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Review Article

Facade Greening: A Way to Attain Sustainable Built Environment

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Abstract: In urban areas today, natural vegetation are been replaced with concrete pavements, buildings and other structures, which bring with it several consequences such as; noticeable increase in the amount of energy used in heating and cooling buildings which led to urban heat island (UHI) effect, degrading of air quality, increasing the amount of hard surfaces in cities which led to rise in temperature and also increase the volume of storm water collected. The technology of integration of plants on building façade became a trend in the last decade. This paper outlined different types of green façade and their benefits to the built environment. The paper through review of related literature is aimed at discussing how façade greening positively affect the built environment through the moderation of air quality; mitigate urban heat stress through transpiration cooling and shading. The paper also shows that façade greening will help in attaining a healthier living and a pollution free work place in the urban areas and any other place. The research concluded that the use of greenery on building façade provides a way to attaining a sustainable built environment.

Keywords: Green Façade, Sustainability, Urban Heat Island, Air Quality

1. Introduction

The integration of vegetation into building and construction of cities has been in use for many centuries, one of the famous examples of such is the Hanging Gardens of Babylon ordered by the ancient civilization of Tigris and Euphrates river valleys in Mesopotamia (Dunnett et al., 2010). Olive trees and grape vines were cultivated purposely to climb building walls in the Greek and Roman Empire cities (Newton et al., 2007). Before the period of industrial revolution there were no dedicated spaces for parks or neighborhood garden in urban planning. But during the period of industrial revolution, when industrial cities were first seen, town planning practice took a new dimension, urban parks, rows of trees along the sides of streets and neighborhood gardens were introduced as part of urban planning.

Nowadays we are living in a world where little is untouched by man. And the urban areas are becoming unhealthier to live in due to increase in air temperature, which led to an increase in the amount of energy required in heating and cooling buildings. The architects and the engineers are now faced with the daunting task of designing and constructing buildings that are environmental friendly as much as possible, while urban planners are looking for where to plant their greenery. This is what gave green facade more popularity (Wong et al., 2009).

"The ficus and climbing plants had developed in an unvaryingly perpendicular direction, imposed by the density of the element which had produced them. Motionless, even after parted them with my hands, the plants immediately returned to their original position. This is the realm of verticality" (Dunnett et al., 2008). The use of vegetation on building facades in form of living walls, green facades and vertical gardens offers an outstanding number of public and private benefits such as: aesthetic, social, ecological and environmental, and it fits in the principle of ecological engineering (Odum, 1995).

The use of plants on building façade gives an essential contribution to improving sustainability of the built environment. Using them as an architectural feature that upgrades façade is ecologically and aesthetically accepted. Plants when properly used on building façade in our design,

would led to an energy conscious design approach that would prevent the deterioration of natural environment in the densely populated urban areas (Krushe et al., 1982).

The advantage of green façade is not only limited to environment and nature but, also help in lowering the operating cost for buildings in long term. It also helps in moderation of the micro climate of a given area when use in larger area, because of the additional layer of vegetation on the building facades of the area. In this case, the vegetation serves as dust filter, as humidifier and also generates cold air, therefore, promoting human health (Sheweka et al.)

2. Literature Review

2.1. Typologies of Green Façade

Green façade can simply be described the vertical integration of planting system on the façade of building or any other structure, the plants may be rooted in the ground or in planter boxes at different levels of the façade as shown in figure 1 (Suleiman, 2013). There are two different typology of green façade that are available until now namely; the one with plants rooted into the soil and that with plants rooted in an artificial substrate at grade as shown in figure 2. (Mir, M. A. 2011)

