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Supported by the ENHSA Network | *Fueled by the* ENHSA Observatory

February**2016**

www.enhsa.net/archidoct

ISSN 2309-0103

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ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 3 (2) / February 2016

Evaluating the impact of vertical greening systems on thermal comfort in low income residences in Lagos, Nigeria

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Abstract

Nigeria has a population of about 120million and is the most populated country in Africa. However there has been insufficient attention to developing sustainable ideas and materials to combat the issue of global warming which has resulted into extreme temperature rise within the country. This should be a concern because combating global warming and improving sustainability should be a collective worldwide effort.

This research took place in Lagos, Nigeria to evaluate the effect of vertical greening system on occupant's thermal comfort. With 70% of the population living below a dollar a day, the focus of the study were low income residences characterized by overcrowding and overheating of interior spaces due to choice of building materials and high ambient temperatures.

Vertical Greening Systems also called wall gardens are simply plants on walls. A VGS that was financially affordable, easy to erect and maintain was setup on selected low income residences. Continuous readings were taken with the tiny tag data logger over a period of 4 months from May to August across the two major seasons, Wet and dry.

The results reveal a significant reduction in the ambient temperature of the immediate surroundings of the VGS setup as well as a reduction in indoor temperatures.

Further research on VGS can be encouraged as complementary qualitative undertaken by the author has shown that majority of the target group are open to embracing sustainable strategies but only at minimum expenses. It is proposed that simulation of further VGS design scenarios using software's should now be explored, to evaluate the potential wider benefits of low cost alterations to the design and build of Low income group housing in Nigeria.

Finally, the importance of a worldwide collective effort towards sustainable houses and cities is extremely important for global reduction in carbon emission to be achieved.

Keywords

VGS, Vertical Greening Systems; Thermal Comfort; Passive Cooling.

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1. Introduction

The location and climatic characteristics of the City of Lagos is briefly discussed to establish the context of the research .This offers background knowledge of the City in order to understand the focus of the research; being the need to provide more sustainable means of providing passive cooling in the average low income residential building which is usually characterized by overcrowdings, overheating and poor ventilation. A brief review of the population characteristics of the city of Lagos is provided and introduces the Low income groups that inhabit the city. The focus is subsequently narrowed down to their housing morphology and characteristics as well as the potential effect on the overall well-being of the occupants.

This paper subsequently discusses the importance and the need for improvement particularly of thermal comfort in these houses, focusing on the potential impact of passive cooling through the use of vertical greening systems might have. The VGS type used are discussed to highlight the reasons behind the prototype choice as well as the factors considered before erecting them on selected low income housing residences. The form of measurements are reported as well as the results and future research possibilities.

1.1 Lagos, Nigeria

The study took place in Lagos, Nigeria, Located in West Africa, very close to the equator. The major characteristic of the climate is high temperature and high humidity, thus overheating in interior spaces is not uncommon (Akande and Adebamowo, 2010). The implication of this is further exacerbated by the tendency of the city to experience urban heat island effect (Akiyode, 2010). This negatively affects thermal comfort within interiors spaces.
n, launched by neurosciences in the recent years.

Figure 1. Location of Lagos, Nigeria
Source: Google Map, Accessed, July 2013

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1.2 Lagos climate and climate change

Lagos is classified as 'AM' (Equatorial, Monsoonal) Category under the Koppen-Geiger Climate Classification. Studies have shown that climate change is a global phenomenon, likewise its impacts, but the biting effects will be felt more by the developing countries, especially those in Africa, due to their limited levels of coping capabilities (Nwafor 2007; Jagtap 2007 cited in Odjugo, 2010). Nigeria is one such developing country.

For Lagos, the climate challenges are further exacerbated by the existing, and likely worsening urban heat island effect. UHI phenomenon can cause air temperature in the cities to be 2-5oC higher than those in the surrounding rural areas mainly caused by the amount of artificial surfaces (high albedo) compared with natural land cover (Taha, 1997 cited in Perini, 2011). Lagos lies on the gulf of Guinea, along the Bight of Benin, with a land area of about 356,861 Hectares (3568.6km2) representing only 0.4% of Nigeria's land area, (Lagos State Government Official Website,2012) 17% of the total land area consists of lagoons, creeks and waterways (Balogun, Odumosi and Ojo 1999, cited in Ilesanmi, 2009). Thus, the effect of UHI is enormously felt with overheating due to the dense population on a relatively small area of land.

