A state of the art review of the impact of Vertical Greenery Systems on the energy performance of buildings in temperate climates

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A state of the art review of the impact of Vertical Greenery Systems (VGS) on the energy performance of buildings in temperate climates

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Abstract: Rapid urbanization and climate change concerns have led to a growing drive to integrate nature into the built environment. It is expected that London will face increasing risks of flooding, overheating and drought, through hotter drier summers and warmer wetter winters. In response, the Mayor of London adopted new policies for encouraging the use of living roofs and green walls. Greenery systems are considered as promising solutions for improving energy and thermal efficiency of buildings as well as reducing pollution, encouraging biodiversity and water runoff, reducing Urban Heat Island (UHI) effects and improving the microclimate overall. The research aims to review the current state-of-the-art literature concerning the potentials and limitations of vertical greenery systems on energy and thermal performance of buildings in temperate climates. This review paper synthesises and summarizes the literature with regards to vertical green systems (VGS) when used as a passive design strategy to enhance energy savings in buildings. From the review of the literature, some key aspects to consider when designing VGS are outlined, such as climate influence, the plant species grown and the different operating mechanisms as associated such as shade, evapotranspiration, insulation and wind barrier. The results achieved from the literature review clearly indicate that green walls may be considered as key solutions to mitigate operational energy consumption of buildings as well as provide thermally comfortable indoor and outdoor environments. The results of this research will prove useful to builders, architects, engineers and policy makers as it will provide an in-depth understanding of the potential of VGS to mitigate building-related energy consumption in a renewable, sustainable, energy-efficient and cost-effective way.

Keywords: Green and living Walls, Vertical greenery systems, Green Façade, Energy Performance, Passive design

Introduction

Living walls and green facades "vertical green systems" are two main ways for integrating vegetation into buildings. Green roofs have been classified, discussed and investigated in many research studies(Green Roof Thermal Performance', 2006, 'Cool Roofs for improving thermal performance of existing EU office buildings', 2016; Grant and Lane, 2006; Köhler, 2006; J K Lanham, 2007; Collins *et al.*, 2017; Koura *et al.*, 2017; Mahmoud *et al.*, 2017; Barozzi *et al.*, 2017; Vera *et al.*, 2017), in contrast vertical green systems "VGS" have not been sufficiently studied regarding its systems, components, benefits and environmental impact particularly in temperate climates.

This might be because it may be more practical to install greenery systems on flat levels and roofs compared to applying it vertically, in addition, its lower cost due to less specialised skills required in the process (Pérez *et al.*, 2014). However, VGS could have a more significant impact on the built environment and microclimate, as the building surface area of facades is much larger than roof area.

Temperate climate

Sometimes authors do not specify the climate of the study, other times they mention it without using a recognised climate classification, and thus comparing them is problematic. Koppen climate classification system is used due to it is recognition worldwide.

It could be classified as the most wide-ranging climate system across the world and it is classified into two types (ISC-AUDUBON, 2013; GA, 2018):

Maritime temperate regions which are located near coastlines where oceanic and sea wind deliver more rain and temperature are fairly steady across the year, such regions include Western Europe the UK particularly, while Continental temperate regions are usually warmer in summer and colder in winter. In temperate climates, buildings are designed to remain cool in the warm summers and be warm in cold winters that could be through seeking solar radiation gain in winter and providing summer shading (HH, 2013). Building materials are also designed with moderate thermal mass, with moderately-sized openings and adequate thermal insulation properties in order to provide satisfactory conditions for most of the time, through overcoming over-heating in summer and cooling in winter (SKAT, 1993).

Few studies on the thermal impact on the energy performance of VGS in a temperate climate was found (Martin and Knoops, 2014), Thus, this paper discusses the findings from an extensive review of the literature concerning the impact of VGS on building energy performance in temperate climates.

