperatures reached a 29.85°C and a low of 28.91°C. The high and minimum temperatures for the living wall's facade were 27.09 °C and 25.12 °C, respectively measured during daytime. On average, the facade temperature in the three scenarios are 40.42 °C, 29.47 °C, 26.47 °C shows the difference between reference façade and the direct green facade is about 10.95 °C, with living wall is 13.95°C. The ΔTsurface between the green facade and living wall is about 3.00 °C. Obviously, the living wall is more efficient in reducing wall temperature. However, a direct green facade considering low maintenance needs and more cost-effective alternatives can be applied for projects in Tehran.

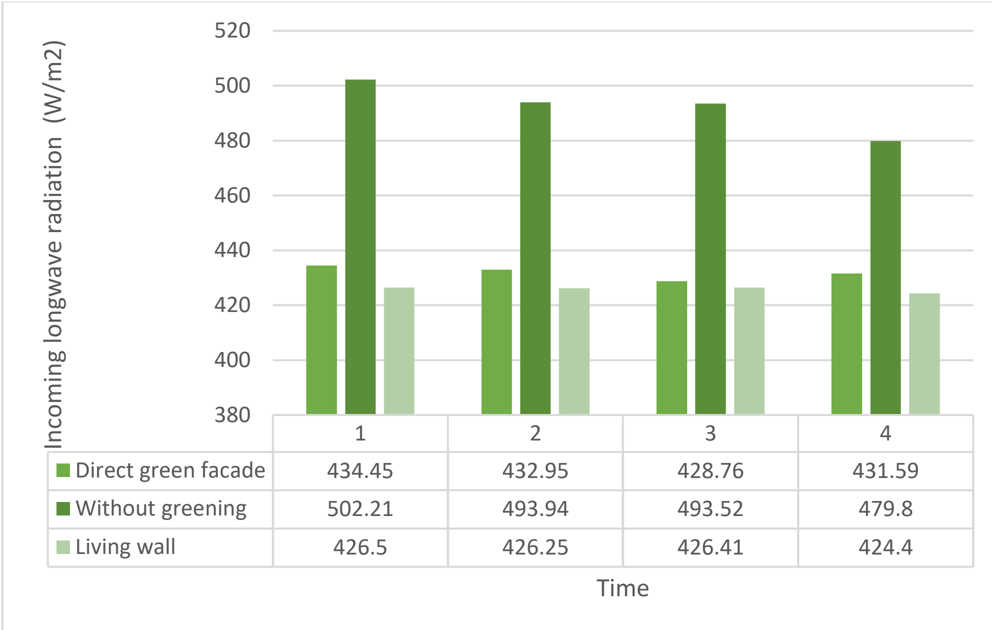


Fig 5.2 Incoming longwave radiation in examined scenarios

Greening uses the sun's heat energy for photosynthesis, which prevents the increase of air temperature due to the reflection of long-wave heat to the environment. Building envelope materials absorb large amounts of the sun's heat radiation and store it. Thus, warmer than the air beneath the urban canopy. It Reflects excess heat into the environment during the day and night and contributes to increasing ait temperature.

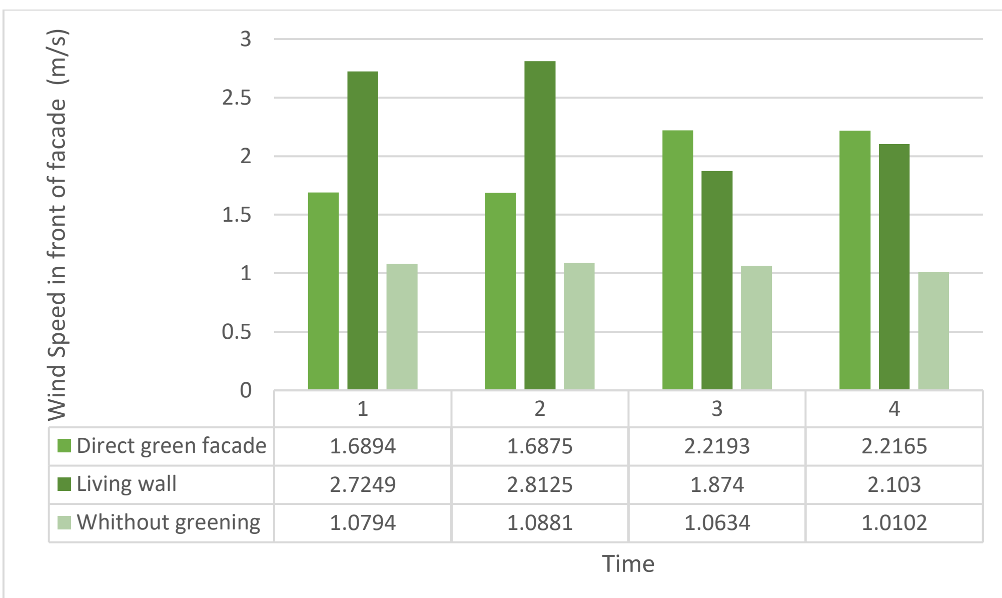


Fig 5.3 Wind speed in front of foliage (in examined scenarios)

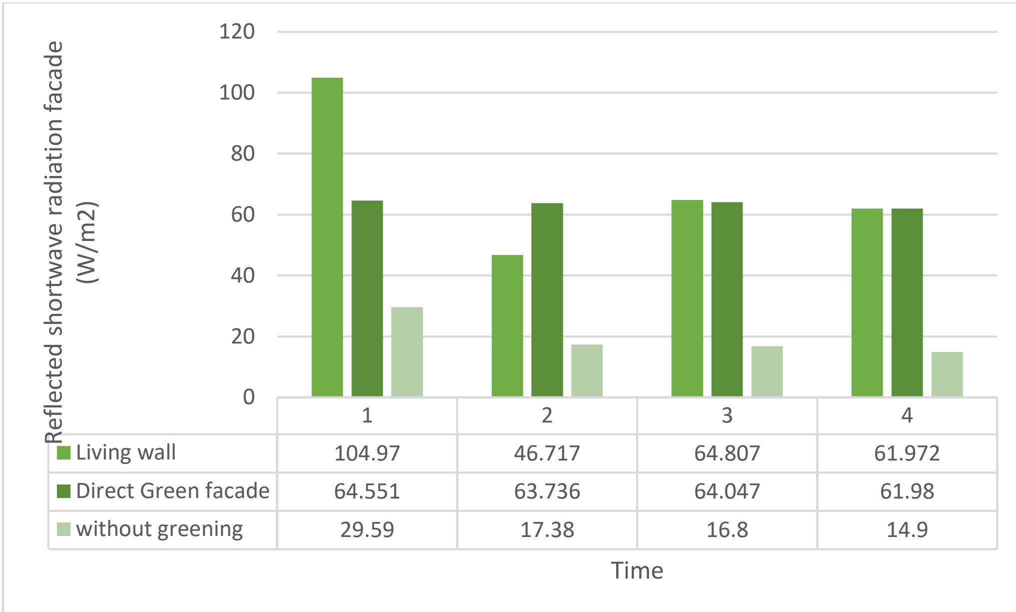


Fig 5.4 Reflected shortwave radiation facades in examined scenarios

As the lower the reflection coefficient, the more likely it is that the heat will increase at the desired level in the comparison of the three mentioned scenarios, the facade's external surface without greenery shows the lowest reflection coefficient. The continuous green facade shows the average reflection coefficient, and the living wall shows the highest amount. Absorption of solar energy by exterior surfaces exposed to radiation cause their temperature to rise to exceeded ambient temperature and its heat in the form of long-wave waves reflects on the environment which contribute to rise in air temprature.

5.2 Research outcomes

Due to urban growth, consequently, energy consumption rises, and the harmful effects of UHI will be increased. Greening envelope recommended as a valuable strategy to combat these effects. However, there is a necessity to analyze thermal behavior to ensure proper functionality in various climates. There is a need for a comprehensive view of various types of VGS and their classification and the main criteria for division. Systematic classification helps the designer to better understanding and have a reasonable perspective.

It should be noted that there are different terms used for greening like vertical greening systems, vertical greenery, green wall, green façade, living wall, façade greening, vertical garden for outdoor greening, and bio wall for the indoor one. In this thesis, vertical greening systems and green walls with the same concept mainly used. By collecting all resources that index in a web of science, books, and Ph.D. thesis firstly most popular classification of VGS collected and analyses secondly, thermal performance of different type extracted, and main criteria affected the performance identified based on climate zone. By searching the indicators that impact the VGS's thermal performance climatic factors of the study site (Mazzali et al., 2013), plants used (Hoelscher,2015; Mårtensson et al., 2015; Perini et al., 2017;), season and time of the research (Holm, 1989), orientation (Carlos, 2015), type of green wall (Wong et al.,2010), methodology and air cavity (Perez et al., 2014) and the characteristics of the substrate (Price, 2010) recognized as the main criteria. Traditional green facades, the earliest kind of VGS, were investigated in Japan in 1987 by Hoyano in a humid subtropical environment and shown in 1988 by the same researcher. With a drop of 13 ° C in the direct green façade and a decrease of 1-3 ° C in the double-skin green facade, the results show a substantial output of *Hedera*. Then, in 1988, Kohler studied direct GF in Germany, which revealed a reduction of 2-6 ° C. Although neither study provides information on plant thickness, direct ones can be utilized as a long-term strategy to lower surface temperature. No information was provided on the study site's research season, plant thickness, or climatic parameters. Stec et al. reported a 20 ° C reduction in surface temperature in 2005. In addition, Perez studied the performance of traditional and double-skin green facades in 2011 and found that the trellis panel reduced the temperature by 17.62 degrees Celsius.

The significant potential of a VGS in decreasing cold weather is verified by the decrease of yearly cooling energy consumption by around 34% with a green façade, 58.9% reduction of energy consumption in a hot season by a living wall, and 33.8 percent reduction by a double-skin facade confirmed by Sosurova. Research in Spain found no evidence of excessive energy usage during the winter season, whereas Stec et al. in 2005 recognized that the plant in the cold season might justify an increase in heat demand. Chan confirmed the maximum rate of surface temperature reduction by the living wall in Wuhan with a drop of 20.8 ° C per year, and (Mazzelli et al., 2013) reported in the north of Italy with a decrease of 12-20 ° C by the pocket based living wall. (Wong et al., 2010) demonstrated the relationship between the type of greening system and the ambient temperature altered by VGS. Studies indicate lower energy use in the summer, particularly in hotter climates, and lower heat in the winter. However, it is not feasible to assure adequate green wall performance in all climates owing to a lack of research on winter days and nights. Since the majority of researches were done in the warm temperature zone before continuing to the equatorial region, there is a lack of data, particularly in hot and dry regions suffering a water problem. According to research done by (Farrokhirad 2020) on a direct green facade covered with *Hedera* in Tehran, the surface temperature drops by 2.8-3° C.

Also, the main gaps identified include lack of study during the whole year; most of the studies conducted in summer definitely should be tested in all seasons. The most significant aspect in the thermal behavior of the green wall has been demonstrated to be the role of selected plants. Changes in system performance can be caused by plant features such as morphological and physiological factors. Only a few studies give enough information to readers about the plant's features, the most important of which is the Leaf Area Index. Moreover, the year-round study is required to understand seasonal variations and shifts in habit growth and their impact on thermal behavior. The number of studies considering the building usage and emphasizing the residential case study is rare, while it can interpret energy consumption patterns.
With the recent growth of production, designers have difficulty choosing which green system is appropriate for a specific project. Moreover, understanding their differences in composition and the main character is essential (Manso & Castro-Gomes, 2015). The study on VGS classification includes the classification of Gf and LW and subgroups. Green wall designers benefit from systematic classification, in which the intended subtype is determined and constructed (Jim, 2015). All green systems in the model must be categorized systematically based on design restrictions, technical characteristics, growing plant types, and weather constraints. Reviewing the current classifications is necessary since technological development is time-dependent, and its influence

on products has been compared in chronological sequence. By reviewing the classifications made by researchers since 1999, which was first done by Pech et al., it can be concluded that the classification was initially based on the plant growing method at the beginning of the emergence of green building systems and their use as an active environmental strategy.

Following Koehler's classification in 2008, (Eumorfopoulou & Kontoleon, 2009) divided green facades and living walls into two groups. *Green facades* are the traditional or direct type in which plants grow upward without any extra constructions. Also, the classification of the green facades into two categories, direct and indirect, is based on the previous classification of the living wall into three types of the planter box, based on felt layers proposed by (Perini et al., 2011). She proposed a new categorization in 2018 based on the amount of maintenance required, considering plant type and average price. Then (Susorova et al., 2013) divided green walls into two types: two-dimensional green facades and three-dimensional. The three-dimensional takes more maintenance than the two-dimensional.

Similarly, (Manso & Castro-Gomes, 2015) offered a categorization with minor subgroup variations. The living wall is divided into two groups: modular and continuous, with the distinction being that the continuous type accommodates lightweight constructions, whereas Sosurova classifies this group as a vegetated mat and hanging pockets. Perez et al. (2014) offered a comprehensive categorization based on a distinct viewpoint. Green systems must be maintained as technology advances, which has an impact on the overall system cost. (Jim 2015) created an analytical and systematic categorization. It is based on the types of plants utilized, divided into two categories: dependent climber (CGW) and mechanically independent herb-shrub (HGW). Furthermore, water needs, maintenance requirements, and nutrition are all factors to consider in this division.