1.3 Urbanization in Lagos

It is estimated that an average of 606 people enters Lagos per minute (Agbola, 2007). As a result of such uncontrolled urbanization, almost 75% of the urban dwellers live in slums in Lagos (Olotuah, 2005). The scenario of urbanization is stated below by Ogunsakin, 1998 cited in Olayiwola, 2005 'This massive flow of population and the existing poor level of city development and state of unpreparedness create profound disruptions and imbalances within the urban tissues. Simultaneously the inability of the city to integrate or absorb the new population socio-economically and in term of infrastructural provision became apparent and almost 'unavoidable'.

In other words, urbanization can be considered an unavoidable phenomenon in Lagos. It therefore falls to designers and researchers to explore viable means of coping with this significant issue, through efforts such as slum upgrading and renewal. Thus informing the context of this research.

2. Low income groups in Lagos

The Low Income Group (L.I.G) is an important part of the economic activities within the state, with the bulk of public transportation and informal trading undertaken by these groups. (Akinmoladun, 2007). UNDP (2008) estimates that 51% of men and 54% of women residing in Lagos survive on less than US$1 a day, with their average income being approximately N15, 000 a month (£55) (Aluko, 2012). These groups, also referred to as the 'urban poor', are further described by Olotuah, 2005 'These are the urban poor who are subjected to a life characterized by precarious conditions of lack of nutrition and health, little or no material possessions, substandard housing and a generally degraded environment. Their housing does not ensure dry shelter, safe water supply, drainage,

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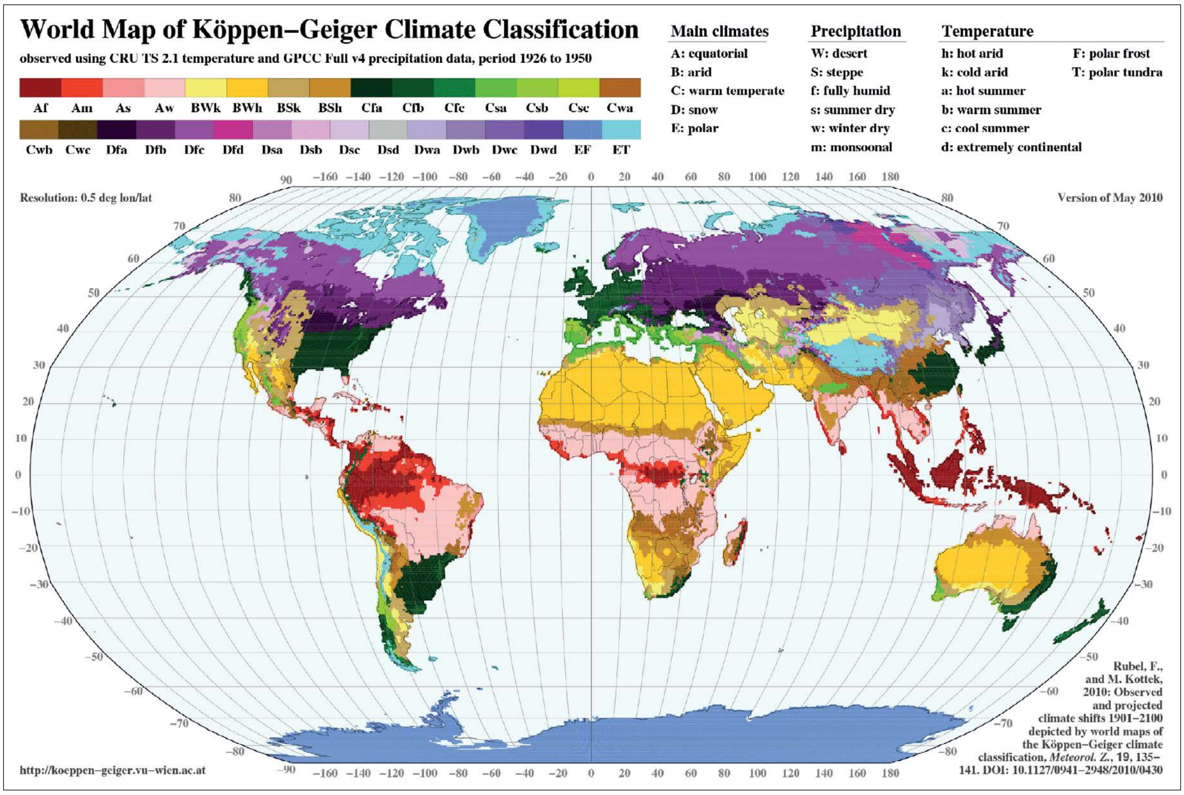