Vertical greenery systems (VGS)

Vertical Greenery Systems are known as vertical gardens or bio-walls. They mainly consist of vertical structures which are fitting vertical expansion whether being attached to the wall of apart from it, It is also classified based on its complexity level, as they could be with a simple configuration or a high-tech design (Pérez-Urrestarazu *et al.*, 2015). Based on plant type, supporting system and its material, etc. Based on that, there are two different types of VGS, one; is a living wall and the other is a green façade (K€ohler, 2008; Manso and Castro-Gomes, 2015). They look similar but their planting systems are different.

The Green Façade (GF)

It is a type of vertical greenery system at which the building facade is climbed by plants either from the soil at the base of the building or from the top through planter boxes. It may take between 3-5 years for the plant to cover the whole façade and be fully grown over. It might harm the façade due to its strong roots such as the English Ivy (Othman and Sahidin, 2016). GF has several advantages as having no materials involved (growing media, support and irrigation), low-cost low maintenance, while its disadvantage lays in limited plant selection, slow surface coverage and its scattered growth along the surface (Manso and Castro-Gomes, 2015). Green Façade is divided into direct and indirect " double skin " green façade (A.M. Hunter, N.S.G. Williams, J.P. Rayner, L. Aye, D. Hes, S.J. Livesley, 2014; T. Safikhani, A.M. Abdullah, D.R. Ossen, M. Baharvand, 2014; E. Cuce, 2016),(K. Perini, 2013).

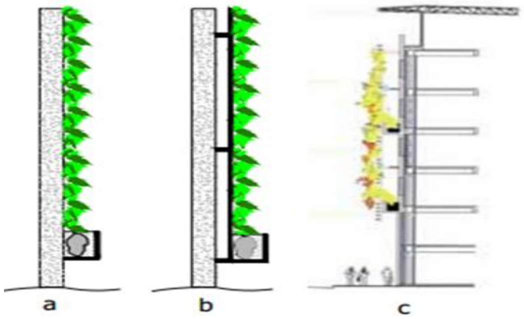

Figure 1 a) Showing planter box at the bottom with plants directly on the wall, b) planter box at the bottom with plants on supporting structure, c) planter box at the bottom of floors with plants of supporting structure *(Shamsuddeen Abdullahi and Alibaba, 2016)*

Direct green façade is a traditional green façade at which climbing plants stick to the building façade through their adhesive roots, without the need for structural support (S. Isnard, W.K. Silk, 2009; A.M. Hunter, N.S.G. Williams, J.P. Rayner, L. Aye, D. Hes).

On the other hand, indirect green façade is a double skin green façade at which structural systems as modular trellises, stainless steel mesh or stainless steel cable are used to support vertical climbing plants through the second layer of façade at a desired distance from façade (Pérez *et al.*, 2014; Manso and Castro-Gomes, 2015; E. Cuce, 2016).

Living Wall System (LWS)

The second type of VGS is the LWS which is composed of a mix of different plants usually used for green walls. Special vertical planting medium allows ground-cover plants to be planted vertically whether in a modular or a continuous system, which is made of one continuous piece of felt-layer or a single continuous concrete block (Dover, 2015; Charoenkit and Yiemwattana, 2016). The structure is metal, plastic, or other materials which are connected vertically by a structural frame. More maintenance and care is needed besides its structural load, in terms of fertilizing, trimming plants, removal and replacement of dead plants (Othman and Sahidin, 2016).

LWSs have several advantages such as the benefit of uniform growth, wide plant variety can be used, easily maintained due to its modular units which could be easily replaced besides its higher aesthetic value, while its disadvantage lays in its frequent maintenance, complex system, high water and nutrients consumption, high environmental burden and its heavy weight (Manso and Castro-Gomes, 2015). There are three systems of living walls which differ according to its function, design and construction system and materials and whether it is being used within the interior or exterior spaces (Loh, 2008).