The results of reviewing the divisions show that generally, VGS can be classified into two major groups: green façades and living walls according to the plant species and growing methods (Dunnett and Kingsbury, 2004; Köhler, 2008; Hunter et al., 2014), supporting structure employed (Kontoleon & Eumorfopoulou, 2010a; Maria Manso & Castro-Gomes, 2015a; Pérez-Urrestarazu et al., 2015; Fernández-Cañero et al., 2018) maintenance needs (Perez et al., 2014) and based on the key components and factors (Jim, 2015). It appears that the classifications developed so far have been connected to the study areas and accessibility to a variety of items. The impact of regional variables on researcher categorization cannot be overlooked. Because a system is developed and manufactured following climatic conditions and limits and the development of plant species in that geographical location, it is unconsciously offered as a standard system referred to as VGS localize classification. As a result, the popularity of techniques within the categorization is influenced by various factors, including geography, climate, cost, knowledge, and management. This study claims that climatic conditions have an essential influence in design, manufacturing, and other aspects of performance that numerous academics have studied. Finally, it indicates that it is feasible to create an economically viable and effective system in one region while imposing numerous limitations on its use in another place. As a result, despite the necessity to standardize systems based on specified criteria, one of the research's flaws is the inability to generalize these findings. This study provided an alternative schematic method to VGS classification based on the research background. The timeline depicts, and a new classification was presented to getting a more systematic evaluation. The new classification proposes regarding indoor and outdoor placement, plant growth methods, installation methods, and maintenance requirements. Therefore, Green facades, if directly attach to the wall or indirectly attach, are in two different groups of direct

Gf and indirect GF. From a growing method point of view, they are ground-based, rooftop-based, wall-based, and flowerpot-based. Considering plant growth method will be self-clinging, and plants need supporter and also hang down plants. Indirect green facades based on application method are consist of mesh (two and three-dimensional) cable systems and perimeter flowerpots. Outdoor living walls include modular and continuous ones. Planter boxes, pocket-based (hydroponic or soil-based), and panel-based are part of modular living walls, and vegetated mat (geotextile) is in continuous section.

Finding the gaps in design process of greening system in buildings: by examining the process of designing green walls in companies and the extent of their interaction with architects, it became clear that most companies follow the same process in design, and architects do not play an influential role in choosing the type of green wall and its location and characteristics.

VGS design lacks a technical standard (Tedesco et al., 2016). It is important to establish a technical standard and standardize the design process to ensure that all factors are considered and stress a multi-criteria design approach (Assimakopoulos et al., 2020). standardization in design and construction can assist the green walls succeed and decrease the chance of error. It's worth noting that green wall manufacturers are currently creating each one according to their own program, which occasionally overlooks aspects that might have a major impact on environmental performance and economic efficiency. It is important to develop a set of technical (structural requirements, maintenance, and execution) as well as non-technical (social, economic) standards that can be applied to all sorts of green building systems. Manufacturing companies will have a baseline by identifying the most significant factors at each stage, as well as the degree to which they are related to one another.

This issue causes more focus on the issues and finding existing gaps, including not paying attention to the social and economic factors of the design context, lack of clear goals, less attention to the scale of the executive project considering expected benefits, and alignment with goals. Also evident is the principal function of botanists in the plant-based solution, the limitation of this role to horticulture, and the minor involvement of users in the maintenance portion. In general, it can be said that the stage of choosing the type of VGS, which is an essential step in its usefulness, is ignored. It means that the selection is based on the company's existing products and is presented to customers and choose by customers with a priority of aesthetic values. However, determining the purpose of designing and advancing the design process on this basis is necessary. In this regard, due to neglect of the target, no action is taken to control the target, including lowering the surface temperature, clearing the air, sound barrier, biodiversity. Therefore, in the proposed approach (VGIS), the monitoring phase is proposed to control environmental factors to ensure proper performance periodically. Due to the different seasonal performance, product evaluation and definition of seasonal performance labels have been recommended, which assures customers of the proper performance of the green wall.

The main obstacles of widespread adaptation of VGS: The beneficial impact of plants on reducing the urban heat island phenomena is only noticeable if there is a large area of the same area is green (e.g., gardens, parks, many green facades) (Onishi et al., 2010). These 'designed experiments' could feasibly satisfy aesthetic and functional design criteria by involving architects, engineers, urban planners, plant biologists, horticulturalists, and soil scientists (Hunter et al., 2014) while also allowing rigorous research with adequate replication (Felson & Pickett, 2005). The biggest issue impeding the growth of living walls is their **high cost** (Riley, 2017), which includes the cost of installation, design, maintenance, and eventual removal. All procedures in the life of VGS support agents are covered by three primary types of duplicate cost components: manpower, equipment, and applications (Huang et al., 2019). **destructive environmental effects, high water demands, dependency on long term maintenance by experts, varying by climate condition, high water demand, dynamic system and depending on time** are recognized as the main challenges. Some of them can be minimize by solution and another one is part of VGS. Analysis combined with technology may be a solution to solve the green wall's current difficulties.

Reviewing the researches, case studies in Tehran, communication with companies, environmental, economic and social factors in Iran, the **water scarcity** were identified as the most critical obstacles to developing this solution. Also, countries in economic crisis, such as Iran, although have a significant share in global warming, no effective action has been taken to reduce its harmful effects in general. The most important factor is the issue of the economy and the lack of priority of climate change by the inhabitants. This approach (VGIS) contributes to the desire of residents of different cities and countries with different socio-economic levels to take advantage of green walls. Because paying attention to users' **project context** and **inhabitants lifestyle** can be influential in choosing the right option. For example, in this case, which is located in Tehran, due to the type of definition of privacy in Iranian culture and due to religious views, the emphasis is on reducing the frequency held by experts and the absence of strangers in the home for maintaining the VGS. This difference in the type of use, such as commercial buildings, museums, hotels, etc., can offer other options according to socio-economic factors. Therefore, the purpose of systematizing the design process apart from enhancing the performance of VGS is to help expand this strategy on a broader scale for greater effectiveness. In this study, these factors were considered simultaneously in the pre-design and design phase. The results of this study can improve the VGS performance, which leads to reducing the negative effects of global warming, improving the urban landscape, and positive psychological effects on citizens. More people tend to these greening systems, increasing demand and financial prosperity of manufacturing companies.

Proposed approach to enhance greening system performance and helps to widespread use of this plant-based solution: The integrated approach Vertical Greening Integrated approach proposed with six phases considering inter-phases and intra-phases relationship between criteria defined in four level.

Pre-design: In this phase critical decision about choosing a type of VGS considering all factors will make. As (Manso & Castro-Gomes, 2015) declare, the choice to execute the green wall type more suited for a specific project would depend not only on the design and climate factors but also on its elements on the atmosphere-related costs over its life cycle.

Buildings of varying social class, as in general, differ in the level of technologies used in green walls, can produce a set of patterns. Because of the pre-design process, studies and analyzes social and economic influences, which are among the most critical barriers to VGS growth today, this approach can be applied to a broader building field.

Goal setting and prioritizing goals: Although VGS are multifunctional, each greening system (depending on the type, including the green facade and the living wall, the structure, and the types of plants used) can fulfill one of the benefits. Therefore, there is one primary objective and several secondary objectives in the creation of VGS. They can be set based on the project's environmental and physical, and geometry, height, social and economic characteristics of the projected context.
Specify the scale of project implementation: The pre-design phase analyzes and evaluates the objectives and prioritizes them based on examining the project's existing potentials and the project platform from an economic, social, and environmental perspective. Benefits generated from VGS can be connected to a number of scales; their effects on the district or city scale; and some work specifically on the building scale (Dunnet N, Kingsbury, 2008; Kohler, 2008; Perini & Rosasco, 2013; Wood et al., 2014). Residential buildings, due to the share of energy consumption, can be devoted to a specific scale.

Talent identification: An inventory should be studied before and after the project implementation to evaluate the appropriateness of planting, achievable soil volume, solar direction, drainage, water availability, and climate restrictions. It will also aid in selecting the appropriate plant material, as plants do not respond to each of these characteristics in the same way. Location and climate conditions are primary considerations used in the design process (Dahanayake & Chow, 2017). In the case of existing buildings, this issue needs to study in-depth and deal with more difficulties. To optimize the greenery advantages, it is advised to take deeper note of plant selection aligned with building architecture and the local environment.

Design

Building characteristics: The thermal behavior of GW is related to **building characteristics** like height, orientation, material, form, and building use. As demonstrated by (Assimakopoulos et al., 2020), a clear impact of the form of the building envelope and the wall thickness on the heat transfer of the building on the efficiency of the LW system.
GW characteristics: Include greening type, construction, materials, equipment and components required, coverage percentage, plant species, substrate. Moreover, more importantly, **climatic factors** like solar radiation, temperature, relative humidity, rainfall, wind, and extreme weather condition. Climate not only directly affects the thermal performance but also specific aspects of plants such as their growth (leaf density, plant height) and their physiological responses (transpiration, leaf position) and thus more from the thermal behavior of the whole system. To stay alive, plant-covered walls require enough light, oxygen, water, and soil. These criteria are affected by climatic variables, so it is essential to assess the project according to them, including temperature, annual and monthly precipitation, humidity, and wind. Plants should be drought resistant and able to thrive in extreme weather conditions.
The VGS height: Due to the choice of the green system's type, the plants that can survive and grow in height and, consequently, the type of maintenance, the maximum height, and growth rate are effective. Moreover, the height at which the greenery connects to the main façade results in different thermal performance.

The findings of the experimental analysis on living walls to measure the effect of height on the thermal efficiency of VGS show that air temperature reduction by the sky garden (29.0) °C and the balcony garden (30.4) °C (Taib, 2010).

Substrate: Moisture content and thickness are important factors affecting the thermal performance of LWs. Maintaining sufficient moisture levels in the substrate is essential for keeping plants healthy and maximizing the cooling impact of transpiration (Cheng et al., 2010). Also, increasing the substrate thickness from 6 to 8 cm improves the insulation capacity of LWs and significantly increases energy savings for space cooling from 2% to 18% (Stav & Lawson, 2011).

Airgap: Airgap between facades and the vegetated wall is another factor that affects the thermal performance of VGS. between four different distances - 30 mm, 200 mm, 400 mm, and 600 mm - the results of an experiment showed that LW with the lowest air gap of 30 mm had the best performance about the lowest wall surface temperature of the outdoor building (Chen et al., 2013). (Perini et al., 2011) investigated the relationship between air cavity thickness and the thermal insulation properties provided by green walls. They found that direct greening facades and living walls (with a 4 cm air gap) were more effective in reducing wind speed around the facade of the building than indirect green walls (with a 20 cm air gap) due to the shorter distance from vegetation and walls.

The coverage percentage: An analysis simulated building with varying greenery coverage found that the rise in coverage proportion will dramatically decrease the mean radiant and ambient temperature. The entire green coverage surface contributes to energy saving is more important.

A 20.5 percent reduction in energy demand for cooling a building can be accomplished (Wong et al., 2009). The direct association of the green façade with plant coverage on the building façade was identified (Yin et al., 2017).

Plant species: The success of VGS mainly depends on the selection of suitable plant species (Kalani et al., 2017). Plant and substrate characteristics are the main factors that affect energy performance (Charoenkit and Yiemwattana 2016; Pérez et al., 2015). It implies that VGS with less vegetation has an unpleasant impact in the winter rather than a cooling effect (Kalani et al., 2017). Plants may increase heat demand (Stec et al., 2005) due to thermal insulation offered by vegetation and substrate (Hoyano 1988; Papadakis et al. 2001) if the plants have not been picked well enough and the climatic conditions have not been evaluated.

Many plant species have not only different cooling capacities but also different surface cooling mechanisms. Therefore, to select plants to optimize cooling in green wall applications, various plant physiological parameters such as leaf area index, leaf absorptivity, and average leaf dimension (Susorova et al., 2013), and morphological characteristics should be considered (Cameron et al. 2014; Montiro et al., 2016). Plants can respond to climate change by changing their leaf traits. Plant species selection relies on various factors, including preferential visual impact, plant species availability, water, nutrient requirements, environmental conditions, and system configuration.

The main physiological parameters: Several studies highlight a strong inverse relationship between LAI or the number of leaf layers and sunlight transmission from the green landscape (Hoyano, 1988; Ip et al., 2010; Susorovaet al., 2013). It is recommended that plants with LAI 4 or higher be preferred for LWs because of their contribution to energy savings, while plants with LAI below two should be avoided (Stav & Lawson, 2012). with less dense vegetation or LAI below three, the insulation capacity of LWs reduced, thus increasing the heating load by 8.3 for a building in Portugal in winter was observed (Carlos, 2014). The amount of water vapor in plants through the leaf surface pores during transpiration with regular leaf stomatal conductance is one of the physiological characteristics of individual plant species (stomatal conduction interaction, stomatal resistance) (Nobel, 2009). plant's average growth rate and its physiological characteristics, such as maximum plant height and leaf density, are influential factors (Susorova, 2015).

The main morphological parameters: Plant height is a structural parameter that affects wind speed in foliage. Radiation properties depend on the plant's type, season, leaf color, texture, and age. Lighter leaf color and longer hair species such as *Heuchera* and *Salvia* have lower leaf temperatures (Dahanayake & Chow, 2017). The influence of leaf size on PM accumulation was dominant over other examined characters (leaf size, shape, and micromorphology); smaller leaved species with a high LAI were identified as the most efficacious (Weerakkody et al., 2018). Experimental results by (Monteiro et al., 2017; Kalani et al., 2017) showed that plant height is not an essential factor in cooling load. The use of shorter plants in VGS increases the energy benefits. The absorption of plant leaves firmly depends on water content, leaf hairs, and leaf thickness. Thick, waxy leaves like conical needles absorb up to 88% of the sun's rays (Jone, 1992). Hairy leaves have also been reported as helpful in catching more particles than smooth-leaved plants by trapping them on the leaf hairs / trichromes with a complicated micromorphology (Leonard et al., 2016). Besides, (Perini, Magliocco, et al., 2017) showed the influence of plant species and structure (leaf shape, epidermis, roughness) on the total amount (number) of particles collected. Waxy leaves (T. jasminoides) collect the highest significant number of particles from the atmosphere. Hairy leaves P. fruticosa) are less effective and thus not a suitable option for improving air quality.