Figure 2. Koppen-Geiger Climate Classification

Source: Koppen-Geiger, Accessed, October, 2012 Lagos, Nigeria

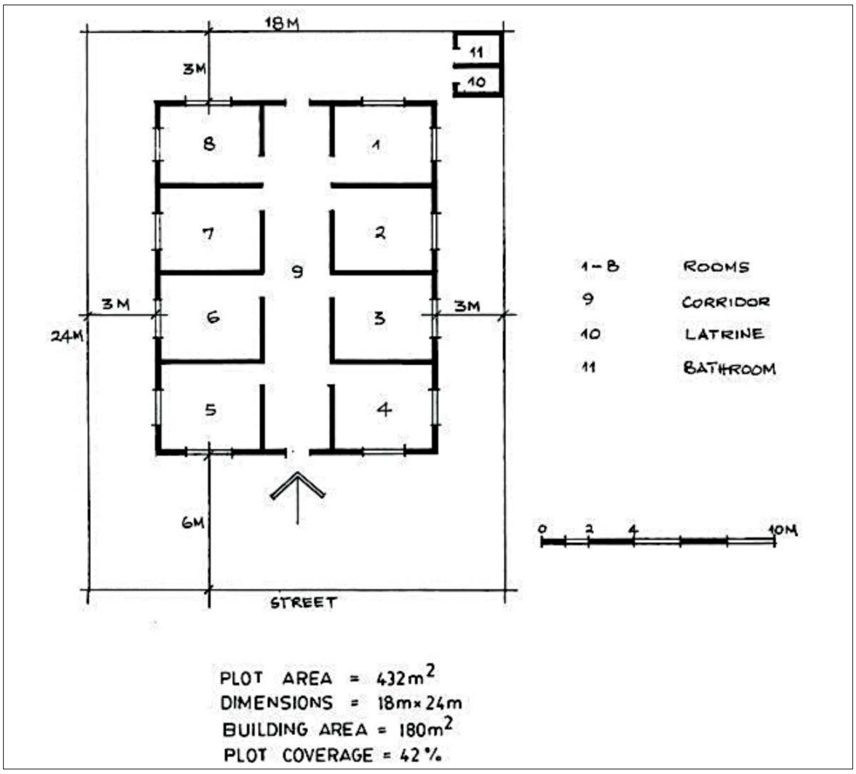

Figure 3. Typical Housing Morphology among Low income Groups in Lagos, Nigeria:

Source: Source Olusanya, 2012, Accessed June 2013

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sewerage and refuse disposal, as well as access roads. The houses constitute a health risk to its occupants'. This accurately captures the life and housing conditions of low income groups in the State.

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2.1 Housing Morphology of Low income Groups

Housing reflects the cultural, social and economic stance of any given society (Olukayode, 2003 et al cited in Gambo, 2012) .The quote by Mandelker cited in Akinmoladun, 2007 explains housing as, "being more than physical structures: housing has become a subject of highly charged emotional content: a matter of strong feeling. It is the symbol of status, of achievement, of social acceptance. It seems to control, in large measure the way in which the individual, the family perceives him/itself and is perceived by others". It encompasses the totality of the environment and infrastructure which provide human comfort, enhance people's health and productivity as well as enable them to sustain their psycho-social or psycho-pathological balance in the environment where they find themselves (Afolayan, 2007). Quality housing can be considered a litmus test of a developed society. This is because a house goes beyond provision of mere shelter; it is a place where people recuperate, rest and bond with family (Aluko, 2012).

Despite the acknowledged importance of housing to man, there are several housing problems throughout the world, and particularly in developing nations. These problems are both qualitative and quantitative in nature, manifesting in different shades of societal ills and decadence (Dogan, 2009 cited in Aduwo, 2011).