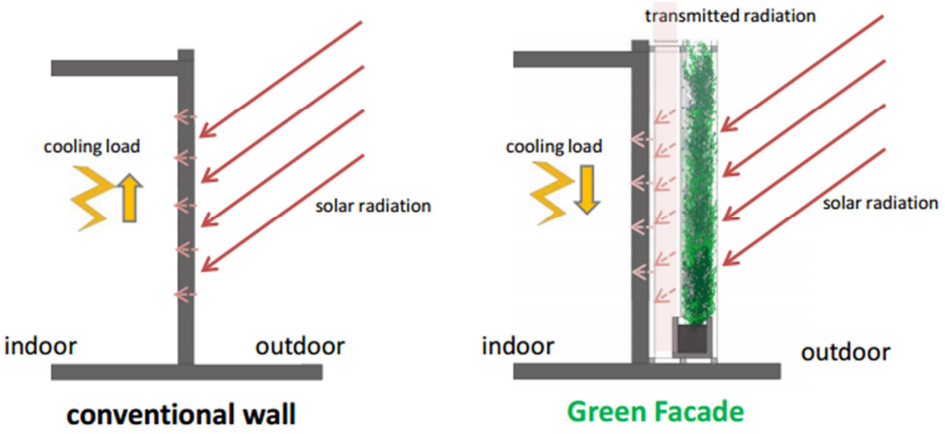

Figure 1. *Showing the difference between a conventional wall facade and a green façade (Suleiman, 2013).*

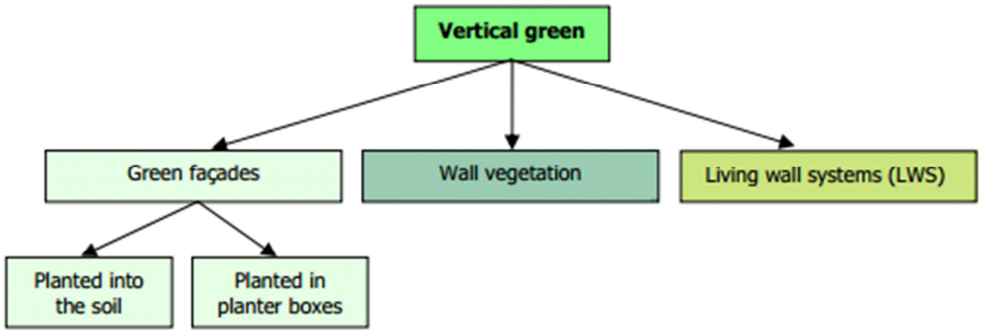

Figure 2. *Showing two different typologies of green façade (Mir, M. A. 2011).*

2.2. Plants Planted into the Soil

In this typology the plants are planted on the ground, their roots are in natural ground, and they grow from the ground against the wall. In this category watering system is not required because; they tap their water from the natural source i.e. rain water and ground water, it take a long time for this type of green to cover the surface of the wall. This category can also be divided into two; self-climbing (directly on wall) and the one with supporting structure (indirectly on the wall), as shown in figure 3 (Mir, M. A. 2011).

The sticky root structure of some plants enables them to attach directly on the façade, covering the whole surface. The type of plants species used will determine how efficiently façade would be covered and how long will it take, and how many plants should be used at what intervals. Some plants species doesn't have the sticky root structure to attach them to the façade directly, thus, they require supportive structure to grow and cover the façade as shown in figure 4 (Mir, M. A. 2011).

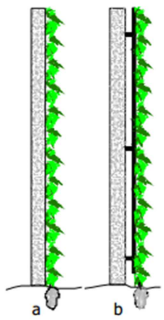

Figure 3. *Shows the type of green façade in which the plants are rooted into the ground; use of self-climbing plants, a) directly on wall, b) with supporting structure (Mir, M. A. 2011).*

Figure 4. *Showing a typical example of supportive structure for plants with non-sticky root structures (greenscreen.com).*

2.3. Plants Planted in Planter Box

In this typology, as the name implies, the plants are planted in planter boxes. The planter boxes are placed either at the bottom of the façade (figure 5a and b) or on roof top, or at the bottom of each floor (figure. 5c). This category requires a continuous watering system because; the roots of the plants are not directly on natural ground. It also requires a long period to cover the surface of the wall, unless in the case of figure 4c where the planter boxes are placed at the bottom of each floor. This category can also be sub divided into two; plants directly on the wall and indirectly on the walls (on supporting structure) figure 5b and c.