Biophysical: The biophysical properties of the plants, moisture gradations, and temperature values in the plant wall structure can influence the amount of energy consumed by the vegetation (Hadba et al., 2017). Even the mechanisms that plants provide through cooling may be different: shading, evapotranspiration, wind barrier, and insulation effect. The relative contribution of cooling mechanisms will depend on the plant form, species, canopy, moisture availability, seasonality, and plant vigor.

Plants tested by (Cameron et al., 2014) show that *Hedera, Lonicera, and Jasminum officinale coils* cool the air and wall surface by shading, while *Fuchsia* cools evapotranspiration. The cooling effect of *Prunus laurocerasus* and *Stachys byzantina* can be attributed equally to shade, evapotranspiration. The amount of this cooling effect depends on the density of the foliage (Georgi and Zephyriadis, 2006). The exact cooling mechanism depends on several factors, including plant maturity, LAI, canopy structure, leaf size, pore size, density, pore conductance and dynamic climatic conditions (Susorova, 2015). According to what was mentioned, the plant is the most important part of the green wall, leading to different thermal behaviors and multiple results. Therefore, a particular focus on plants selected by botanists can make the green wall design more successful. Reviewing the projects of different companies, it seems that a specialist named botanist is not active in the design process. Planting and selecting plants are done by horticulture that does not have enough knowledge about the physiology and morphology of plants. It can take the green wall away from its real purpose and prioritize the aesthetic goal. A more comprehensive way to evaluate the thermal performance of plant facades is to use mathematical models, not just experiments. Such models should simulate the effect of plants on the thermal performance of the facade for variable plant characteristics, facade characteristics, building direction, and climatic conditions.

Material: The choice of materials used is calculated by considering the high environmental effect, the low amount of environmental damage, the amount of thermal transmittance (U value) or thermal conductivity, and (R-Value) amount of thermal conductivity resistance of the materials.

Adequate information about the thermal capacity of materials and solar absorption in external walls can reduce energy consumption and the cooling load in summer.

Orientation: The simulation evaluation of a building in Portugal reveals that heating loads can be lowered by 6-11.2% through LW on the east facade, 8.2-13.3% for the west, and 24.4-28.6% for the north facade (Carlos, 2014). In green facades, a simulation study shows that while all facades are fully covered by plants cooling load reductions differ based on the exterior wall configuration (Kontoleon & Eumorfopoulou, 2010). The cooling load of a building without openings is lowered by up to 20 percent, 18 percent, 8 percent, and 5 percent if the greening system is built in the west, east, south, and north (Kontoleon & Eumorfopoulou, 2010).

Build up

Fire safety: Although VGS is an effective strategy but ignoring its safety in all aspects can contribute to the incidents. Fire safety is a challenge that has not been adequately addressed (Chow and Chow 2003; Lau et al., 2016). Various factors influence green wall's flammability, including moisture content, physical structure, and chemical composition. Moisture content (MC) is the most critical factor affecting Vegetation's ignitability (Livingston and Varner, 2016). Maintenance insufficiency will cause unsuitable irrigation systems and dry plants in VGS, creating significant fire hazards (Dahanayake & Chow, 2018). Fire propagation is a possible VGS threat. The plants may be dried out by insufficient irrigation, providing a suitable situation for burning. However, plants can hardly burn if it is kept green and alive (Fire Performance of Green Roofs and Walls).

Structural stability: a stable structure that has good longevity and provides a supporting function for plant growth plays a vital role in double-skinned green facades. However, the construction's features and resilience to extreme weather conditions, such as severe winds and floods, and appropriate resistance to rust and fire during the build-up process must be considered. It not only eliminates possible dangers during the existence of the green wall. Instead, it strengthens the green wall's helpful existence. Besides, one of the significant steps in selecting the type of green wall and the supporting framework is the weight of the additional structure, given the structural resistance of the current building and the volume of load bearing in critical situations.

Maintenance: Since plants are living members of VGS, it is critical to satisfying all of their requirements to survive. According to Maslow's pyramid, which illustrates a sequence of human requirements in order of priority, the suggested pyramid for plants includes the plant's fundamental survival needs, much as it does for humans. Water, light, carbon dioxide, and soil or growth medium are essential for a plant's survival.

Control insects, nutrients are in the second level. Pruning the plants situated in the third level, although not one of the plant's basic needs, can hinder the plant's proper growth. Plant health and pest control, which are impacted by lower levels and can also be induced by environmental factors, is at the top of the health pyramid. Creating a plant needs pyramid based on Maslow's human needs pyramid emphasizes the hierarchy of requirements and relevance. So, routine maintenance operations such as irrigation, fertilizer delivery, pruning, and weed control must ensure plant health.

Simple design, functional analysis, risk assessment, defect analysis, reliability-centered maintenance (RCM), and optimized O&M via planned maintenance programs are all maintainability criteria (Chew et al., 2017). The primary solution suggested for the maintenance phase:

- Reduce the number and complexity of maintenance work
- Preventive maintenance measures that users can sometimes control
- Ability to quickly replace parts and replace plants if needed
- Reduce maintenance needs and the presence of specialized personnel as much as possible
- Careful selection of irrigation system according to plants that can cause the least destructive effects of biological material growth on surfaces

Irrigation system: The irrigation needs depend on the type of greening system, plants used, and climatic conditions (Manso & Castro-Gomes, 2015). The following should be considered for planning and designing a drainage system:

- Average monthly and annual rainfall
- Rainfall and especially in the worst weather conditions
- The lowest and highest annual rainfall according to the rainy season
- Planned discharge capacity, including discharge dimensions and diameter of gutters and evacuation pipes
- Depending on the existing system and substrate, consult irrigation times
- Check the maximum load with irrigation water saturation (structural calculation)
- Determine the amount of influence at different times of the year.
- Find the available mixture to determine irrigation needs
- Perform tests to determine flooding in lower areas.

Pest control: IPM (Integrated Pest Management) is a pest-control approach that entails the rational use of a mix of biological, biotechnological, chemical, agricultural, or plant selection measures to reduce the usage of health products. **Depending on plants species and climate region, the time of controlling** is varied.

Monitoring: Monitoring during the life cycle is a reliable way to evaluate the VGS proper performance.

There are six parameters that all experimental green facade studies should report as a minimum for adequate quantification of thermal performance and microclimatic benefit:1. Solar radiation in front of or away from the green facade,2. air temperature in front of or away from the green facade, and3. Wind speed in front of or away from the green facade, as well as:4. Solar radiation between the green facade and the wall,5. air temperature between the green facade and the wall, and6. Wind speed between the green facade and the wall (Hunter et al., 2014). Using more advanced equipment and sensors achieves more accurate data.

Dynamic urban features: Microclimate variability in urban environments depends on factors related to population growth like, the new construction and thermal efficiency of building material design (Oke et al., 1991), industrial and high-density residential areas that are 5 to 7 ° C hotter relative to rural areas (Bonan, 2002), paved surface materials (Jaafar & Rasidi, 2011), street geometry (Shafaghat et al., 2016), urban reform (Hall et al., 2016) proportion of green and grey areas (Lin et al., 2008) and agricultural landscapes. Owing to changes in the number of users, urban population, and occupants' behaviors, the need for resources and anthropogenic heats (Oke,1982, Grimmond 2007), the surface characteristics (Quattrochi and Ridd, 1998; Xian and Crane 2006) can affect urban surface temperature. The city's average air temperature of 1 million or more inhabitants can be 1 to 3 ° C warmer than its surroundings (US EPA, 2008). local geographic characteristics and weather events can affect UHI (Zhao et al., 2014). UHI phenomena are heavily dependent on land cover changes and energy consumption, as well as surplus energy from human activity, decreased vegetation, building materials that retain heat during daytime and move it at night (Oke 1982; Grimmond 2007). Buildings' energy efficiency would differ by 10 percent based on urban design (Ratti et al., 2005).

Dynamic urban climate: Significant changes in air temperature, surface temperature, sea-level rise, and the scale and frequency of severe climatic events (IPCC, 2007b) occur as a result of global climate change, influencing rain-dominated catchments to include greater precipitation extremes (Harmsen et al., 2009). Humans influence the environment through building cities, and it is actions in the creation of "waste heat" as a result of energy usage that impact the environment (e.g., heating, traffic). VGS's thermal behavior is determined by four plant properties: insulation, evapotranspiration, shade, and wind protection. Depending on the climatic circumstances, any of these might have an impact on total efficiency. For instance, the volume of evapotranspiration and the connection with the water delivery network are defined by the yearly rainfall level (Liu et al., 2002). It may contribute to VGS altering the arrangement, as well as the replacement or removal of plants.

Dynamic Vertical Greening systems features: While LAI may be a significant predictor of solar radiation transmittance, it should be noted that it is not a static value. In response to fluctuations in seasonal temperature and vapor pressure deficit, light source levels, quality of soil and substrate, phenology, availability of soil nutrients, and plant maturity, LAI can alter (Whitehead and Beadle, 2004). Evergreen species retain their leaves for several years and reach a saturation point. The age of plants is also a vital factor in the VGS inflammability rate (Beckett et al., 2000). Plant shape, age, and color change during the life cycle of a greening system, affecting thermal behavior. The structural parameters (height and leaf area index (LAI), radiative properties (albedo and dispersion), plant traits (leaf hairs, color, thickness), and processes (aperture / Deciduous water) of plant species used in VGS (Monteiro et al., 2017). Leaf capacity for reflecting, absorbing, and transmitting sunlight varies considerably between and within species due to morphological and physiological differences such as leaf thickness, age, water content, leaf surface texture (smooth, loose, mature, or waxy), and Leaf orientation (Jones, 1992).

Disposal: However, sustainable materials are environmentally sustainable or environmentally responsible (Spiegel and Meadows, 1999; Franzoni, 2011). Sustainable construction materials are connected to the following criteria: availability of resources, energy efficiency (including original and replicated embodied energy and GHG Emissions), avoidance of pollution (including indoor air quality) (Pacheco-Torgal et al., 2014). However, advanced VGS testing approaches are planned to be more cost-effective, with the goal of using recyclable and renewable materials (Urrestarazu& Burés., 2012). In the design process, materials and their environmental burden should be regarded to lower the destructive effects of materials.

Simulating the selected greening systems based on extracted criteria in the case study in Tehran with a hot and dry climate: Over the past 20 years, classifications made by researchers have been collected and analyzed to identify effective criteria. In this regard, by extensive analysis of research and review of VGS produced by companies, 18 indicators with different impact rates were identified. Among these, the relationship between indicators was considered at four different levels. IRAN is also affected by global warming. Little research has been done on global warming and its consequences on energy consumption, buildings, and thermal comfort by researchers in Iran (Roshan et al., 2012). However, many studies have focused on climate change in Iran (Amiri et al., 2010; Ahmadinejad et al., 2013; Abbasnia et al., 2016). By extracting effective indicators and logical relationships between them, the design process is defined in 6 phases (Pre-design, Design, Build-up, Maintenance, Monitoring, and Disposal). In the case study, due to climatic conditions, available greening systems, and feasibility, 18 indicators played a more critical role, and six VGS selected. These indicators contain economic factors like initial cost, maintenance cost, disposal cost, and socioeconomic indicators, such as maintenance frequency, pruning frequency, the frequency of the plant replacement, the frequency of irrigation check, irrigation system service life, longevity, and pay-back time.

Moreover, environmental aspects include stability in harsh weather, water demand; aesthetic value such as design flexibility; architectural aspects such as weight, fire safety, rust resistance, recyclable and reusable materials were investigated. Based on information obtained from companies, the continuous living wall has a lightweight of about 2o kg/m2 compared to planter boxes, panel-based 70 and 30 kg/m2, respectively. Due to providing the stable construction relating to the age of the case study (five years) and life span of about 25 years lightweight alternative is preferred. In case of green facades, cable system 15 kg/m2, trellis panel 40 kg/m2, grid system 20 kg/m2 and direct green façade 7 kg/m2 entered. Maintenance cost for the continuous living wall 270-380 euro/m2, panel system 230-410 euro/m2, planter boxes 220-310 euro/m2 and pocket-based living wall 220-370 euro/m2 considered. From the frequency of maintenance point of view, including pruning and irrigation check green facades in all types need less maintenance and planter boxes highest maintenance check every week, continuous living wall every two weeks, panel and pocket based should be controlled monthly. Longevity of planter boxes 70 years is highest one, panel 40 years and continuous and pocket- based living wall on average 15-20 years estimated. All green facades are high longevity, about 40-50 years. Disposal cost of panel-based 40 euro/m2, planter box 28 euro/m2, continuous 28 and pocket based 23 euro/m2.

Fuzzy TOPSIS made the comparison according to the six existing green building systems. Furthermore, the two direct green facades and the felt-based living wall obtained the highest score. To ensure the proper performance of the selected systems leading to reduce the surface temperature, both alternatives simulated by ENVI-met. The results show the surface temperature reduction on average 10.95 °C by direct green façade and a living wall of about 13.95°C.

With greenery coverage, the envelope thermal transfer value (ETTV) is observed to be significantly decreased. It is clear that VGS is good at regulating heat transfer into the building and heat gain via the wall on hot days with high ambient air temperatures, resulting in less heat flux through the wall into indoor space and decreased cooling load (Jim, 2015).as a result, will reduce the amount of energy used by the air conditioning system (Dahanayake & Chow, 2017). These facts demonstrate that VGS can efficiently balance the solar radiation that a building facade receives. As a result, selecting plants to reduce the cooling load in the summer and increase the winter's insulation properties is critical. Since this research only investigated the thermal efficiency of the vertical green system on July 14, the hottest day of the year, it is suggested that future research study at the thermal activity in the winter.