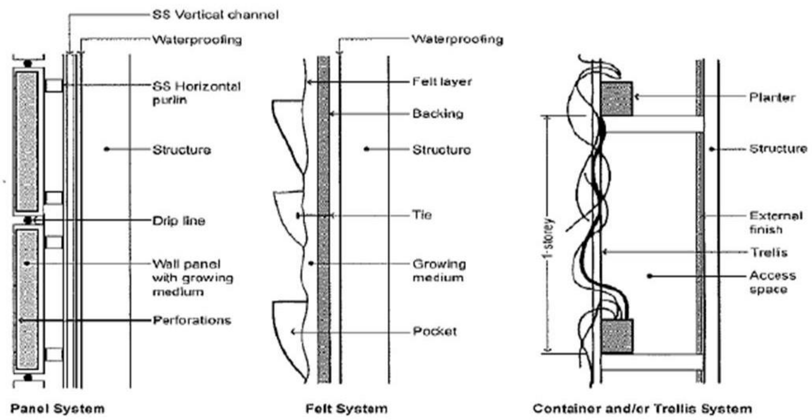

Figure 2 a) Panel system (Left), b) Felt system (Middle), c) Container/ Trellis system (Right)(SAA, 2014)

The first type is Trellis / Container System, in which containers are used to grow plants and climb onto trellises irrigation is done by controlled drip-lines. Felt System is the second type, made of felt pockets of growing medium attached to a waterproof packing where plants are grown, which is then connected to a structure behind. The felt is kept moist with water which contains plant nutrients. The third system is the Panel System which usually consists of pre-planted panels and connected to a structural system with a mechanical irrigating system.

Benefits of VGS in temperate climates

VGS potentials and positive impact on buildings through several aspects, socially, economically and environmentally which is the main aim of this paper to determine the influence and impact on building energy performance.

Environmental Benefits

Three main factors are considered in this paper as the key parameters for determining the impact of VGS as a passive technique for energy saving in a building through thermal insulation, Carbon emissions reductions and urban heat island effect.

There have been several approaches and studies on the advantages and disadvantages of VGS on energy performance in temperate climates. These aspects have been studied through synthesising and analysing outcomes of key studies.

The main aspects of focus are the orientation of the VGS, climate and sub-climate classification, the season of growth, duration of the study and finally whether empirical data analysis or modelling and simulation was used.

Key considerations for VGS energy performance (EP):

VGS as a passive tool for energy savings in buildings is mainly controlled by key factors, which influence its EP impact on building fabric, thus it should be well considered. The first factor is the climate influence, which is not only affecting the microclimate around the building, but it also affects the plant species used and how it will grow. The type of VGS used is the second factor, whether it is direct, indirect green facade or living wall. The third factor is the plant species, whether it is evergreen or deciduous or climbing, etc. the façade orientation is very important as different plant species require different orientation, as well as the different impact of each species on building EP depending on which façade orientation it is applied to. Finally, the particular study focus and concern were outlined in order to illustrate the key findings and their influences in temperate climates.

Based on these considerations three study tables for VGS classification were carried out to illustrate and analyse the research which was carried so far on VGS influence on EP in Temperate climate. It was classified into three tables which are direct, and indirect green facades and living walls.

Direct green facades studies on VGS as a passive tool for improving energy performance in temperate climate

12 study has been carried out for direct green façade in a temperate climate. Most of the studies have been carried out in summer with the main focus on its thermal performance.

There was no focus on carbon reductions although it was mentioned in Hasim Altan study through calculating the LCA of green facades, while with one study on wind study impact on energy performance.