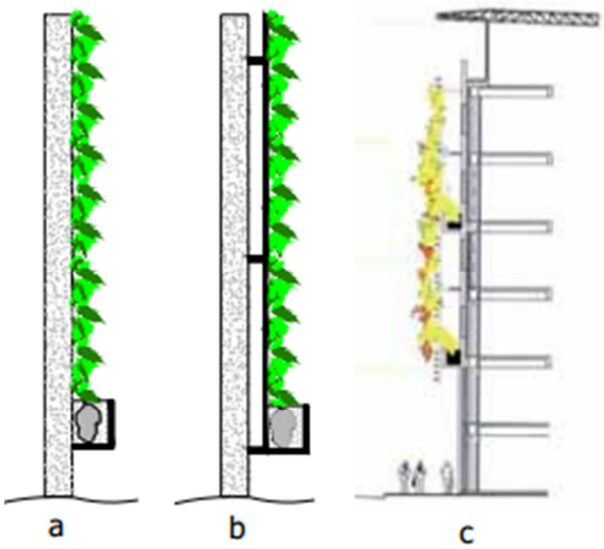

Figure 5. *a) Showing planter box at the bottom with plants directly on the wall, b) planter box at the bottom with plants on supporting structure, c) planter box at the bottom of floors with plants of supporting structure (Mir, M. A. 2011).*

2.4. Importance of Greenery on Built Environment

The rate at which urban areas are developing leaves less available space for greening. Major councils in the city of Sydney accept façade greening as space as part of planning process (Mark, 2011). This shows the importance of green areas in urban areas where urbanization is growing fast.

In developing countries, urbanization is growing rapidly and the cities are becoming denser in terms of population. Urbanization is causing the replacement of green areas with buildings and other structures, which brings more hard surface development and less green areas. The use of greenery on building façade in urban environment can solve the above mentioned problems by creating a natural green environment. In advanced and developed countries like Europe, Australia and New Zealand, this has become a successful trend as part of their urban development planning practice (Ling, et al., 2012).

2.5. Effect of Green Façade on Urban Heat Island

According to Encyclopedia of Earth, "heat island refers to urban air and surface temperatures that are higher than nearby rural areas" (Agency, E. 2012). The difference of air temperature between the cities and their surrounding rural areas is ranging from 1°C to 7°C. All this is as a result of the replacement of green areas with paved surfaces and other structures. By replacing trees and shrubs with asphalt, concrete and other impermeable surfaces which only absorb rather than reflect the heat, causes rise in the overall surface ambient temperature of the area. Urbanization is a factor that lead to increase in urban heat island phenomenon, due to the fact that nature is been replaced with manmade structures, which are good in absorbing and retaining heat than normal in nature (Al-musaed et. at., 2007).

According to Al-musaed (2007), cited by sheweka et. al., (2012), both urban and rural areas are been affected by heat island which causes a high demand of energy during the summer for cooling, air pollution and greenhouse gas emittion and other health related illnesses. In the figure 6 below, we can clearly see the effect of urban heat island.

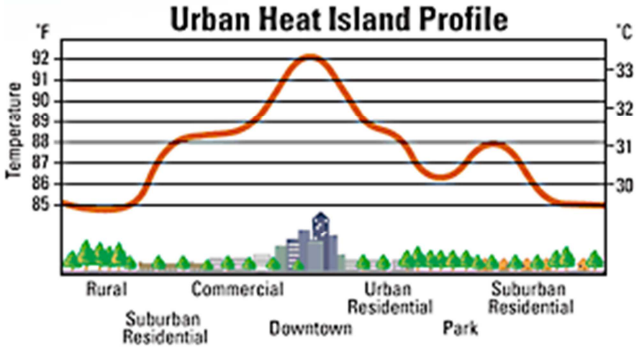

Figure 6. *Urban heat island profile (Agency, E. 2012).*

The micro climate of a particular area can be affected by facades and the streets around it due to their impermeable nature. This causes discomfort and increase in the amount of energy required for cooling (Oke, 1987). In this case, use of greenery on concrete roofs and façade whereby the heat will be consumed through the process of evapotranspiration can be a possible solution a (Figure 7).