LAI is considered as the most influential plant property affecting the thermal performance of VGS. The results show that increasing the LAI from 1 to 5 can reduce the external surface temperature peak from 12 ° C, reasonable heat transfer from 48 watts per square meter, and latent heat transfer from 40 watts per square meter hot summer day. In addition, the annual cooling load has increased by 1.4% (Cameron, 2017). Increasing the LAI from 1 to 5 significantly reduces the VGS outer surface temperature from 52 ° C to 40 ° C. same results were shown by Susorova et al. (2013). Another study, from experimental experiments, obtained interesting energy savings (up to 34% for Boston ivy plant species with LAI 3.5-4, during summer under Mediterranean continental climate). In addition, the orientation dependence was confirmed with the participation of the representative in the overall energy saving from the east and west (Perez et al., 2017). LAI up to 3 can significantly increase the cooling effect in the air (Takakura et al., 2000). Comparing the results of a previous study (Farrokhirad, 2020) in Tehran shows direct green facades covered by *Hedera helix* with LAI 1.5 with 0.03 m thickness to this study with the same plant but LAI 5.00 and 0.20m thickness considering south and south-east facades, respectively. It is clear that as plant density rises, the fraction of total solar radiation absorbed by plants rises as well. It demonstrates that plant LAI and thickness have a major impact on the cooling surface. Strongly, it can confirm that plant-based solutions like VGIS positively affect Tehran's arid region and contribute to energy saving in the summertime.

5.3. Limitation of the study

- Since this study aims to analyze the process of designing and installing vertical green systems, they are the primary source of information extraction of manufacturing companies, and due to the importance of economic status for companies, sometimes encounter inaccurate information. In this regard, to ensure the accuracy of the information received, checking and analyzing previous LCA studies has been done.
- Due to the infancy of this design sector, particularly in Iran, the number of manufacturing companies is small. As a result, the quantitative and qualitative benefits of this sustainable solution have been studied less. For example, no research has been done on the thermal efficiency of green walls or their function in mitigating pollution. Simultaneously, no experimental and simulation study has been performed on the plants currently used in Tehran's green walls. Also, the only criteria for choosing plants are survival, even though they might not perform well in the environment. So, the knowledge about plants and their behavior in green walls is limited.
- There is only one high-rise sample in Tehran that can be studied to determine the green wall's lifespan and side costs, and environmental variables such as heavy winds and harsh weather. Given that this is a commercial building maintained by a contractor and does not need users to inspect it regularly, maintenance in the residential building will have more restrictions.

5.4. Recommendation for the future studies

Given the irreversible impact of global warming in recent decades and the importance of green walls as a sustainable environmental response, as well as the role of large cities like Tehran in global warming, research on the success of VGS in reducing the negative impact on the environment needed. So, plant functional analysis to best results should be taken into account. The use of greenery in buildings has become a design trend among architects. Even though it is not considered an efficient design member, architects need to analyze the environmental efficiency of these VGS during the design process. As discussed with architects in Tehran who use greenery in their projects, it understood that GW is treated as a prefabricated member such as doors and windows. Whereas designers play an undeniable role in selecting the form of the green wall, its proper location concerning energy usage in spaces and cooling and heating loads, as well as describing its purpose. More research is required on its thermal behavior in different seasons, particularly in Tehran's winter, since its poor output will increase energy consumption in the winter. In general, studies on the ratio of green area protection to the rate of thermal load reduction in hot and dry climates are missing since water supply for plant irrigation in these areas is a challenging task. Since there is a lack of knowledge on the role of substrate and growing media in living walls in terms of thermal characteristics, more research is needed to clarify the association. The chemical properties of standard soils, such as pH and electrical conductivity, are not well defined. More research is required to determine the effect of these soil properties on plant growth rate and habit, this field of study is suggested for future research. Researchers can also concentrate on the amount of evapotranspiration that each plant produces and how it affects temperature reduction, especially in hot and dry clime. The air cavity between the living wall and façade surface affects the VGIS thermal behavior. There is a lack of study to finding optimal distance. A study by (Safikhani et al., 2017) noted that 0.30 m is the desire distance in Malaysia. Another study by Perini et al. (2011) to analyze airflow showed the 0.7 m is acceptable in climate. It is recommended for future studies to emphasize the optimized air gap in living walls in hot and dry climates.

References

Papers

Perini, K., Ottelé, M., Fraaij, A. L. A., Haas, E. M., & Raiteri, R. (2011). Vertical greening systems and the effect on air flow and temperature on the building envelope. *Building and Environment*, *46*(11), 2287-2294.

Azamati, Aliakbar & Hosseini, Hossein , Investigating the effect of orientation of educational buildings on thermal and refrigeration loads in different climates, Environmental Science and Technology, Volume 15, Number 2, Summer 2011

Francis, R. A., & Lorimer, J. (2011). Urban reconciliation ecology: the potential of living roofs and walls. *Journal of environmental management*, *92*(6), 1429-1437

Bibliography

Afshari, A. (2017). A new model of urban cooling demand and heat island—application to vertical greenery systems (VGS). *Energy and Buildings*, *157*, 204–217. https://doi.org/10.1016/j.enbuild.2017.01.008\

Ahmadnezhad, E., HOLAKOUEI, N. K., Ardalan, A., MAHMOUDI, M., YOUNESIAN, M., Naddafi, K., & Mesdaghinia, A. R. (2013). Excess mortality during heat waves, Tehran Iran: an ecological time-series study

Akbari, H., & Taha, H. (1992). The impact of trees and white surfaces on residential heating and cooling energy use in four Canadian cities. *Energy*, *17*(2), 141-149

Akbari, H., Pomerantz, M., & Taha, H. (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Solar energy*, *70*(3), 295-310

Alexandri, E., & Jones, P. (2004). The thermal effects of green roofs and green façades on an urban canyon. In *Plea Conference on Passive and Low Energy Architecture, Eindhoven, Netherlands* (pp. 19-22)

Alexandri, E., & 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. https://doi.org/10.1016/j.buildenv.2006.10.055

Al-Mulali, U., Sab, C. N. B. C., & Fereidouni, H. G. (2012). Exploring the bi-directional long run relationship between urbanization, energy consumption, and carbon dioxide emission. *Energy*, *46*(1), 156-167

Amiri, M. J., & Eslamian, S. S. (2010). Investigation of climate change in Iran. *Journal of Environmental Science and Technology*, *3*(4), 208-216

Ascione, F. (2017). Energy conservation and renewable technologies for buildings to face the impact of the climate change and minimize the use of cooling. *Solar Energy*, *154*. https://doi.org/10.1016/j.solener.2017.01.022

Asmone, A. S., & Chew, M. Y. L. (2016). Sustainable facilities management and the requisite for green maintainability. *In Proc. SMART Facilities Management Solutions Regional Focus Group Session*, *April*, 1–19.

Assimakopoulos, M. N., De Masi, R. F., Fotopoulou, A., Papadaki, D., Ruggiero, S., Semprini, G., & Vanoli, G. P. (2020). Holistic approach for energy retrofit with volumetric add-ons toward nZEB target: Case study of a dormitory in Athens. *Energy and Buildings*, *207*. https://doi.org/10.1016/j.enbuild.2019.109630

Atlas of Tehran metropolis ,VOL. 1. LAND AND PEOPLE : ENVIRONMENT, POPULATION, EMPLOYMENT, HOUSING,2005

Azmoodeh, M., & Heidari, S. (2017). Effect of Urban Green Walls on Reduction of Temperature in Microclimates and Urban Heat Island. *Journal of Environmental Science and Technology*, *19*(5), 597-606

Azkorra, Z., Pérez, G., Coma, J., Cabeza, L. F., Burés, S., Álvaro, J. E., ... & Urrestarazu, M. (2015). Evaluation of green walls as a passive acoustic insulation system for buildings. *Applied Acoustics*, *89*, 46-56.

Bacci, P., & Maugeri, M. (1992). The urban heat island of Milan. *Il Nuovo Cimento C*, *15*(4), 417–424. https://doi.org/10.1007/BF02511742

Bartfelder, F., & Köhler, M. (1987). *Experimentelle Untersuchungen zur Funktion von Fassadenbegrünungen. A (1987)*. Berlin-Verlag.

Bass, B., & Baskaran, B. (2003). Evaluating rooftop and vertical gardens as an adaptation strategy for urban areas.

Beckett, K. P., Freer-Smith, P. H., & Taylor, G. (2000). Particulate pollution capture by urban trees: Effect of species and windspeed. *Global Change Biology*, *6*(8), 995–1003. https://doi.org/10.1046/j.1365-2486.2000.00376.x

Beecham, S., Razzaghmanesh, M., Bustami, R., & Ward, J. (2018). The Role of Green Roofs and Living Walls as WSUD Approaches in a Dry Climate. In *Approaches to Water Sensitive Urban Design: Potential, Design, Ecological Health, Urban Greening, Economics, Policies, and Community Perceptions*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-812843-5.00020-4

Berndtsson, J.C., Emilsson, T., Bengtsson, L., 2006. The influence of extensive vegetated roofs on runoff water quality. Sci. Total Environ. 355, 48-63

BellomoA(2003) Pareti Verdi.Sistemi editoriali, Napoli

Besir, A. B., & Cuce, E. (2018). Green roofs and facades: A comprehensive review. *Renewable and Sustainable Energy Reviews*, *82*(September 2017), 915–939. https://doi.org/10.1016/j.rser.2017.09.106

Bianco, L., Serra, V., Larcher, F., & Perino, M. (2017). Thermal behaviour assessment of a novel vertical greenery module system: first results of a long-term monitoring campaign in an outdoor test cell. *Energy Efficiency*, *10*(3), 625–638. https://doi.org/10.1007/s12053-016-9473-4

Bjurström, A., & Polk, M. (2011). Physical and economic bias in climate change research: a scientometric study of IPCC Third Assessment Report. *Climatic Change*, *108*(1), 1-22

Blocken, B., & Carmeliet, J. (2004). A review of wind-driven rain research in building science. *Journal of wind engineering and industrial aerodynamics*, *92*(13), 1079-1130.

Blocken, B., Stathopoulos, T., & Carmeliet, J. (2007). CFD simulation of the atmospheric boundary layer: wall function problems. *Atmospheric environment*, *41*(2), 238-252.

Buccola, N., & Spolek, G. (2011). A pilot-scale evaluation of greenroof runoff retention, detention, and quality. *Water, Air, & Soil Pollution*, *216*(1), 83-92

Bustami, R. A., Belusko, M., Ward, J., & Beecham, S. (2018). Vertical greenery systems: A systematic review of research trends. *Building and Environment*, *146*(August), 226–237. https://doi.org/10.1016/j.buildenv.2018.09.045

Bustami, R., Brien, C., Ward, J., Beecham, S., & Rawlings, R. (2019). A Statistically Rigorous Approach to Experimental Design of Vertical Living Walls for Green Buildings. *Urban Science*, *3*(3), 71. https://doi.org/10.3390/urbansci3030071

Cameron, R. W. F., Taylor, J. E., & Emmett, M. R. (2014). What ' s ' cool ' in the world of green façades ? How plant choice in fl uences the cooling properties of green walls. *Building and Environment*, *73*, 198–207. https://doi.org/10.1016/j.buildenv.2013.12.005

Carlos, J. S. (2015). Simulation assessment of living wall thermal performance in winter in the climate of Portugal. *Building Simulation*, *8*(1), 3–11. https://doi.org/10.1007/s12273-014-0187-2

Charoenkit, S., & Yiemwattana, S. (2016). Living walls and their contribution to improved thermal comfort and carbon emission reduction: A review. *Building and environment*, *105*, 82-94

Chen, C. T. (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy sets and systems*, *114*(1), 1-9

Chen, Q., Li, B., & Liu, X. (2013). An experimental evaluation of the living wall system in hot and humid climate. *Energy and Buildings*, *61*. https://doi.org/10.1016/j.enbuild.2013.02.030

Cheng, C. Y., Cheung, K. K. S., & Chu, L. M. (2010). Thermal performance of a vegetated cladding system on facade walls. *Building and Environment*, *45*(8), 1779–1787. https://doi.org/10.1016/j.buildenv.2010.02.005

Chew, M. Y., & Conejos, S. (2016). Developing a green maintainability framework for green walls in Singapore. *Structural Survey*

Chew, M. Y. L., Conejos, S., & Asmone, A. S. (2017). Developing a research framework for the green maintainability of buildings. *Facilities*, *35*(1–2), 39–63. https://doi.org/10.1108/F-08-2015-0059

Cities, I. E. A. (2009). Towns&Renewable Energy. *IEA: Paris, France*

Cohen, A. J., Anderson, H. R., Ostro, B., Pandey, K. D., Krzyzanowski, M., Künzli, N., ... & Smith, K. R. (2004). Urban air pollution. *Comparative quantification of health risks: global and regional burden of disease attributable to selected major risk factors*, *2*, 1353-1433

Colgan, J. D. (2009). The international energy agency. *Challenges for the 21st Century. GPPi Energy Policy Paper*, *6*

Coma, J., Pérez, G., Solé, C., Castell, A., & Cabeza, L. F. (2014). New green facades as passive systems for energy savings on buildings. *Energy Procedia*, *57*, 1851-1859

Coma, J., Pérez, G., de Gracia, A., Burés, S., Urrestarazu, M., & Cabeza, L. F. (2017). Vertical greenery systems for energy savings in buildings: A comparative study between green walls and green facades. *Building and Environment*, *111*. https://doi.org/10.1016/j.buildenv.2016.11.014

Corradi L. Hydroponic growing system. US 2009/007486 A1; 8 January 2009

Cooper, C.B., Dickinson, J., Phillips, T., Bonney, R., 2007. Citizen science as a tool for conservation in residential ecosystems. Ecology and Society 12 (2), 1

Crowley, T. J., & Kim, K. Y. (1999). Modeling the temperature response to forced climate change over the last six centuries. *Geophysical Research Letters*, *26*(13), 1901-1904

Chow, W. K. (2003). Fire safety in green or sustainable buildings: Application of the fire engineering approach in Hong Kong. *Architectural Science Review*, *46*(3), 297-303

Cuce, E. (2017). Thermal regulation impact of green walls: An experimental and numerical investigation. *Applied Energy*, *194*. https://doi.org/10.1016/j.apenergy.2016.09.079