Table 1 Direct green facades studies

Author / Year	Location	Koppen classification	Study Period	Plant Species	orientation	Model/ Real analysis	Study Focus
(Hoyano, 1988)	Tokyo, Japan	Cfa	Summer	Boston ivy	West	Real	Thermal and cooling load
(Eumorfopoulou , 2009)	Thessaloniki, Greece	Cfb	Summer	Boston ivy	East	Both	Thermal performance
(Sternberg, Viles and Cathersides, 2011)	Byland,Abbey,Ramsey, Oxford , UK	Cfb	All Year	Hedra Helix	West, South	Real	Wall surface temperature
(Perini *et al.*, 2011)	Delft, Netherlands	Cfb	Autumn	Hedra Helix	North, West	Real	Wind Speed
(Cameron, Taylor and Emmett, 2014)	Reading, UK	Cfb	Summer	Hereda Helix, Stachys byzantina	North, South	Real	Wall surface temperature

(Bolton *et al.*, 2014)	Manchester, UK	Cfb	2 cold snowy Winters	Hedra Helix	North	Real	Internal and External Wall Temperature. Ambient Temp Energy Consumption
(Alexandri, Jones and Doussis, 2005)	London, UK	Cfb	Typical hottest day in the hottest month	Hedra Helix	Canyon orientation NS EW	micro scale model	Urban Heat Island Effect for climates and Canyon geometries
(Yoshimi and Altan, 2011)	Sheffield, UK	Cfb	Summer, winter	Several species	All	Both	Indoor thermal performance
(Ottelé *et al.*, 2011)	Several Temperate Climates	C	--	Several species	All	Both	Thermal performance Energy Performance
(Oosterlee, 2018)	Eindhoven, Netherlands	Cfb	Summer, Winter	--	All	Software Model	Thermal and Energy performance
(Altan *et al.*, 2017)	Sheffield, UK	Cfb	All		all	Real	Life cycle Energy and Carbon savings
(Lee, 2014)	Leicester, UK	Cfb	All	creepers and ivies	All	Software	Thermal Performance

In-Direct "double" green facades studies on VGS as a passive tool for improving energy performance in temperate climate

All indirect green façade energy performance related studies have been carried out through real analysis with a general main focus on South façade with the thermal insulation as the main goal. Compared to direct green façade, indirect green façade are quite not common due to its higher cost which could be avoided by using the direct green façade.

Table 2 In-Direct "double" green facades studies

Author / Year	**Location**	**Koppen classification**	**Study Period**	**Plant Species**	**orientation**	**Model/ Real analysis**	**Study Focus**
(Hoyano, 1988)	Tokyo, Japan	Cfa	Summer	Boston ivy	West	Real	Thermal and cooling load
(Koyama *et al.*, 2013)	Chikusa, Japan	Cfa	Summer	Bitter melon, Morning glory,	South	Real	Wall surface temperature
(Ip, Lam and Miller, 2010)	Brighton, UK	Cfb	--	Virginia Creeper	South, West	Real	Wall surface temperature
(Perini *et al.*, 2011)	Rotterdam, Netherlands	Cfb	Autumn	Hereda helix, Vitis	--	Real	Wind speed
(Gabriel Pérez *et al.*, 2011)	Lleida, Spain	Csa	All year	Parthenocissus tricuspidata, Lonicera japonica	South East (SE)	Real (physical model)	illuminance and light transmission factor values Thermal insulation, Relative Humidity, Thermal comfort

Living wall studies on VGS as a passive tool for improving energy performance in temperate climate

8 studies have been carried out for living walls in a temperate climate. Most of the studies have been carried out in summer, South and South West facade with the main focus on its thermal performance. There was no focus on carbon reductions although it was mentioned in Hasim Altan study through calculating the LCA of green facades, while with one study on wind study impact on energy performance. Most of the studies have been carried out for real case studies.

Table 3 Living wall studies

Author / Year	**Location**	**Koppen classification**	**Study Period**	**Plant Species**	**orientation**	**Model/ Real analysis**	**Study Focus**