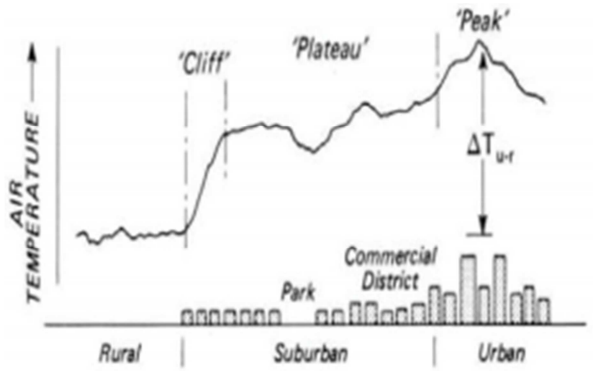

Figure 7. *Longitudinal section of urban island effect (sheweka et. al., 2012).*

In addition, use of greenery on building roofs and facades to cover the impermeable surfaces can contribute to vertical mixing of air; therefore the temperature over the surface may likely be lower than that of the surrounding built up areas. Fresh air is always denser than warm air, so, here the warm air on the heated surfaces is replaced by the fresh air produced by the vegetation around, therefore reducing heat effect (Jonhston et. al., 2004).

Plants has the ability to absorb "smog" and producing oxygen, therefore helps in improving air quality. The planted vegetation on the façade or roof can reduce the "smog" by either absorbing to some extend the suspended particles in air or by moderating the temperature (Dinsdale et. al., 2006).

According to climates studies the use of greenery on building roofs and facades have great effect in moderating temperature in urban canyon, it will be more effective if both the two are combined i.e. green roofs and green facades, to cover most of the urban surfaces (Alexandri et. al,. 2007).

2.6. Façade Greening to Improve Aesthetical Value of Urban Living

According to Frank Lloyd Wright "A doctor can bury his mistakes, but an architect can only advise his clients to plant vines." (Wright, 1931). This brought a good idea for those who use their roof tops for gardening; instead they can hang them on the walls to make it more visible for people (Alter, 2008).

The master of green façade Edouard Francois was quoted saying "Man can live solely within architecture. He needs a complex building which must be decorated. Only in this way can he be happy". Indeed, in Francois' view, working with nature offers a welcome complexity: 'Watch a tree. It has a thousand branches, it moves, grows, changes color' (Alter, 2008).

Sir William Dobell once said "A sincere artist is not one who makes a faithful attempt to put on to canvas what is in front of him, but one who tries to create something which is, in itself, a living thing." (Mike, 2011)

Now that it is a known problem, that green spaces in urban areas are disappearing day by day due to urbanization. Integrating greenery on building façade as part of city planning will have an impact urban areas. If carefully designed and constructed, it can also be applied to other structures like bridges and can also serve as a cover for ugly and old buildings. Green façade will definitely improve the environment aesthetically (Michelle, 2011).

If properly designed and maintained, green façade can enhance the appearance of building and any other structure. Another thing is the careful selection of plants to use which varies in their looks and texture; if properly done it can also enhance the building appearance. In parts of the world where graffiti is not accepted, façade greening can serve as protection which makes it almost impossible (Mir, M. A. 2011).

High degree of maintenance is the weakness of façade greening, it requires a lot of maintenance work such as trimming, replacing the death once and watering to keep it natural and in healthy condition (GhaffarianHoseini, 2012) (Ghaffarian Hoseini, 2012).

2.7. Green Façade to Improve Urban Climate

Green façade have a direct positive impact on both the cities and their inhabitants. Those living in the cities can see the plants used on green façade as hanging gardens. Walls that are directly exposed to sun and UV will conduct heat and transfer it into the building, which will lead to a significant rise of temperature in the building. This shows the Urban Heat Island effect. The plants used on green façade lose water via their leaves in a process called evapotranspiration which helps in moderating the temperature around the buildings. Green façade in urban areas helps in moderating the microclimate therefore, improving the living condition in such cities (Peter, 2013).

Now that green areas are disappearing in urban areas, the excessive heat built up due to the presence of more hard surfaces which doesn't absorb but only reflect the heat, combined with other pollutants distorts the weather of a particular area and its surrounding environment. This is what led to urban heat island effect. The urban heat island effect is an area of the city that is extremely warmer than its neighboring rural area. Integration of plants on building façade can drastically bring down the urban heat island effect and make urban life more healthier (Patrick, 2011).