Dahanayake, K. W. D. K. C., & Chow, C. L. (2015, August). 63: A brief discussion on current vertical greenery systems in Hong Kong: the way forward. In *14th Int. Conf. Sustain. Energy Technol.(SET2015)* (pp. 25-27)

Dahanayake, K. W. D. K. C., & Chow, C. L. (2017). Studying the potential of energy saving through vertical greenery systems: Using EnergyPlus simulation program. *Energy and Buildings*, *138*(November 2017), 47–59. https://doi.org/10.1016/j.enbuild.2016.12.002

Dahanayake, K. C., & Chow, C. L. (2018, June). Comparing reduction of building cooling load through green roofs and green walls by EnergyPlus simulations. In *Building Simulation* (Vol. 11, No. 3, pp. 421-434). Springer Berlin Heidelberg

Department for Communities and Local Government London. Fire Performance of Green Roofs and Walls. 2013

Dhalluin, A., & Bozonnet, E. (2015). Urban heat islands and sensitive building design–A study in some French cities' context. *Sustainable Cities and Society*, *19*, 292-299

Dimoudi, A., & Nikolopoulou, M. (2003). Vegetation in the urban environment: microclimatic analysis and benefits. *Energy and buildings*, *35*(1), 69-76

Di, H. F., & Wang, D. N. (1999). Cooling effect of ivy on a wall. *Experimental Heat Transfer*, *12*(3), 235-245

Ding, G. K. C. (2013). Life cycle assessment (LCA) of sustainable building materials: An overview. In *Eco-Efficient*

Construction and Building Materials: Life Cycle Assessment (LCA), Eco-Labelling and Case Studies. https://doi.org/10.1533/9780857097729.1.38

Dunnett, N., & Kingsbury, N. (2008). *Planting green roofs and living walls*. Portland, OR: Timber press

Dunnett, N., Nagase, A., & Hallam, A. (2008). The dynamics of planted and colonising species on a green roof over six growing seasons 2001–2006: influence of substrate depth. *Urban Ecosystems*, *11*(4), 373-384

Dunnett, N.a., 2010. Planting Green Roofs and Living Walls. Timber Press, Portland. Grant, G., 2010. Green Roofs and Facades. IHS–BRE Press, Bracknell

Eumorfopoulou, E. A., & Kontoleon, K. J. (2009). Experimental approach to the contribution of plant-covered walls to the thermal behaviour of building envelopes. *Building and Environment*, *44*(5), 1024–1038. https://doi.org/10.1016/j.buildenv.2008.07.004

Farrokhirad, Ensiyeh, (2020); *A simulation study of the direct green façades in semi-arid climate by ENVI-met.* International Conference "Design in the Digital Age"

Felson, A. J., & Pickett, S. T. A. (2005). Designed experiments: New approaches to studying urban ecosystems. In *Frontiers in Ecology and the Environment* (Vol. 3, Issue 10). https://doi.org/10.1890/1540-9295(2005)003[0549:DENATS]2.0.CO;2

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

Fernández-Bregón, N., Urrestarazu, M., & Valera, D. L. (2012). Effects of a vertical greenery system on selected thermal and sound mitigation parameters for indoor building walls. *J Food Agric Environ*, *10*(3-4), 1025-7

Fernández-Cañero, R., Pérez Urrestarazu, L., & Perini, K. (2018). Vertical greening systems: Classifications, plant species, substrates. *Nature Based Strategies for Urban and Building Sustainability*, 45–54. https://doi.org/10.1016/B978-0-12-812150-4.00004-5

Florez, L., & Castro-Lacouture, D. (2013). Optimization model for sustainable materials selection using objective and subjective factors. *Materials & Design*, *46*, 310-321

Francis, R. A., & Lorimer, J. (2011). Urban reconciliation ecology: the potential of living roofs and walls. *Journal of environmental management*, *92*(6), 1429-1437

Franzoni, E. (2011). Materials selection for green buildings: which tools for engineers and architects?. *Procedia Engineering*, *21*, 883-890

Green, B. (2004). A guide to using plants on roofs, walls and pavements. *Mayor of London. Greater London Authority*.

Grosso, M. (1998). Urban form and renewable energy potential. *Renewable energy*, *15*(1-4), 331-336

Gago, E. J., Roldan, J., & Ordóñez, J. (2013). *The city and urban heat islands : A review of strategies to mitigate adverse effects*. *25*, 749–758. https://doi.org/10.1016/j.rser.2013.05.057

Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). Adapting cities for climate change: The role of the green infrastructure. *Built Environment*, *33*(1), 115–133. https://doi.org/10.2148/benv.33.1.115

Gorsevski, V., Taha, H., Quattrochi, D., Luvall, J., 1998. Air pollution prevention through urban heat island mitigation: an update on the Urban Heat Island Pilot

Hadba, L., Mendonça, P., & Silva, L. T. (2017). Green walls an efficient solution for hygrothermal, noise and air pollution control in the buildings. *Architecture_MPS (Ed.), Living and Sustainability: An Environmental Critique of Design and Building Practices, Locally and Globally*

Haggag, M.A. The Use of Green Walls in Sustainable Urban Context: With Reference to Dubai, UAE. WIT Trans. Ecol. Environ. **2010**, 128, 261–270

Haaland, C., & van den Bosch, C. K. (2015). Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban Forestry and Urban Greening*, *14*(4), 760–771.

Haggag, M.A. The Use of Green Walls in Sustainable Urban Context: With Reference to Dubai, UAE. WIT Trans. Ecol. Environ. **2010**, 128, 261–270

Haggag, M. A., Elmasry, S. K., & Hassan, A. (2012). Design with nature: integrating green façades into sustainable buildings with reference to Abu Dhabi. *WIT Transactions on Ecology and the Environment*, *160*, 37-47

Haggag, M., & Hassan, A. (2015). Cost-benefit analysis of living wall systems on school building skins in a hot climate. *Energy and Sustainability V: Special Contributions*, *1*. https://doi.org/10.2495/ess140011

Hammond , G.P. (2000) ' Energy, environment and sustainable development: a UK perspective ', *Process Safety and Environmental Protection* , 78 (4), 304 – 323

Hansen, J., Sato, M., Kharecha, P., Russell, G., Lea, D. W., & Siddall, M. (2007). Climate change and trace gases. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *365*(1856), 1925-1954

Happle, G., Fonseca, J. A., & Schlueter, A. (2017). Effects of air infiltration modeling approaches in urban building energy demand forecasts. *Energy Procedia*, *122*, 283-288.

Hassid, S., Santamouris, M. N. A. N. C., Papanikolaou, N., Linardi, A., Klitsikas, N., Georgakis, C., & Assimakopoulos, D. N. (2000). The effect of the Athens heat island on air conditioning load. *Energy and Buildings*, *32*(2), 131-141

He, Y.; Yu, H.; Ozaki, A.; Dong, N.; Zheng, S. An investigation on the thermal and energy performance of living wall system in Shanghai area. Energy Build. **2017**, 140, 324–335

Hoelscher, M. T., Nehls, T., Jänicke, B., & Wessolek, G. (2016). Quantifying cooling effects of facade greening: Shading, transpiration and insulation. *Energy and Buildings*, *114*, 283-290

Holm, D. (1989). Thermal improvement by means of leaf cover on external walls—a simulation model. *Energy and Buildings*, *14*(1), 19-30

Hong, T., Kim, J., Lee, J., Koo, C., & Park, H. S. (2013). Assessment of seasonal energy efficiency strategies of a double skin façade in a monsoon climate region. *Energies*, *6*(9), 4352-4376

Hop, M.; Hiemstra, J.A. Contribution of Green Roofs and Walls to Ecosystem Services of Urban Green. Acta Hortic. 2012, 990, 475–480

Hoyano, A. (1988). Climatological uses of plants for solar control and the effects on the thermal environment of a building. *Energy and buildings*, *11*(1-3), 181-199

Huang, Z., Lu, Y., Wong, N. H., & Poh, C. H. (2019). The true cost of "greening" a building: Life cycle cost analysis of vertical greenery systems (VGS) in tropical climate. *Journal of Cleaner Production*, *228*, 437–454. https://doi.org/10.1016/j.jclepro.2019.04.275

Hunter, A. M., Williams, N. S. G., Rayner, J. P., Aye, L., Hes, D., & Livesley, S. J. (2014). Quantifying the thermal performance of green fac ¸ ades : A critical review. *Ecological Engineering*, *63*, 102–113. https://doi.org/10.1016/j.ecoleng.2013.12.021

Hutton, T. A. A. (2016). Critical Introductions to Urbanism and the City

Irga, P. J., Braun, J. T., Douglas, A. N. J., Pettit, T., Fujiwara, S., Burchett, M. D., & Torpy, F. R. (2017). The distribution of green walls and green roofs throughout Australia: Do policy instruments influence the frequency of projects?. *Urban Forestry & Urban Greening*, *24*, 164-174

ICOVA, 2013. Available from: http://www.icova.nl/web/Contact-met-Icova.htm, (accessed 20.05.13.)
Ip, K., Lam, M., & Miller, A. (2010). Shading performance of a vertical deciduous climbing plant canopy. *Building and Environment*, *45*(1), 81-88

Irwin, G, 2015 Living Wall Breakdown - Material & Flora Relationship, Green- Roofs.Com

Intergovernmental Panel on Climate Change. (2014). Climate Change, Adaptation, and Vulnerability. *Organization & Environment*, *24*(March), 1–44. https://doi.org/http://ipcc-wg2.gov/AR5/images/uploads/IPCC_WG2AR5_SPM_Approved.pdf

Jaafar, B., Said, I., & Rasidi, M. H. (2011). Evaluating the Impact of Vertical Greenery System on Cooling Effect on High Rise Buildings and Surroundings: A Review. *Review of Urbanism and Architectural Studies*, *9*(2), 1–9.

Jaafar, B., Said, I., Reba, M. N. M., & Rasidi, M. H. (2013). Impact of Vertical Greenery System on Internal Building Corridors in the Tropic. *Procedia - Social and Behavioral Sciences*, *105*, 558–568

Jim, C. Y., & He, H. (2011). Estimating heat flux transmission of vertical greenery ecosystem. *Ecological Engineering*, *37*(8), 1112-1122

Jim, C. Y. (2015). Greenwall classification and critical design-management assessments. *Ecological Engineering*, *77*, 348–362. https://doi.org/10.1016/j.ecoleng.2015.01.021

Kalkstein, L. S., & Sheridan, S. C. (2003). The impact of heat island reduction strategies on health-debilitating oppressive air masses in urban areas. *Prepared for US EPA Heat Island Reduction Initiative*

Khasnis A. A and Mary D. Nettleman(2005), Global Warming and Infectious Disease, Archives of Medical Research , vol36 , pp 689–696

Keyhani, A., Ghasemi-Varnamkhasti, M., Khanali, M., Abbaszadeh, R., 2010. An assessment of wind energy potential as a power generation source in the capital of Iran, Tehran. Energy 35, 188e201

Kingsbury, N. (2004). Contemporary Overview of Naturalistic Planting Design. I Dunnet, M & Hitcchmough, J. *The Dynamic Landscape: Design, Ecology and Management of Naturalistic Urban Planning*

Ko¨hler, M., 1993. Fassaden und Dachbergrunung. Stuttgart: Ulmer Fachbuch Landschafts- und Grunplanung

Köhler, M. (2008). Green facades-a view back and some visions. *Urban Ecosystems*, *11*(4), 423–436.

Kontoleon, K. J., & Eumorfopoulou, E. A. (2010). The effect of the orientation and proportion of a plant-covered wall layer on the thermal performance of a building zone. *Building and Environment*, *45*(5), 1287–1303. https://doi.org/10.1016/j.buildenv.2009.11.013

Koyama, T., Yoshinaga, M., Hayashi, H., Maeda, K. I., & Yamauchi, A. (2013). Identification of key plant traits contributing to the cooling effects of green façades using freestanding walls. *Building and Environment*, *66*, 96-103

Krusche, M. Krusche, D. Althaus, I. Gabriel**Ökologisches bauen** Herausgegeben vom umweltbundesamt, Bauverlag (1982)

Lam, M. H. Y., Ip, K., & Miller, A. (2005, September). Thermal shading effect of climbing plants on glazed facades. In *The 2005 World Sustainable Building Conference, Tokyo*

Larsen, S. F., Filippín, C., & Lesino, G. (2014). Thermal simulation of a double skin façade with plants. *Energy Procedia*, *57*, 1763–1772. https://doi.org/10.1016/j.egypro.2014.10.165

Larsen, S. F., Rengifo, L., & Filippín, C. (2015). Double skin glazed façades in sunny Mediterranean climates. *Energy and Buildings*, *102*, 18-31

Lau, D., Qiu, Q., Zhou, A., & Chow, C. L. (2016). Long term performance and fire safety aspect of FRP composites used in building structures. *Construction and building materials*, *126*, 573-585

Li, D., & Bou-Zeid, E. (2013). Synergistic interactions between urban heat islands and heat waves: The impact in cities is larger than the sum of its parts. *Journal of Applied Meteorology and Climatology*, *52*(9), 2051-2064

Liu, C., Zhang, X., & Zhang, Y. (2002). Determination of daily evaporation and evapotranspiration of winter wheat and maize by large-scale weighing lysimeter and micro-lysimeter. *Agricultural and Forest Meteorology*, *111*(2), 109-120

Loh, S. (2008). TEC 26 ● August 2008 Living Walls – A Way to Green the Built Environment LIVING WALLS – A WAY TO GREEN THE BUILT ENVIRONMENT. *BEDP Environment Design Guide*, *1*, 1–7

Magliocco, A., & Perini, K. (2015). The perception of green integrated into architecture: installation of a green facade in Genoa, Italy. *AIMS Environ Sci*, *2*, 899-909

Manso, M., & Castro-Gomes, J. P. (2016). Thermal analysis of a new modular system for green walls. *Journal of Building Engineering*, *7*(March 2019), 53–62. https://doi.org/10.1016/j.jobe.2016.03.006

Manso, Maria, & Castro-Gomes, J. (2015). Green wall systems: A review of their characteristics. *Renewable and Sustainable Energy Reviews*, *41*, 863–871. https://doi.org/10.1016/j.rser.2014.07.203

Manuel Posse, Carlos, Revista elektron, Vol. 3, No. 1, pp. 10-15 (2019)

Martilli, A. (2002). Numerical study of urban impact on boundary layer structure: Sensitivity to wind speed, urban morphology, and rural soil moisture. *Journal of Applied Meteorology*, 41(12), 1247-1266.