(Cheng, Cheung and Chu, 2010)	Wuhan, China	Cfa	Summer	Six different species	West	Real	Thermal performance
(G Pérez *et al.*, 2011)	Benthnizen, Netherlands	Cfb	Autumn	Evergreen species	West	Real	Wind speed
(Olivieri, Olivieri and Neila, 2014)	Colmenar, Spain	Csa	Summer	Sedum species	South	Real	Thermal-energy performance
(Mazzali *et al.*, 2013)	(A)Lonigo,Venez a (B) Pisa,Italy	Cfa Csb	Summer	Several, shrub, herbaceous and climber species	(A)South (B)South, West and East	Real	Energy performance
(Ottelé *et al.*, 2011)	Several Temperate Climates	Cf	--	Several species	All	Both	Thermal performance Energy Performance
(Oosterlee, 2018)	Eindhoven, Netherlands	Cfb	Summer, Winter	--	All	Softwar e Model	Thermal and Energy performance
(Altan *et al.*, 2017)	Sheffield, UK	Cfb	All	Hedra Helix	all	Real	Life cycle Energy and Carbon savings
(Bianco *et al.*, 2017)	Turin, Italy	Cfa	Summer, Winter	Lonicera nitida	South	Real	Thermal Performance

Key findings based on VGS EP studies TABLE 1, TABLE 2 AND TABLE 3:

It is clear that studies undertaken in temperate climates have been mainly focusing on GF more than LW studies that might be due to its low cost and low maintenance, in addition to requiring less expertise in planting field.

It was found within the same seasons in (Eumorfopoulou and Kontoleon, 2009; Perini et al., 2011; Yoshimi and Altan, 2011; Mazzali et al., 2013; Bolton et al., 2014) that winter in Greece, UK, Netherlands and Italy are different in findings regarding VGS performance, although they are located within the same Koppen classification in warm temperate; fully humid; warm summer “Cfb”, based on authors classification for their cities. Notably, after further investigation into the results from those studies, it was found that several cities are not located within the same sub-climate zone based on Koppen climate, leading to inconsistence in VGS performance particularly between oceanic and Mediterranean temperate climates.

Comparing the Mediterranean and temperate climates it was found that both direct and indirect GF systems in both climates have the same amount of reduction in heating by 1.2% and cooling by 43%, while temperature reduction was 4.5C and 2.6C for the Mediterranean and temperate climates respectively. Thus the temperate Mediterranean has higher saving than Temperate oceanic due to higher energy consumptions in summer for cooling. Energy saving for LW with planter boxes and felt system had the same percentage of savings in both climates 6.3% and 4% respectively. While temperature reduction was found on both systems with 4.5C and 2.6C for the same systems. While energy saving for cooling was 45% for both systems in a Mediterranean climate, while it was not applicable in a temperate climate (Ottelé *et al.*, 2011).

It has also been noticed that several studies are not illustrating the same climatic properties of its zone when carrying out a study, which was clear in (Bolton et al., 2014), at which his case study was in two winters and it was extreme cold snowy winters which are not representing the basic case of the climate in Manchester, UK. Most of the studies have been undertaken on evaluating the thermal performance of VGS either wall surface temperature, indoor temperature or both while very few studies focused on wind speed and carbon savings which is also contributing in the EP.

Studies which was carried out was mainly focusing on summer season, south or south-west façade. Which shows the main goal of these studies has been more concerned about lowering the cooling load. There was a lack of long-duration studies for a whole year and for several years, which would have been a great way to show if VGS has an influence on climate change adaptation. Wall surface temperature was the main concern in several studies, showing savings in average between 11 to 20.8 1°C in the summer period and 5–16 1°C in autumn, while indoor thermal improvements ranged between 1-2°C.

A thermal regulation feature of green wall systems highly depends on vegetation type, plant intensity and orientation. The vegetation layer should not block the summer winds but should reduce the cold winter wind. Furthermore, direct solar radiation to south wall and roof is necessary for places with high heating degree days in a temperate climate. Expanding the greenery surfaces in cities by about 10% or more can help minimise the local temperature rise projected for the upcoming future.