Proper design and construction of green façade will promote the cooling process in buildings, by making the problem of rain water management less severe; the soil either on the ground or in the planter boxes trap and retain the collected rain water, which is absorbed by the plants through their roots. This process helps in cooling the building structure. Even the heat absorbed by the plants through direct expose to sun and UV will be evaporated through the process called evapotranspiration (Paul, 2010)

2.8. Green Façade to Reduce Carbon Footprint and Improve Air Quality

Biologically, plants absorb carbon dioxide in order to synthesize food from sun light; this process is generally known as photosynthesis. Oxygen is been released as a bi product of this process. This shows that the more plants we

have in urban areas the more clean air we get (Patrick, 2011).

Plants growing on building façade absorb carbon dioxide and release oxygen. The plants also serve as filter to other pollutants like; cadmium and lead. They also act as carbon filters by absorbing the greenhouse gases emitted by the atmosphere and store them in their tissues. The arrangement of plants on living walls are thick which gives room for planting more on a small area. The carbon absorbed by $20m^2$ of a living wall is equivalent to that absorbed by a medium sized tree (Patrick, 2011).

Integration of greenery to building façade can improve the air quality in cities. Air quality can also be improved through the process called bio filtration. Bio filtration can simply be described as a technique used in controlling pollution using living materials; here the living materials serve as filter for the air and dust that passes through it. The microbes contained by the plants absorb must of the pollutants. In this process the plants absorb the carbon dioxide produced, therefore releasing oxygen to the environment (Appropedia, 2012).

It is proved that; green façade have the capabilities of saving energy in buildings. They also help in preventing the formation of dust by absorbing dangerous atmospheric particles (Marie, 2012).

According to Patrick (2011), the moisture level of green wall needs to be monitored and controlled, due to too much amount of water retention which may contribute to high moisture index leading to mold growth effect.

2.9. Thermal Impact of Green Façade

2.9.1. Temperature Reduction

According to research, in humid climate the use of greenery on building façade in an urban canyon can help in achieving a substantial benefits of maximum temperature reduction of up to 8.4°C (Alexandri et. al,. 2008). This is important because, energy consumption of buildings is influenced by the distribution of ambient air in a canyon as higher temperatures in canyon increase heat convection to a building and similarly increases the cooling load (Santamouris, 2001).

By directly shading the heat absorbing surfaces of a building with vegetation, it will help in alleviating UHI through evapotranspiration cooling (McPherson, 1994). The use of greenery on building façade can drastically reduce the temperature of a building to as much as 50% by shading walls from direct sunlight. The process of evapotranspiration helps in converting large amount solar radiation into latent heat which does not cause any rise in temperature. Furthermore, an efficient green façade have the ability to protect the building from intense solar radiation during the summer period and can use its leaf cover to reflect and absorb between 40% and 80% of the received radiation, which depend on the amount and the type of vegetation used (sheweka et. al., 2012).

In another studies, at the University of Toronto since 1992, surface temperature of vertical greenery have been observed in different settings (Bass, et. al., 2003). The results consistently shows that areas with vertical greenery are cooler than areas with light coloured bricks, walls and other surfaces found in the urban areas. Another experiment in japan shows that climbing plants can reduce the temperature of a veranda with south-western exposure (Hoyano, 1988). While in Africa, the temperature reduction of 2.6°C behind panels covered with vines (Holm, 1989). Thus, temperature fluctuations on the wall surface can be moderated from between 10°C and 60°C to between 5°C and 30°C (Peck, et. al., 1999)

2.9.2. Shading and Insulation

The use of greenery on building façade as shades to solar radiation is obvious, with the advantage that the traditional concrete or brick facades which radiate the heat in and around the building, while greenery does not. This depends crucially on the density of the foliage (sheweka et. al., 2012).

In a double skin façade, the temperature is generally lower if greenery is used in between the skins. In a case where plant is used instead of slat in double skin façade the temperature never exceed 35°C, while with slats, temperature can exceed 55°C. The amount of energy required for air conditioning can be reduced by up to 20% with the use of plants in an internal double skin façade (Stec, et. al., 2004).