Mårtensson, L., Wuolo, A., Fransson, A. M., & Emilsson, T. (2014). Plant performance in living wall systems in the Scandinavian climate.

Mathers, H. M., Lowe, S. B., Scagel, C., Struve, D. K., & Case, L. T. (2007). Abiotic factors influencing root growth of woody nursery plants in containers. *HortTechnology*, 17(2), 151-162

Mayrand, F., & Clergeau, P. (2018). Green roofs and green walls for biodiversity conservation: a contribution to urban connectivity?. *Sustainability*, *10*(4), 985

Mazzali, U., Peron, F., & Scarpa, M. (2012). Thermo-physical performances of living walls via field measurements and numerical analysis. *WIT Transactions on Ecology and the Environment*, *165*, 251-259

Mazzali, U., Peron, F., Romagnoni, P., Pulselli, R. M., & Bastianoni, S. (2013). Experimental investigation on the energy performance of Living Walls in a temperate climate. *Building and Environment*, *64*, 57–66. https://doi.org/10.1016/j.buildenv.2013.03.005

Medl, A., Stangl, R., & Florineth, F. (2017). Vertical greening systems–A review on recent technologies and research advancement. *Building and Environment*, *125*, 227-239

Meral, A., Başaran, N., Yalçinalp, E., Doğan, E., Ak, M. K., & Eroğlu, E. (2018). A comparative approach to artificial and natural green walls according to ecological sustainability. *Sustainability (Switzerland)*, *10*(6).

https://doi.org/10.3390/su10061995

Minke G, Witter G (1982) Haeuser mit Gruenem Pelz, Ein Handbuch zur Hausbegruenung, Verlag Dieter Fricke GmbH, Frankfurt (partially translated in English)

Minx, J. C., Callaghan, M., Lamb, W. F., Garard, J., & Edenhofer, O. (2017). Learning about climate change solutions in the IPCC and beyond. *Environmental Science & Policy*, *77*, 252-259

Miller, A., Shaw, K., & Lam, M. (2007). Vegetation on building facades:" Bioshader". *Case study report*

Mohajerani, A., Bakaric, J., & Jeffrey-bailey, T. (2017). The urban heat island effect , its causes , and mitigation , with reference to the thermal properties of asphalt concrete. *Journal of Environmental Management*, *197*, 522–538. https://doi.org/10.1016/j.jenvman.2017.03.095

Monteiro, M. V., Blanuša, T., Verhoef, A., Richardson, M., Hadley, P., & Cameron, R. W. F. (2017). Functional green roofs: Importance of plant choice in maximising summertime environmental cooling and substrate insulation potential. *Energy and buildings*, *141*, 56-68

Muahram, A., Kennedy, J., Kanaani, M., & Demircay, V. (2019). Creating urban health through the promotion of green walls. *International Journal of Advanced Engineering Research and Science*, *6*(12), 451–457. https://doi.org/10.22161/ijaers.612.52

Nabil A,MardaljevicJ. Useful daylight illuminances are placement for daylight factors. Energy and Buildings2006; 38:905–13

Nakayama, T., & Fujita, T. (2010). Cooling effect of water-holding pavements made of new materials on water and heat budgets in urban areas. *Landscape and urban planning*, *96*(2), 57-67

Natarajan, M., Rahimi, M., Sen, S., Mackenzie, N., & Imanbayev, Y. (2015). Living wall systems: evaluating life-cycle energy, water and carbon impacts. *Urban Ecosystems*, *18*(1), 1–11. https://doi.org/10.1007/s11252-014-0378-8

Nobel, P. S. (1999). *Physicochemical & environmental plant physiology*. Academic press

OCHOA, JM. (1999): Vegetation as an instrument for climate control, Doctoral Thesis. Technical University of Catalonia, School of Architecture, Director:Rafael Serra Florensa

Olivieri, F., Neila, F. J., & Bedoya, C. (2009). Energy saving and environmental benefits of metal box vegetal facades. *WIT Transactions on Ecology and the Environment*, *127*, 325–335

Olivieri, F., Olivieri, L., & Neila, J. (2014). Experimental study of the thermal-energy performance of an insulated vegetal façade under summer conditions in a continental mediterranean climate. *Building and Environment*, *77*, 61-76

Olivieri, F., Grifoni, R. C., Redondas, D., Sánchez-Reséndiz, J. A., & Tascini, S. (2017). An experimental method to quantitatively analyse the effect of thermal insulation thickness on the summer performance of a vertical green wall. *Energy and Buildings*, *150*, 132-148

O'Malley, C., Piroozfar, P., Farr, E. R., & Pomponi, F. (2015). Urban Heat Island (UHI) mitigating strategies: A case-based comparative analysis. *Sustainable Cities and Society*, *19*, 222-235

Omer, A. M. (2008). Energy, environment and sustainable development. *Renewable and Sustainable Energy Reviews*, *12*(9), 2265–2300. https://doi.org/10.1016/j.rser.2007.05.001

Oke, T. R., & TR, O. (1979). Review of urban climatology 1973-1976

Oke, T. R. (1988). The urban energy balance. *Progress in Physical geography*, *12*(4), 471-508

Oke, T. R. (1989). The micrometeorology of the urban forest. *Philosophical Transactions of the Royal Society of London. B, Biological Sciences*, *324*(1223), 335-349

Oke, T. R., Johnson, G. T., Steyn, D. G., & Watson, I. D. (1991). Simulation of surface urban heat islands under 'ideal'conditions at night part 2: Diagnosis of causation. *Boundary-layer meteorology*, *56*(4), 339-358

Oke, T. R., Spronken-Smith, R. A., Jáuregui, E., & Grimmond, C. S. (1999). The energy balance of central Mexico City during the dry season. *Atmospheric environment*, *33*(24-25), 3919-3930

Onishi, A., Cao, X., Ito, T., Shi, F., & Imura, H. (2010). Evaluating the potential for urban heat-island mitigation by greening parking lots. *Urban Forestry and Urban Greening*, *9*(4). https://doi.org/10.1016/j.ufug.2010.06.002

Othman, A. R., & Sahidin, N. (2016). Vertical Greening Façade as Passive Approach in Sustainable Design. *Procedia - Social and Behavioral Sciences*, *222*, 845–854. https://doi.org/10.1016/j.sbspro.2016.05.185

Ottelé, M. (2011). The Green Building Envelope Vertical Greening. In *Department of Materials and Environment*.

Ottelé, M., Bohemen, H. D. Van, & Fraaij, A. L. A. (2010). *Quantifying the deposition of particulate matter on climber vegetation on living walls*. *36*, 154–162. https://doi.org/10.1016/j.ecoleng.2009.02.007

Ottelé, M., Perini, K., Fraaij, A. L. A., Haas, E. M., & Raiteri, R. (2011). Comparative life cycle analysis for green façades and living wall systems. *Energy and Buildings*, *43*(12), 3419–3429. https://doi.org/10.1016/j.enbuild.2011.09.010

Pachauri, S., van Ruijven, B. J., Nagai, Y., Riahi, K., van Vuuren, D. P., Brew-Hammond, A., & Nakicenovic, N. (2013). Pathways to achieve universal household access to modern energy by 2030. *Environmental Research Letters*, *8*(2), 024015

Pachauri, Rajendra K., et al. (2014). Climate change 2014 synthesis report summary chapter for policymakers. *Ipcc*, 31

Pacheco-Torgal, F., Cabeza, L. F., Labrincha, J., & De Magalhaes, A. G. (2014). *Eco-efficient construction and building materials: life cycle assessment (LCA), eco-labelling and case studies*. woodhead Publishing

Pan, L., & Chu, L. M. (2016). Energy saving potential and life cycle environmental impacts of a vertical greenery system in Hong Kong: a case study. *Building and Environment*, *96*, 293-300

Papadakis, G., Tsamis, P., & Kyritsis, S. (2001). An experimental investigation of the effect of shading with plants for solar control of buildings. *Energy and buildings*, *33*(8), 831-836

Parizotto, S., & Lamberts, R. (2011). Investigation of green roof thermal performance in temperate climate: A case study of an experimental building in Florianópolis city, Southern Brazil. *Energy and buildings*, *43*(7), 1712-1722

Pearce, W., Holmberg, K., Hellsten, I., & Nerlich, B. (2014). Climate change on Twitter: Topics, communities and conversations about the 2013 IPCC Working Group 1 report. *PloS one*, *9*(4), e94785

Peck, S. W., & Callaghan, C. (1999). Greenbacks from Green Roofs: Forging a new industry in Canada. *Canada Mortage and Housing Corporation*, *March*, 1–78.

Peck, S. W., Callaghan, C., Kuhn, M. E., & Bass, B. (1999). Greenbacks from green roofs: Forging a new industry in Canada status report on benefits, barriers and opportunities for green roof and vertical garden technology diffusion. *Environment*, *March*, 78. http://ohio.sierraclub.org/miami/images/files/Greenbacks.pdf

Pérez-Urrestarazu, L., Blasco-Romero, A., & Fernández-Cañero, R. (2017). Media and social impact valuation of a living wall: The case study of the Sagrado Corazon hospital in Seville (Spain). *Urban Forestry and Urban Greening*, *24*(March), 141–148. https://doi.org/10.1016/j.ufug.2017.04.002

Pérez-Urrestarazu, L., Fernández-Cañero, R., Franco-Salas, A., & Egea, G. (2015). Vertical Greening Systems and

Sustainable Cities. *Journal of Urban Technology*, *22*(4), 65–85. https://doi.org/10.1080/10630732.2015.1073900

Pérez, G., Rincón, L., Vila, A., González, J. M., & Cabeza, L. F. (2011). Behaviour of green facades in Mediterranean Continental climate. *Energy Conversion and Management*, *52*(4), 1861–1867. https://doi.org/10.1016/j.enconman.2010.11.008

Pérez G, Rincón L, Vila A, González JM, Cabeza LF. Green vertical systems for buildings as passive systems for energy savings. Appl Energ 2011; 88:4854-4859

Pérez, Gabriel, Coma, J., Martorell, I., & Cabeza, L. F. (2014). *Vertical Greenery Systems (VGS) for energy saving in buildings : A review*. *39*, 139–165. https://doi.org/10.1016/j.rser.2014.07.055

Pérez, G., Coma, J., Sol, S., & Cabeza, L. F. (2017). Green facade for energy savings in buildings: The influence of leaf area index and facade orientation on the shadow effect. *Applied energy*, *187*, 424-437

Perini, K., & Magliocco, A. (2012). *The Integration of Vegetation in Architecture , Vertical and Horizontal Greened Surfaces*. *4*(2), 79–91. https://doi.org/10.5539/ijb.v4n2p79

Perini, K., Bazzocchi, F., Croci, L., Magliocco, A., & Cattaneo, E. (2017). The use of vertical greening systems to reduce the energy demand for air conditioning. Field monitoring in Mediterranean climate. *Energy and Buildings*, *143*, 35-42

Perini, K., Magliocco, A., & Giulini, S. (2017). *Vertical greening systems evaporation measurements : does plant species influence cooling performances ? 3315*. https://doi.org/10.1080/14733315.2016.1214388

Perini, K., Ottelé, M., Fraaij, A. L. A., Haas, E. M., & Raiteri, R. (2011). Vertical greening systems and the effect on air flow and temperature on the building envelope. *Building and Environment*, *46*(11), 2287–2294. https://doi.org/10.1016/j.buildenv.2011.05.009

Perini, K., Ottelé, M., Giulini, S., Magliocco, A., & Roccotiello, E. (2017). Quantification of fine dust deposition on different plant species in a vertical greening system. *Ecological Engineering*, *100*, 268–276. https://doi.org/10.1016/j.ecoleng.2016.12.032

Perini, K., Ottelé, M., Haas, E. M., & Raiteri, R. (2011). Greening the building envelope, facade greening and living wall systems. *Open Journal of Ecology*, *01*(01). https://doi.org/10.4236/oje.2011.11001

Perini, K., & Rosasco, P. (2013). *Cost e bene fi t analysis for green façades and living wall systems*. *70*, 110–121. https://doi.org/10.1016/j.buildenv.2013.08.012

Price, J. (2010). *Green facade energetics* (Doctoral dissertation)

Priyadarsini, R. (2009). Urban heat island and its impact on building energy consumption. *Advances in building energy research*, *3*(1), 261-270

Pulselli, R. M., Pulselli, F. M., Mazzali, U., Peron, F., & Bastianoni, S. (2014). Emergy based evaluation of environmental performances of Living Wall and Grass Wall systems. *Energy and Buildings*, *73*, 200–211. https://doi.org/10.1016/j.enbuild.2014.01.034

Radić, M., Dodig, M. B., & Auer, T. (2019). Green facades and living walls-A review establishing the classification of construction types and mapping the benefits. *Sustainability (Switzerland)*, *11*(17), 1–23. https://doi.org/10.3390/su11174579

Radic, M., Arsic, J., Džaleta, M., & Stevovic, S. (2011). Eco-architecture and sustainable design as a function of the quality of environment. In *Sustainable Buildings and Urban Oasis, Proceedings of International Green Build Conference* (pp. 4-7)

Raji, B., Tenpierik, M. J., & van den Dobbelsteen, A. (2015). The impact of greening systems on building energy performance: A literature review. *Renewable and Sustainable Energy Reviews*, *45*, 610-623

Ramayah, T., & Rahbar, E. (2013). Greening the environment through recycling: an empirical study. *Management of Environmental Quality: An International Journal*

Rayner JP, Raynor KJ, Williams NSG. Façade greening: a case study from Melbourne, Australia. II International Conference on Landscape and Urban Hort; 2010. p. 6

Raxworthy, J. (2008). Patrick Blanc. *Landscape Architecture Australia*, *118*(May 2008), 59-60

Raziee, T, 2017, Vision of climate condition in Iran based on Coppen-Gigger in, Geophysics Iran, volum11, number 1, 1-84pp

Razzaghmanesh, M., & Razzaghmanesh, M. (2017). Thermal performance investigation of a living wall in a dry climate of Australia. *Building and Environment*, *112*, 45-62

Reid, W. V. (2005). *Millennium ecosystem assessment*

Reznik, G., & Schmidt, E. (2009). *Immissionsminderung durch Pflanzen – Abscheidung und Abwaschung von Feinstaub an Efeu*.