Thermal Improvement *Table 1, Table 2 and Table 3*

There are several factors affecting thermal performance of LW as LW types; substrate type and depth, plant characteristics, air cavity and environment impact on plant performance as limited light, high wind speed, and water shortages (Charoenkit and Yiemwattana, 2016). (Bolton et al., 2014) found that, the ivy covering reduced temperature fluctuations, increased the mean external wall temperature by 0.5 C, while on average 1.4 C warmer at night and 1.7 C cooler in the middle of the day, leading to 8% reduction in energy loss.

Temperatures above 12.2 C the ivy covering increased energy loss due to blocking the warm sun, although the covering was more effective on cold days. Evergreen living walls can reduce heating costs, particularly when placed on the North of buildings, while the South side deciduous climbers are more effective as it allows warm sunlight to get into the building.
(Yoshimi and Altan, 2011) proved that plant cover improved indoor thermal comfort in both summer and winter, and reduced heat gains and losses through the wall structure.

This resulted in lower annual energy loads for heating and cooling and these effects were more significant in the case of plant cover on lightweight buildings. Plants on south or west walls appeared to be the most effective to decrease daytime indoor room temperature in summer. In cold conditions, the foliage layer increased the minimum temperature when it was applied on the north and west facing walls. Vegetation could also have negative effects such as increasing the night-time indoor temperatures in summer and obstructing daytime solar heating in winter.

Vegetation also reduced the heat gains and losses by conduction through external walls. This resulted in lower energy loads for mechanical heating and cooling.
(Besir and Cuce, 2018) showed that external surface temperature is observed to reduce in the range of 3.7–11.3 °C while increasing the percentage of foliage between 13% and 54%. The temperature difference between living wall and the bare wall is 1–31.9 ℃. The range of the heat flux reduction is reported to be 30–70 W/m2 during daytime and 1.5 W/m2 during the night. Wind speed within foliage decreases nearly 0.43 m/s compared to 10 cm distance from the bare wall and the wind speed inside vegetation is found to be zero.

Energy Improvement:

The foliage covering has three properties that will affect the heat transfer amount between the indoor and the outdoor climate which are wind speed reduction, solar radiation reduction and evaporation. The annual energy consumption decreased by almost 1%. Due to a decrease in cooling and increasing heating loads (Oosterlee, 2018).

Annual energy loads for heating and cooling were significantly reduced by vegetation more significantly through the green roof system in comparison to the green wall system through roof level, while the opposite was noticed through the whole building façade vegetation case (Lee, 2014).

(Oosterlee, 2018) Changing structure from Heavy to light structure, increased energy consumption by 41% leading to energy saving by 24 %. Attaching the LW system to the poorly insulated heavyweight structure caused the annual energy consumption to drop from 18,35 kWh to 14,65 kWh. The LW system can have a significant influence on the resistance value (0.9 m2 K W-1) of the wall. The VGS energy savings aspect of could be significantly beneficial when a high cooling demand is required for the building and with neglecting heating demand.

Therefore, these type of buildings is found in dry, tropical and Mediterranean climate zones. Throughout uninsulated physical model, mean energy consumption was reduced by 21, 37% compared to bare cuboids during the first & Second winter, while under extreme scenarios, GF has increased energy efficiency from 40-50% leading to wall surface temperatures enhancement by 3 C (Cameron, Taylor and Emmett, 2015).

Based on (L. Malys, M. Musy, 2014), 1-2C is the temperature reduction in the LW substrate layer. LW Energy performance is varied based on façade orientation in Portugal temperate climate (Csa), as with North walls a reduction of 24.4-28.6% of heating loads followed by west wall then East walls by 8.2-13.3% and 6-11.2% respectively (J.S. Carlos, 2014; Charoenkit and Yiemwattana, 2016).

(Ottelé *et al.*, 2011) No difference was found in the air temperature and wind profiles starting from 1 m in front of the façades till inside the foliage. Inside the foliage of the direct and indirect systems and inside the air cavity of the LWS a low (respectively 0.08 m/s and 0.1 m/s) wind velocity was measured The higher wind velocity found inside the air cavity of 20 cm thickness of the indirect greening system demonstrates that it is also possible to speak about an optimal air cavity thickness for greening systems (around 40-60 mm). Due to the reduction of wind velocity measured (<0.2 m/s), the exterior surface resistance (Re) could be equalized to the interior surface resistance (Ri). This affects the total thermal resistance of the façade which results in energy savings.