The physiology of plant implies that some portion of sunlight received by the vegetation is used for the process of photosynthesis, while the remaining is used for evapotranspiration, hence, making them mechanism for temperature moderation. This is what makes vegetation effective in blocking solar radiation without increasing it temperature. The transmittance factor of a leaf is 0.2, while it absorbance is 0.5 (sheweka et. al., 2012).

According to an experiment "Bioshader" conducted in University of Brighton, in this experiment an office space was used as a case study, the windows of the office were covered with vegetation. The temperature recorded was between 3.5°C to 5.6°C lower than when the windows are covered with other materials. The solar transmittance of the foliage was also measured, which ranges from 0.43, with a single layer leaves, and up to 0.14 with five layers of leaves, and also a reduction in solar radiation of up to 37% in a single layer leaf cover and 86% in five layer leaf cover as shown in figures (7, 8 and 9). (Miller, et. al., 2007).

In another experiment, it suggested that more thermal energy flows into the non-shaded walls due to their direct exposure to sun light, which results in higher wall surface temperature. The heat absorbed by the non-shaded surface will later advance to the inner wall surfaces making the temperature interior rise, which lead to more energy consumption for cooling (Neila, 2004).

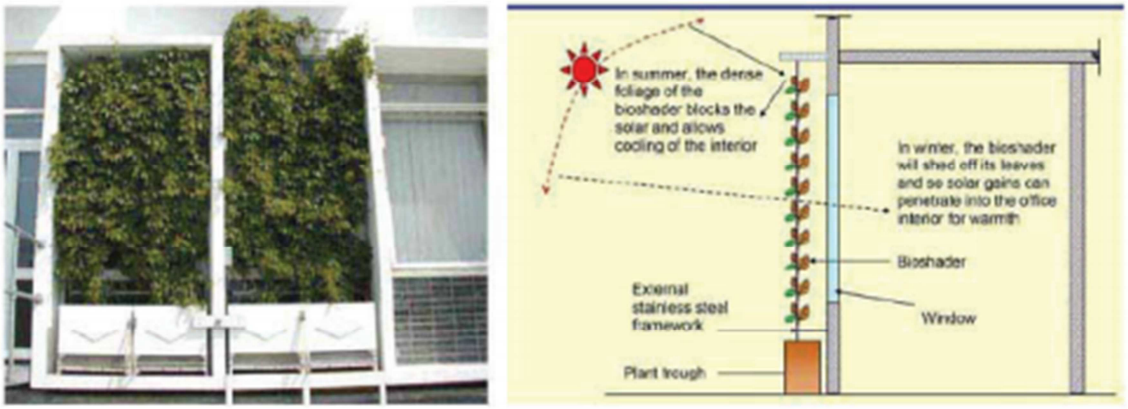

Figure 8. *Bioshader experiment (Miller, et. al., 2007).*

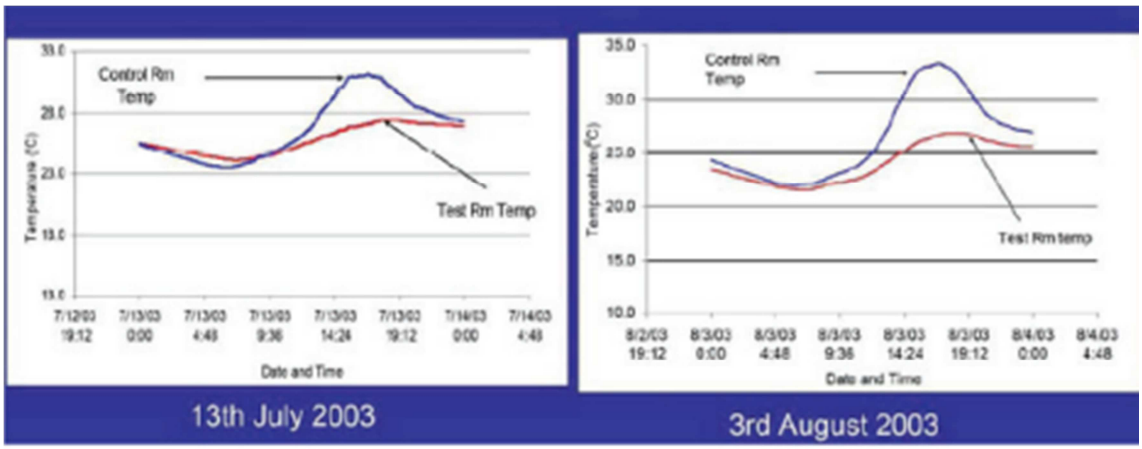

Figure 9. *Bioshader experiment; showing temperature distribution graph (Miller, et. al., 2007).*