Riley, B. (2017). The state of the art of living walls: Lessons learned. In *Building and Environment* (Vol. 114). https://doi.org/10.1016/j.buildenv.2016.12.016

Rosasco, P. (2018). Economic Benefits and Costs of Vertical Greening Systems. In Nature Based Strategies for Urban and Building Sustainability (pp. 291-306). Butterworth-Heinemann

Rosenzweig, C., Solecki, W. D., Hammer, S. A., & Mehrotra, S. (Eds.). (2011). Climate change and cities: First assessment report of the urban climate change research network. Cambridge University Press

Roshan, G. R., Orosa, J. A., & Nasrabadi, T. (2012). Simulation of climate change impact on energy consumption in buildings, case study of Iran. *Energy Policy*, *49*, 731-739

ROTH, M., OKE, T. R., & EMERY, W. J. (1989). Satellite-derived urban heat islands from three coastal cities and the utilization of such data in urban climatology. *International journal of remote sensing*, *10*(11), 1699-1720

Sadineni, S. B., Madala, S., & Boehm, R. F. (2011). Passive building energy savings: A review of building envelope components. Renewable and sustainable energy reviews, 15(8), 3617-3631

Saligheh, Mohammad, 2015, Climate change and hazards in Tehran, Spatial analysis environmental hazards, second year, number3, 15-32 pp

Safikhani, T., Abdullah, A. M., Ossen, D. R., & Baharvand, M. (2014). A review of energy characteristic of vertical greenery systems. *Renewable and Sustainable Energy Reviews*, *40*, 450–462. https://doi.org/10.1016/j.rser.2014.07.166

Salamanca, F., Georgescu, M., Mahalov, A., Moustaoui, M., & Wang, M. (2014). Anthropogenic heating of the urban environment due to air conditioning. *Journal of Geophysical Research: Atmospheres*, *119*(10), 5949-5965

Santamouris, M., Papanikolaou, N., Koronakis, I., Livada, I., & Asimakopoulos, D. (1999). Thermal and air flow characteristics in a deep pedestrian canyon under hot weather conditions. Atmospheric Environment, 33(27), 4503-4521

Santamouris, M., Papanikolaou, N., Livada, I., Koronakis, I., Georgakis, C., Argiriou, A., & Assimakopoulos, D. N. (2001). On the impact of urban climate on the energy consumption of buildings. *Solar energy*, *70*(3), 201-216

Santamouris, M., Synnefa, A., & Karlessi, T. (2011). *Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions*. *85*, 3085–3102. https://doi.org/10.1016/j.solener.2010.12.023

Santamouris, M. (2013). Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments. *Renewable and Sustainable Energy Reviews*, *26*, 224-240

Shafiee, E., Faizi, M., Yazdanfar, S. A., & Khanmohammadi, M. A. (2020). Assessment of the effect of living wall systems on the improvement of the urban heat island phenomenon. *Building and Environment*, *181*, 106923

Shafaghat, A., Keyvanfar, A., Lamit, H., Mousavi, S. A., & Abd Majid, M. Z. (2014). Open Plan Office Design Features Affecting Staffâ€™ s Health and Well-being Status. *Jurnal Teknologi*, *70*(7)

Shafaghat, A., Keyvanfar, A., Zakaria, W. Z., Zaimi, M. Z. A., Lamit, H., Ali Kh. N., Ahmad, M. H., Iskandar Ariffin, S. A. 2014. Investigation of Future Building Performance Factors Towards Energy Efficient Travel Plan in Regional Development. *Jurnal Teknologi (Sciences & Engineering).* 70(7): 77–81

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

Schmidt, M. (2003). Energy saving strategies through the greening of buildings the example of the Institute of Physics of the Humboldt-University in Berlin-Adlershof, Germany. *Forest*, *29*, 4

Serra, V., Bianco, L., Candelari, E., Giordano, R., Montacchini, E., Tedesco, S., ... & Schiavi, A. L. E. S. S. A. N. D. R. O. (2017). A novel vertical greenery module system for building envelopes: The results and outcomes of a multidisciplinary research project. Energy and Buildings, 146, 333-352

Seto, K. C., Güneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(40), 16083–16088

Sheweka, S. M., & Mohamed, N. M. (2012). Green facades as a new sustainable approach towards climate change. *Energy Procedia*, *18*, 507–520. https://doi.org/10.1016/j.egypro.2012.05.062

Sheweka, S., & Magdy, N. (2011). The living walls as an approach for a healthy urban environment. *Energy Procedia*, *6*, 592–599. https://doi.org/10.1016/j.egypro.2011.05.068

Smit, B., Burton, I., Klein, R. J., & Wandel, J. (2000). An anatomy of adaptation to climate change and variability. In *Societal adaptation to climate variability and change* (pp. 223-251). Springer, Dordrecht

Stone Jr, B., & Rodgers, M. O. (2001). Urban form and thermal efficiency: how the design of cities influences the urban heat island effect. *American Planning Association. Journal of the American Planning Association*, *67*(2), 186

Song, Y., Maher, B. A., Li, F., Wang, X., Sun, X., & Zhang, H. (2015). Particulate matter deposited on leaf of five evergreen species in Beijing, China: Source identification and size distribution. *Atmospheric Environment*, *105*, 53–60. https://doi.org/10.1016/j.atmosenv.2015.01.032

Souch, C., & Grimmond, S. (2006). Applied climatology: Urban climate. *Progress in Physical Geography*, *30*(2), 270–279. https://doi.org/10.1191/0309133306pp484pr

Spiegel, R., & Meadows, D. (1999). Green Building Materials: A Guide to Product Selection and Specification.[ohn Wiley & Sons. *New York*

Spiegel, R., & Meadows, D. (2010). *Green building materials: a guide to product selection and specification*. John Wiley & Sons

Stav, Y., & Lawson, G. (2011). Vertical vegetation design decisions and their impact on energy consumption in subtropical cities. *WIT Transactions on Ecology and the Environment*, *155*, 489–500. https://doi.org/10.2495/SC120411

Stav, Y., & Lawson, G. (2012). Vertical vegetation design decisions and their impact on energy consumption in subtropical cities. *The Sustainable City VII: Urban Regeneration and Sustainability [WIT Transactions on Ecology and the Environment, Volume 155]:*, 489-500

Sternberg, T., Viles, H., Cathersides, A., & Edwards, M. (2010). Dust particulate absorption by ivy (Hedera helix L) on historic walls in urban environments. *Science of the Total Environment*, *409*(1), 162-168

Stec, W. J., Van Paassen, A. H. C., & Maziarz, A. (2005). Modelling the double skin façade with plants. *Energy and Buildings*, *37*(5), 419–427. https://doi.org/10.1016/j.enbuild.2004.08.008

Sternberg, T., Viles, H., & Cathersides, A. (2011). Evaluating the role of ivy (Hedera helix) in moderating wall surface microclimates and contributing to the bioprotection of historic buildings. *Building and Environment*, *46*(2), 293–297. https://doi.org/10.1016/j.buildenv.2010.07.017

Sternberg, T., Viles, H., Cathersides, A., & Edwards, M. (2010). Dust particulate absorption by ivy (Hedera helix L) on historic walls in urban environments. *Science of the Total Environment*, *409*(1), 162–168. https://doi.org/10.1016/j.scitotenv.2010.09.022

Sudimac, B., Ilić, B., Munćan, V., & Anđelković, A. S. (2019). Heat flux transmission assessment of a vegetation wall influence on the building envelope thermal conductivity in Belgrade climate. *Journal of Cleaner Production*, *223*, 907–916. https://doi.org/10.1016/j.jclepro.2019.02.087

Sunakorn, P., & Yimprayoon, C. (2011). Thermal performance of biofacade with natural ventilation in the tropical climate. *Procedia Engineering*, *21*, 34-41

Susorova, Irina, Angulo, M., Bahrami, P., & Brent Stephens. (2013). A model of vegetated exterior facades for evaluation of wall thermal performance. *Building and Environment*, *67*, 1–13. https://doi.org/10.1016/j.buildenv.2013.04.027

Susorova, I. (2013). *Evaluation of the effects of vegetation and green walls on building thermal performance and energy consumption*. Illinois Institute of Technology

Susorova, I., Tabibzadeh, M., Rahman, A., Clack, H. L., & Elnimeiri, M. (2013). The effect of geometry factors on fenestration energy performance and energy savings in office buildings. *Energy and Buildings*, *57*, 6-13.

Susorova, I., & Bahrami, P. (2013). Facade-integrated vegetation as an environmental sustainable solution for energy-efficient buildings. *MADE Research Journal of Cardiff University: Cardiff, UK*, 6-14.

Susorova, I., Azimi, P., & Stephens, B. (2014). The effects of climbing vegetation on the local microclimate, thermal performance, and air infiltration of four building facade orientations. *Building and Environment*, *76*, 113-124

Susorova, I. (2015). Green facades and living walls: Vertical vegetation as a construction material to reduce building cooling loads. In *Eco-efficient Materials for Mitigating Building Cooling Needs: Design, Properties and Applications*. Elsevier Ltd. https://doi.org/10.1016/B978-1-78242-380-5.00005-4

Swart, R., Robinson, J., & Cohen, S. (2003). Climate change and sustainable development: expanding the options. *Climate policy*, *3*(sup1), S19-S40

Taib, N., Abdullah, A., Fadzil, S. F. S., & Yeok, F. S. (2010). An assessment of thermal comfort and users' perceptions of landscape gardens in a high-rise office building. *Journal of sustainable development*, *3*(4), 153

Taib, T. (2010). *Efficiency in construction process* (Doctoral dissertation, Universiti Teknologi Malaysia)

Tan, C. L., Wong, N. H., & Jusuf, S. K. (2014). Effects of vertical greenery on mean radiant temperature in the tropical urban environment. *Landscape and Urban Planning*, *127*, 52-64

Taha, H., Sailor, D. J., & Akbari, H. (1992). *Lawrence Berkeley National Laboratory Recent Work Title High-Albedo Materials for Reducing Building Cooling Energy Use*. https://escholarship.org/uc/item/09b669b8

Takakura, T., Kitade, S., & Goto, E. (2000). Cooling effect of greenery cover over a building. *Energy and Buildings*, *31*(1), 1–6. https://doi.org/10.1016/S0378-7788(98)00063-2

Takebayashi, H. (2007). Study on a Simple Evaluation Method of Urban Heat Island Measure Effects Using Upper Weather Data. *Journal of Environmental Engineering (Transactions of AIJ)*, *72*(621), 57–62. https://doi.org/10.3130/aije.72.57_4

Taslim, S., Parapari, D. M., & Shafaghat, A. (2015). Urban design guidelines to mitigate urban heat island (UHI) effects in hot-dry cities. *Jurnal Teknologi*, *74*(4)

Tayebi, S., Mohammadi, H., Shamsipoor, A., Alavi, S. A., & Hoseinioun, S. (2019). Analysis of land surface temperature trend and climate resilience challenges in Tehran. *International Journal of Environmental Science and Technology*, *16(12), 8585-8594*

Tedesco, S., Giordano, R., & Montacchini, E. (2016). How to measure the green façade sustainability? A proposal of a technical standard. Energy Procedia, 96, 560-567

Thormark, C. (2006). The effect of material choice on the total energy need and recycling potential of a building. *Building and environment*, *41*(8), 1019-1026

Thomsit-Ireland, F. (2019). *Overcoming the barriers to green walls in urban areas of the UK* (Doctoral dissertation, University of Reading)

Urrestarazu, M., & Burés, S. (2012). Sustainable green walls in architecture. *J Food Agric Environ*, *10*(1), 792-4

Van Renterghem, T., Hornikx, M., Forssen, J., & Botteldooren, D. (2013). The potential of building envelope greening to achieve quietness. Building and Environment, 61, 34-44

Veisten, K., Smyrnova, Y., Klæboe, R., Hornikx, M., Mosslemi, M., & Kang, J. (2012). Valuation of green walls and green roofs as soundscape measures: Including monetised amenity values together with noise-attenuation values in a cost-benefit analysis of a green wall affecting courtyards. *International Journal of Environmental Research and Public Health*, *9*(11). https://doi.org/10.3390/ijerph9113770

Vox, G., Blanco, I., & Schettini, E. (2018). Green façades to control wall surface temperature in buildings. *Building and Environment*, *129*, 154-166

Wang, Y., Chen, L., & Kubota, J. (2016). The relationship between urbanization, energy use and carbon emissions: evidence from a panel of Association of Southeast Asian Nations (ASEAN) countries. *Journal of Cleaner Production*, *112*, 1368-1374

Wang, N., Phelan, P. E., Harris, C., Langevin, J., Nelson, B., & Sawyer, K. (2018). Past visions, current trends, and future context: A review of building energy, carbon, and sustainability. Renewable and Sustainable Energy Reviews, 82, 976-993