The most common form of Urban Housing in Lagos is the double banked Apartment block with rooms or flats on two sides opening to a common corridor leading to a stairwell. The corridor is generally narrow with poor lighting and ventilation. Cross ventilation is difficult to achieve within the flat because the door to the corridor is always locked for reason of security and windows do not open for security reasons. (Olusanya, 2012). This is also called 'Brazilian style housing' or the more informal term called 'face me I face you'. It is not unusual to find an average of 6 people in an 18m2 space. This is

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partly due to greed by the Landlords or squatting with friends and relatives.

2.2 Thermal comfort in low income houses

Thermal comfort can be considered to be a key factor in achieving housing quality, being one of the most important parameters that impact the satisfaction level of occupants (Adebamowo, 2008, cited in Akande, 2010). The definition of a good indoor climate is important to the success of a building, not only because it will make its occupants comfortable, but also because it will decide its energy consumption and thus influence its sustainability (Nicol and Humphreys', 2002).

For thermal comfort to be achieved in tropical Lagos (Adaptive thermal comfort standard), a reliance on mechanical cooling devices is often needed. This usually imposes financial burden on the target group in this study which are the Low income groups. In addition, the impact is felt at a larger scale through climate change due to burning of fossil fuels to generate the electricity required for cooling systems. Combustion of these fuels emits CO2 and other greenhouse gases harmful to the environment that contribute to turning the earth's atmosphere to a greenhouse with the harmful effect of producing global warming as well as causing localised air and noise pollution.

A significant amount of electricity generated is often used for cooling interior spaces. (Lagos State Government, 2012). Due to the poor electricity supply in the country, a huge number of people resort to the use of back up electricity in the form of petrol generators. These generators require petrol or diesel to run them, thus a huge amount of money is spent on powering the devices and proportionally higher quantities of CO2 are emitted into the atmosphere due to low efficiencies.

The potential of VGS to offer cooling for houses prone to overheating in the tropics is researched in this study. This is important due to the potential of financial savings and subsequent reduction in the effect of global warming it has to offer due to reduction in electricity demand for cooling. The reason for the relative scarcity of these systems in the city will be investigated, in terms of user acceptability/ awareness (which is not reported in this paper) to form a basis for future study that might take place in this area of research.

Overheating in interior spaces remains a challenge for buildings located in the tropics. The lifespan of anyone exposed to excessive heat for too long is often compromised. It also has adverse effect on the skin, internal organs and physical well-being which may include asthma, tuberculosis, dizziness, stress and restlessness (Ahianba et al, 2008) .This can lead to great discomfort and diseases such as asthma or even heat stroke in extreme cases.

The need for further research on potential passive cooling opportunities to promote thermal comfort in interior spaces remains paramount, especially among the low income groups in the city of Lagos, being the most vulnerable financially and more often feel unable to afford the cost of cooling their homes (Akinmoladun, 2007).

3. Vertical Greening Systems

Various studies have been undertaken to date on the impacts of Vertical Greening Systems (VGS) systems on indoor thermal comfort in Mediterranean climate, temperate climate and some parts of Asia with similar climatic conditions to those of Lagos, Nigeria. The resulting impact they have been found to have on indoor thermal comfort can be seen to vary from one research outcome to another. (Kontoleon and Eumorfopoulou, 2009) have reported a temperature cooling potential

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of plant covered walls in a Mediterranean climate: the effect was up to 10.8C of wall surface temperature. For a similar climate with Lagos, a study by Wong et al, 2010, through measurement on a free standing wall is Singapore with vertical greening types shows a maximum reduction of 11.6C. Alexandri and Jones in 2008 simulated a temperature decrease in an urban canyon with greened facades with a reduction of air temperature of 4.5C for the Mediterranean climate and 2.6C for the temperate climate.

There has been no reported research on the impact of VGS systems in tropical Africa. The results from countries with similar climatic conditions like Singapore and China have been reported to varying degrees of results on temperature reduction. However, factors peculiar to the tropical city of Lagos like overcrowding, inappropriate building orientation, building materials with high thermal conductivity are yet to be considered in research undertaken to date.

The figure on the right was gotten from the detailed literature review by Perez, 2014 who accurately described the location of VGS studies as well as their classification around the world, Clearly, the dearth of studies in Africa, Particularly Western Africa, where Solar radiation is very intense is highlighted above.