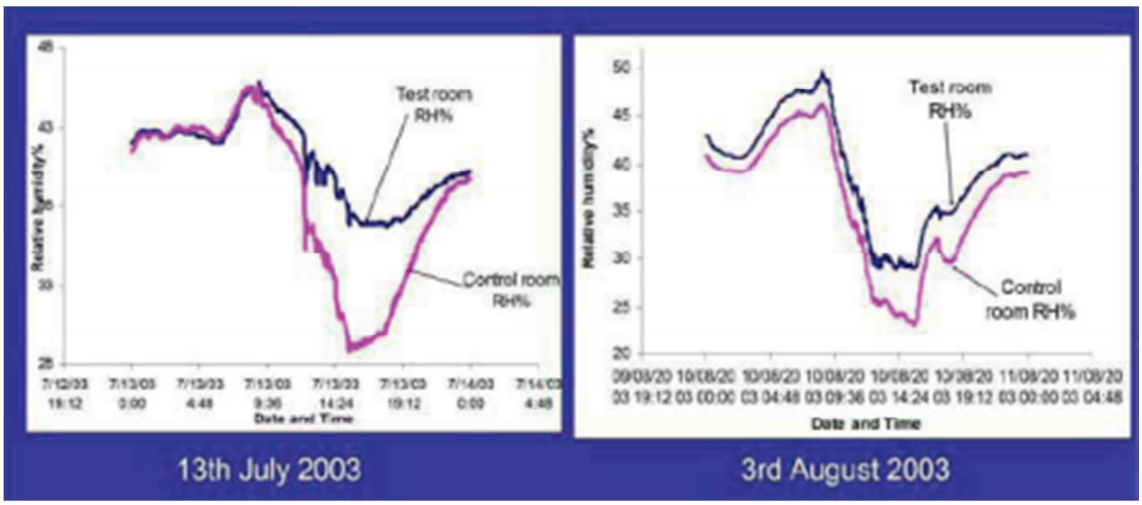

Figure 10. *Bioshader experiment showing relative humidity distribution (Miller, et. al., 2007).*

2.9.3. Evaporative Cooling

According to a study, in tropical climate, it was confirmed that vegetation has cooling effect. The study was done by measuring the temperature atmosphere at different altitudes. The maximum difference in temperature recorded was 4.2°C. Based on this study, it shows that the cooling effect is limited with the height (Wong, et. al., 2003).

In the project of the institute of physics of the Humbolt University Berlin, Adolershof, combines rain water management and energy savings with natural conditioning through vegetated walls. The shadow casted on the façade by the vegetation affect the cooling of the building, which influence the energy consumption of the building Figure 11 (www.gebaeudekuehlung.de).

Figure 11. *Institute of Physics, University of Humboldt (www.gebaeudekuehlung.de).*

Evapotranspiration is the most significant environmental benefit of green roofs and facades in the urban areas. This process has effect on urban hydrology, in reducing the temperature of urban surfaces and improving the management of rainwater run off (Stec, et. al., 2004).

More so, experiment conducted at University of Brighton "Bioshader" which compared an office space with window covered with vegetation and with other covers, verifies that humidity level in the office with bioshade is higher than that without. This shows that, the use of greenery on building façade provides additional moisture to the dry indoor environment (Miller, et. al., 2007).