The payback period of direct GF ranges between 16-24 years, 16-42 for indirect GF, Thus GFs are more economically sustainable than LW which its payback time is not less than 50 years. The living wall system analysed in this study can not be considered economically sustainable due to high (compared with the other greening systems analysed in this study) installation and maintenance costs (Perini and Rosasco, 2013).

Carbon sequestration (CS)

Considering the carbon reduction tax as 20$/ton (Kyoto Protocol) the annual benefit in carbon reduction: 0.055X10-3 to 0.065X10-3 €/m2/year.

In London, payments "£60/tonne.co2" should be paid in instead of remaining carbon emissions for developments which will not meet the targets of achieving zero carbon for residential buildings on October 2016 followed by non-domestic by 2019, which should already achieve 35% of carbon reductions (STROMA, 2014; STORMA, 2018). Thus the required cost of a dwelling lifetime is (£60 x 30 years = £1,800/t.CO2).

Owing to carbon emissions environmental hazardous, most of the countries are targeting to minimizing their emissions, thus cutting energy consumption is a must in addition to enhancing green infrastructures as a solution key (Besir and Cuce, 2018).

LW have poorer performance than green roofs (GR) in CS which is 0.14-0.98 kg C/m2 for LW and 0.375-30.12 kg C/m2 for GR even though using same plants. LW CS is similar to GR sedum green substrate with 6cm depth, as it is concluded that there is a relationship between

CS and substrate depth, at which the deeper the substrate is the higher CS is occurring (Getter *et al.*, 2009; L.J. Whittinghill *et al.*, 2014; H. Luo *et al.*, 2015; Charoenkit and Yiemwattana, 2016)

Urban Heat Island Mitigation

Climate change may increase the number of heat-related deaths in the European countries rising from 152,000 to 239,758 a year by 2080, leading to 50 times death rise, while in the UK by 540 per cent increase by 2080 as nearly 11,000 persons could die every year as a result of heatwaves. On another hand, It is predicted a 118% spread of urban areas in the UK and a 148% increase in people living flooding areas (Martin Bagot, 2017).

Dr Forzieri declared that continuous urbanisation will amplify urban heat island effect in that built-up area in which heat is trapped and absorbed inside canyons (Giovanni Forzieri, 2017). South East of UK temperatures in Summer are expected to go up to 3.5°C, 5°C warmer by the 2050s and 2080s respectively in addition to that Urban Heat Island (UHI) adds 5-6°C to summer night time temperatures (Hulme et al., 2002). London centre will face up to 9°C in temperature higher than the surrounding greenbelt with expectations to frequency increase of these effects (GLA, 2006).

For all European countries climates examined in a study by Jones, green walls have a deeper influence than green roofs. Yet, green roofs have a greater impact on the roof level, consequently, at the urban scale. They could mitigate raised urban temperatures, through applying that to the whole city scale, which can lead to major energy savings, additional “human-friendly” urban spaces, ensuring a sustainable future, from a thermal perspective, for urban inhabitants (Alexandri, 2017)

In general, green walls have a stronger influence within the canyon than green roofs, but they do not affect the temperature of the air masses above the canyon.

Due to VGS plants evapotranspiration, Institute of Physics in Berlin illustrated that a mean cooling value of 157kWh/day could be achieved based on a 56 planter boxes study on 4 floors of their building (Schmidt, Reichmann and Steffan, 2018). A study made by (Gill et al., 2007) for green infrastructure potential in cities climate change adaption by 2080 found that maximum surface temperature is reduced by 2.5°C through increasing 10% of green cover, while removing the same percentage would lead to 7°C increase in surface temperature (Steven W. Peck, 2009). The frequency of heat-wave events is probably rising across Europe and the UK (Robertson, 2016).