Wang, X., Gard, W., Borska, H., Ursem, B., & van de Kuilen, J. W. G. (2020). Vertical greenery systems: from plants to trees with self-growing interconnections. *European Journal of Wood and Wood Products*, *78*(5), 1031-1043

Weerakkody, U., Dover, J. W., Mitchell, P., & Reiling, K. (2017). Particulate matter pollution capture by leaves of seventeen living wall species with special reference to rail-traffic at a metropolitan station. *Urban Forestry and Urban Greening*, *27*(June), 173–186. https://doi.org/10.1016/j.ufug.2017.07.005

Weerakkody, U., Dover, J. W., Mitchell, P., & Reiling, K. (2018). Quantification of the traffic-generated particulate matter capture by plant species in a living wall and evaluation of the important leaf characteristics. *Science of the Total Environment*, *635*, 1012–1024. https://doi.org/10.1016/j.scitotenv.2018.04.106

Widiastuti, R., Prianto, E., & Budi, W. S. (2016). Performance Evaluation of Vertical Gardens. *Int. J. Arch. Eng. Const*, *5*, 13-20

Wilby, R. L. (2007). A review of climate change impacts on the built environment. *Built environment*, *33*(1), 31-45

Whitehead, D., Beadle, C.L., 2004. Physiological regulation of productivity and wateruse in Eucalyptus: a review. For. Ecol. Manag. 193, 113–140

Whitford, V., Ennos, A. R., & Handley, J. F. (2001). "City form and natural process" - Indicators for the ecological performance of urban areas and their application to Merseyside, UK. *Landscape and Urban Planning*, *57*(2), 91–103. https://doi.org/10.1016/S0169-2046(01)00192-X

Weinmaster, M. (2009). Are green walls as "green" as they look? An introduction to the various technologies and ecological benefits of green walls. *Journal of Green Building*, *4*(4), 3-18

Wong, N. H., Tan, A. Y. K., Tan, P. Y., & Wong, N. C. (2009). Energy simulation of vertical greenery systems. *Energy and Buildings*, *41*(12), 1401–1408. https://doi.org/10.1016/j.enbuild.2009.08.010

Wong, N. H., Kwang Tan, A. Y., Chen, Y., Sekar, K., Tan, P. Y., Chan, D., Chiang, K., & Wong, N. C. (2010 a). Thermal evaluation of vertical greenery systems for building walls. *Building and Environment*, *45*(3), 663–672. https://doi.org/10.1016/j.buildenv.2009.08.005

Wong, N. H., Kwang Tan, A. Y., Tan, P. Y., Chiang, K., & Wong, N. C. (2010 b). Acoustics evaluation of vertical greenery systems for building walls. *Building and Environment*, *45*(2), 411–420. https://doi.org/10.1016/j.buildenv.2009.06.017

Wong, N.H., et al., 2010c. Perception studies of vertical greenery systems in Singapore. J. Urban Plan. Dev. 136 (4), 330-338

Wong, I., & Baldwin, A. N. (2016). Investigating the potential of applying vertical green walls to high-rise residential buildings for energy-saving in sub-tropical region. *Building and Environment*, *97*, 34-39

Wood, A., Bahrami, P., & Safarik, D. (2014). *Green walls in high-rise buildings: An output of the CTBUH sustainability working group*. Images Publishing

Xing, Q., Hao, X., Lin, Y., Tan, H., & Yang, K. (2019). Experimental investigation on the thermal performance of a vertical greening system with green roof in wet and cold climates during winter. *Energy and Buildings*, *183*, 105-117

Xu, L., & Ojima, T. (2007). Field experiments on natural energy utilization in a residential house with a double skin façade system. *Building and Environment*, *42*(5), 2014-2023

Yaghoobian N, Srebric J. Influence of plant coverage on the total green roof energy balance and building energy consumption. Energy and Buildings 2015; 103:1–13

Yap, D. (1975). Seasonal excess urban energy and the nocturnal heat island—Toronto. Archiv für Meteorologie, Geophysik und Bioklimatologie, Serie B, 23(1), 69-80

Yin, H., Kong, F., Middel, A., Dronova, I., Xu, H., & James, P. (2017). Cooling effect of direct green façades during hot summer days: An observational study in Nanjing, China using TIR and 3DPC data. *Building and Environment*, *116*, 195-206

Yu, C., & Hien, W. N. (2009). Thermal impact of strategic landscaping in cities: A review. *Advances in Building Energy Research*, *3*(1), 237-260

Zhang, X. Q. (2016). The trends, promises and challenges of urbanisation in the world. *Habitat international*, *54*, 241-252

Appendix

Grading VGS according to criteria

Very High	High	Medium	Low	Very Low	Indicator	System
	✓				Disposal cost	Modular soil-based pocket
				✓	Weight	
	✓				Pay-back time	
			✓		Flexibility in Design	
	✓				Fire safety	
	✓				Stability in harsh weather	
		✓			Maintenance cost	
	✓				Initial cost	
		✓			Rust resistance	
	✓				Longevity	
			✓		Recyclable materials	
		✓			Reusable materials	
		✓			Maintenance frequency	
			✓		Pruning frequency	
			✓		Water demand	
		✓			The frequency of the Plant replacement	
		✓			Frequency of irrigation check	
	✓				Irrigation system service life	

Very High	High	Medium	Low	Very Low	Indicator	System
	✓				Disposal cost	Geotextile Felt system(continuous)
	✓				Weight	
	✓				Pay-back time	
✓					Flexibility in Design	
			✓		Fire safety	
			✓		Stability in harsh weather	
			✓		Maintenance cost	
		✓			Initial cost	
	✓				Rust resistance	
		✓			Longevity	
			✓		Recyclable materials	
			✓		Reusable materials	
			✓		Maintenance frequency	
		✓			Pruning frequency	
		✓			Water demand	
		✓			The frequency of the Plant replacement	
			✓		Frequency of irrigation check	
		✓			Irrigation system service life	

Very High	High	Medium	Low	Very Low	Indicator	System
			✓		Disposal cost	Panel-based
			✓		Weight	
	✓				Pay-back time	
			✓		Flexibility in Design	
	✓				Fire safety	
	✓				Stability in harsh weather	

			✓		Maintenance cost	
		✓			Initial cost	
	✓				Rust resistance	
	✓				Longevity	
		✓			Recyclable materials	
		✓			Reusable materials	
			✓		Maintenance frequency	
		✓			Pruning frequency	
			✓		Water demand	
		✓			The frequency of the Plant replacement	
		✓			Frequency of irrigation check	
		✓			Irrigation system service life	
Very High	**High**	**Medium**	**Low**	**Very Low**	**Indicator**	**System**
		✓			Disposal cost	Planter boxes
	✓				Weight	
	✓				Pay-back time	
			✓		Flexibility in Design	
	✓				Fire safety	
	✓				Stability in harsh weather	
	✓				Maintenance cost	
		✓			Initial cost	
	✓				Rust resistance	
	✓				Longevity	
	✓				Recyclable materials	
		✓			Reusable materials	
			✓		Maintenance frequency	
		✓			Pruning frequency	
			✓		Water demand	
		✓			The frequency of the Plant replacement	
		✓			Frequency of irrigation check	
		✓			Irrigation system service life	

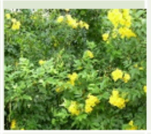
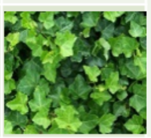
Very High	High	Medium	Low	Very Low	Indicator	System
		✓			Disposal cost	Pocket- based Hydroponic
✓					Weight	
	✓				Pay-back time	
	✓				Flexibility in Design	
					Fire safety	
		✓			Stability in harsh weather	
		✓			Maintenance cost	
					Initial cost	
	✓				Rust resistance	
		✓			Longevity	
		✓			Recyclable materials	
				✓	Reusable materials	
					Maintenance frequency	
		✓			Pruning frequency	
		✓			Water demand	
		✓			The frequency of the Plant replacement	
		✓			Frequency of irrigation check	
		✓			Irrigation system service life	

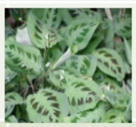
Very High	High	Medium	Low	Very Low	Indicator	System
	✓				Disposal cost	Direct green facade
	✓				Weight	
			✓		Pay-back time	
	✓				Flexibility in Design	
	✓				Fire safety	
	✓				Stability in harsh weather	
✓					Maintenance cost	
	✓				Initial cost	
✓					Rust resistance	
✓					Longevity	
✓					Recyclable materials	
✓					Reusable materials	
✓					Maintenance frequency	
	✓				Pruning frequency	
✓					Water demand	
✓					The frequency of the Plant replacement	
✓					Frequency of irrigation check	
✓					Irrigation system service life	

List of suggested plants based on Iranian companies

Plant species		Cycle	growing rate	Hardness	Lighting needs	Maintenance needs	Soil features Moisture	Bloom color and time	Foliage color	Mature Height
				Specific feature	Water needs			Flower color		
								Fruit		
English name Felce di Boston (Sword fern)	**Plant Type** herbaceous	Evergreen	Fast / Medium	High	half shade	Low	pH level: Slightly acidic Rich in humous	Non-flowering	light green	80 cm
Scientific name Nephrolepis exaltata				Dangerous for rabbits -good air purification	High			Non-flowering		
English name	**Plant Type** 	Evergreen	Normal / fast	High	Partial shade, Full sun	Low	Chalky, Clay, Loamy, Sandy Medium moisture	winter and spring	Dark Green	2.5 meters 5-10 years
Scientific name Jasminum	Shrubby & climbing				Medium to high			white		
English name **Plantain lilies**	**Plant Type** herbaceous	Evergreen	Normal / fast	-40°F minimum) southward as far as zone 9 (20°F minimum	Half shade	Low	Sub-acid to sub-alkaline	May and Septemb er	Dark green and blue-leaved	15-120 cm
Scientific name Hosta					Medium to high			Non-flowering		

Plant species		**Cycle**	**growing rate and pattern**	**Hardness**	**Lighting needs**	**Maintenance needs**	**Soil features Moisture**	**Bloom color and time**	**Foliage color**	**Mature Height**
				Specific feature	**Water needs**			**Flower color**		
								Fruit		
English name Lysimachia nummularia	**Plant Type** Perennials shrub	Evergreen	Fast	Heavy Shade, Clay Soil, Air Pollution	Full sun	Low	Normal/dray	Yellow	Green-Yellow	5-7 cm
Scientific name Aucuba					High			Summer		
English name Yarrow	**Plant Type** Perennials	Evergreen	Moderate	Drought Tolerant-Fire-resistant-Attracts pollinators and beneficial insects	full sun	Low	Dry / Medium	Yellow	Silver-Grey	60-90 cm
Scientific name Achillea millefolium	**Plant Type** 				Low			Summer		
English name	**Plant Type** Perennials	Evergreen	Fast		Full sun to part shade	Low	6.0 to 7.0 (slightly acid to neutral)	lavender or blue purple trumpet spikes	dark green, variegated white and green	30-45 cm
Scientific name Liriope muscari								Summer-Autumn		

Plant species		Cycle	Growing rate	Hardness	Lighting needs	Maintenance needs	Soil features	Bloom color and time	Foliage color	Mature Height
				Specific feature	Water needs		Moisture	Flower color		
								Fruit		
English name	**Plant Type** Perennials	Deciduous	Medium	Frost resistance	Full sun / partial shade	Medium		Summer	Light green	0.05 m
Scientific name					Low			Yellow		
English name yellow bells	**Plant Type** Perennials shrub	Evergreen	Fast	-4.00 degrees Celsius	Full sun- partial sun	Medium	pH 5.6-8.5	Yellow	Dark green	3.1 m
Scientific name Tecoma stans					Medium			Spring to fall		
English name English ivy	**Plant Type** Perennial Climbing	Evergreen	Fast	Toxic to dogs and cats	Full sun, partial shade	low	Acidic	Yellow, cream	Green & white	20–30 m
Scientific name Hedera helix					Low		Medium	Fall, early winter		

Plant species		Cycle	Growing rate	Hardness Specific feature	Lighting needs Water needs	Maintenance needs	Soil features & Preferred Humidity	Bloom color and time Flower color Fruit	Foliage color	Mature Height
English name Garden croton **Scientific name** Codiaeum variegatum	**Plant Type** Shrub 	Evergreen	Fast	-15/ +20 degrees Celsius	Bright, indirect light Medium-high	Low	Well drained potting soil	November to February No flower	yellow, orange, green, reddish, pink to purple	2.00 m
English name **Scientific name** Maranta	**Plant Type** Herbaceous perennial 	Evergreen	Fast	15-26 degrees Celsius	Partial shade, full shade Average	Medium	Well drained Neutral to acidic High to very high High	Spring White	Dark green	0.3 m
English name **Scientific name** Atriplex halimus	**Plant Type** Shrub 	Evergreen	Slow	-10.00 degrees Celsius	Full sun Low	Low	Neutral Medium	July -August No flowering	Light green	1.5-2.5 m

Plant species		**Cycle**	**Growing rate**	**Hardness**	**Lighting needs**	**Maintenance needs**	**Soil features & Preferred Humidity**	**Bloom color and time**	**Foliage color**	**Mature Height**
				Specific feature	**Water needs**			**Flower color** / Fruit		
English name Fescues	**Plant Type** herbaceous perennial	Evergreen	Medium/ slow	Drought, Dry Soil, Shallow-Rocky Soil, Black Walnut, Air Pollution	Full sun	High	Well drained	June to July	blue-green	2.00 m
Scientific name Festuca					Low			Greenish to yellow		
English name	**Plant Type** Perennial succulent	Evergreen	Slow	Drought	Partial shade	Low	Well drained Neutral to acidic	Spring/summer	Light green	0.15 m
Scientific name Crassula					Medium		Medium	Yellow		
English name perforate St John's-wort	**Plant Type** Herbaceous perennial	Deciduous	Medium	Antidepressant, Drought	Full sun, partial shade	Low	Neutral	June to August	Green-yellow	1.00 m
Scientific name Hypericum perforatum					Medium			yellow		