Lastly, the cooling effect of greenery due to evapotranspiration, helps in moderate the temperature around the building, and the evaporated water by the plants increase the humidity up to 2 kg of water per m^3 of dry air (Papadakis, et, al., 2001).

3. Findings and Discussion

Integration of greenery to façade system of buildings and other structures is not only limited to new projects; it can also be applied to existing once in order to bring them back to life, either from sustainability point of view or aesthetic point of view. From sustainability point of view, among the properties of plant is making their own food through the process called photosynthesis, the process requires carbon dioxide to be done and the byproduct of this process is oxygen; therefore plants absorb the carbon dioxide which pollute the environment and produce oxygen which is good for humans and their environment. And from the aesthetic point of view green façade can help in hiding the mistakes of designers and engineers and it can also make the appearance of a building and other structures more pleasing to the eye.

The major factor that is causing the urban heat island (UHI) effect is high degree of urban development; for example, how many square meters of green area are in order to construct houses and streets for the growing population in the cities, and most of the materials used in these constructions are concrete and asphalt, which are all impervious materials; they absorb heat in the day time and realize it at night. This effect can be reduced through the process called evapotranspiration; the process through which liquid water is converted to water vapor and it is removed from the evaporating surfaces, such as pavements, soil and wet vegetation.

Using greenery of façade systems can give aesthetic difference in the environment where people carry out their daily activities. Studies show that, the presence of plant within

an environment helps in improving mental health and the wellbeing of the inhabitants of that environment. Apart from being essential to life on this planet, they add beauty and attraction with their unique colors and textures. Nowadays, improving aesthetics is among the primary objectives of designing green façade projects. If we look at the large areas we have on façade of buildings and other structures in our cities today, we can utilize them as hanging gardens; that will also improve the aesthetics of urban streets.

Surfaces in urban area that are not used such as roof and façade could be used in order to moderate the urban temperature; this can be achieved by covering such surfaces with greenery. The thermal performance of a building can drastically be affected by the influence of greenery on the microclimate. The climbing plants used in greening facades serves as shading devices to the façade, which prevents it from direct solar exposure, therefore reducing the amount of energy require in cooling the interior.

4. Conclusion

The integration of vegetation on buildings and other structures façade can of great benefit to urban environment; it can also be used as a tool for passive thermal control of buildings. If carefully design and maintained, green façade have the ability to moderate urban temperature.

In conclusion, the benefits of façade greening can be categorize into two; private benefits and public benefits

Private Benefits:

- Green facade helps in improving indoor air quality: when used in the interior of building, the plants on the façade have the ability to filter the noxious gases from the carpets and other furniture. The greenery also absorbs the airborne pollutants like dust and other unwanted gases.
- Protecting the building structure: Generally building facades are exposed sun, water and other weathering elements and with time most of the construction materials start to break down, due to heating and cooling which causes contraction and expansion of the materials. Green façade can protect the building façade from direct exposure to sun light.
- Energy efficiency in building: Green façade can serve as a wind breaker during the winter; it can also reduce the ambient temperature through evapotranspiration process. If applied internally helps in reducing the amount of energy required in cooling the outdoor air for indoor use.

Public Benefits:

- Green façade helps in reducing urban heat island effect: this effect is caused by the replacement of green areas with hard surfaces, which lead to conversion of sunlight to heat. It is a well-known fact that greenery cools the building by shading it from direct exposure to sunlight which leads to the reduction of reflected heat and also through evapotranspiration, therefore with this we can say façade greening helps in natural cooling processes of buildings and environment and moderating ambient temperature in urban areas.
- Green façade helps in improving outdoor air quality: there is a lot of pollution in urban area due to presence of high number of industries, vehicles and other things that emit a lot of unwanted gases. One of the benefits of green façade is that the plants have the ability to absorb the airborne pollutants and other deposits on their leaf.
- Green façade helps in improving the appearance of a building or a street, due to the nature of the plants used. They may have different appearance and texture which will give variation in the appearance.

Finally, the integration of greenery on building façade shows great potentials in attaining a sustainable built environment through reduction of urban heat island effect, improving both indoor and outdoor air quality, making the environment more aesthetically pleasing and also reducing the carbon foot prints in urban areas.

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