While (Alexandri, Jones and Doussis, 2005), showed that Green walls have a higher impact than green roofs within the canyon, while green roofs have a larger influence at the roof level and urban scale. Green roofs and green walls combination lead to the highest mitigations of urban temperatures, even for cold climates as London and Moscow which got the least benefits in temperature reduction 1.7 - 2.1C and maximum from 2.6 -3.2C for the green-walls, while it ranged between 3.0 - 3.8C and maximum from 3.6-4.5C for green all case.

***The Major Limitations for Implementing VGS in a temperate climate** (GRHC, 2009; Amy Storey, 2015; Mayrand and Clergeau, 2018)*

VGS are similar to gardens, thus maintenance is required regularly for different systems parts as weeding, irrigation and other gardening activities as fertilizing, depending on plant type and season besides installation costs (RA Francis and Lorimer, 2011). Recent technologies showed that green systems reached 28% cost reduction due to industry innovations in 2017 (Martin and Knoops, 2014), on top of an affordable cost study which was carried out by (Oluwafeyikemi and Julie, 2015), who afforded VGS for low-income neighbourhood in Nigeria living on less than £1 from recycled materials.

The structure could be a barrier especially for retrofitted buildings due to its load impact, therefore the vegetation weight should be considered while calculating structural load, although through using light weighted recycled plastics and media with decrease total weight considerably. Patric Blanc also designed much light weight VGS with less than 6 lbs./ft2,

Survivability of different vegetating species is a concern as not all plants can be surely guaranteed to grow and flourish, thus based on the climate, thus it is advised to prioritize the survivability than the plant beauty.

VGS can protect buildings from fire if they followed general main guidelines in addition to being well irrigated and maintained. While if not, only 10% is flammable material VGS policies might be more problematic for smaller communities, due to the lack of applying VGS in the construction sector. However, larger cities started to implement programs and incentives to encourage green infrastructures. VGS enhances wildlife habitat as birds and insects which might not be wanted by building occupants, who might ask for more protection.

Conclusion

This review classifies, analyses and summarizes the literature on (VGS) as a passive tool for energy savings in buildings in a temperate climate. Generally, VGS can be a useful tool for thermal control of buildings, leading to carbon and energy savings. Thus when studying VGS influence on passive energy savings, these points should be taken in considerations as, VGS type, sub-climate classification, plant species, season and façade orientation.

The review classified the different types and systems of VGS, then grouping direct, indirect green façade and living walls studies in three different tables in order to summarize the studies which were carried out. Afterwards, the outcomes and conclusions are classified into three parts which are building energy performance, carbon reductions and urban heat island effect. Then limitation of applying VGS in a temperate climate are being mentioned.

Evergreen living walls can reduce heating costs, particularly when placed on the North of buildings, while the South side deciduous climbers are more effective as it allows warm sunlight to get into the building. Annual heating and cooling energy loads are more significant in the case of plant cover on lightweight buildings with south or west walls in summer while in cold conditions, the foliage layer increased the minimum temperature when it was applied on the north and west facing walls.

VGS in Temperate Mediterranean is performing better than temperate oceanic due to higher energy saving for cooling during summer days, which is confirming the benefits of VGS as passive insulation technique for buildings.

VGS is more effective, when insulation is not existing or as a method of existing insulation enhancement, through convective heat loss reduction and decreasing wind chill beside precipitation protection. Decreasing wind speed leads to equalizing internal and external wall surface thermal resistance.

VGS installation on efficient buildings is not economically viable in cold climates from energy wise due to low heating energy savings due to blocking warming sunlight in heating seasons (Feng and Hewage, 2014). One of the clear conclusions is that the payback time is so long for the VGS “energy-wise”. While the payback period of direct and indirect GFs are more economically sustainable than LW. VGS is related to GDP and countries motivations, as it increases within countries with higher GDP and dense cities.

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