VGS has the potential to relieve the financial stress of attaining thermal comfort among these groups. This is due to non-demand for electricity by this system. However, while financial implications of erecting and maintaining these systems are not escapable, however, the VGS can be adapted to suit the financial levels of the low income groups
This research aimed to target an aspect of urban renewal as a means of coping with urbanization. This aspect has to do with the study of green walls and its effects. VGS are known for their ability to reduce indoor temperatures (albeit to varying degrees), clean indoor air, offer a means of planting crops and enhancing aesthetics. This research involves measuring the impact these systems can have on the interior temperature of L.I houses. The common challenges of overheating of indoor spaces in low income buildings could be tackled with these systems.

4. Experimental Setup: (Quantitative aspect of Research - 1st Phase of Research)

The choice of the Experimental set-up which involves monitoring the effect of VGS on occupant's thermal comfort through measurements by data loggers is in response to the primary aim of this research.

Convenience sampling that was also representative was selected from a sampling frame. This was the basis of selecting the case study residences to set-up the experimental prototype needed to represent the typical low income residence in Lagos, Nigeria. The inculcation of convenience sampling was important because of the need for co-operation by the landlords and occupant's (the survey involved an invasion of their personal space over a period of time) for a successful field work to be achieved.

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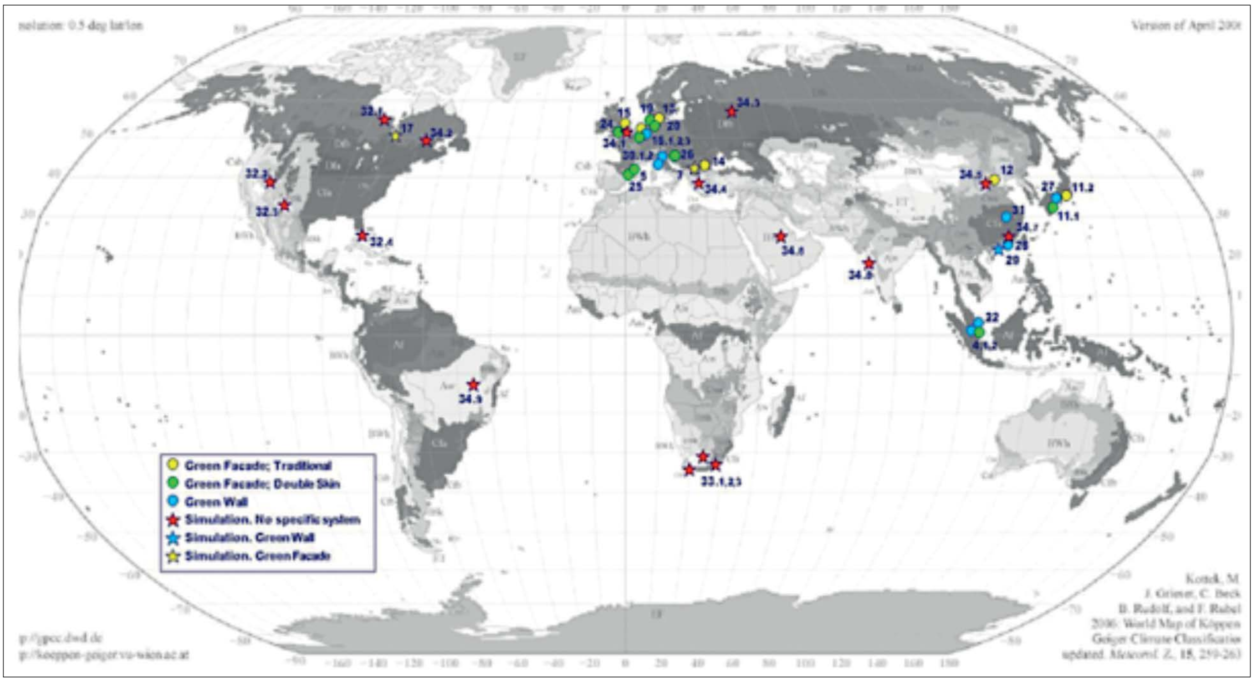

Figure 4.
Documented VGS studies and Classifications around the world.
Source: Perez, 2014.

Plate 1.
Vertical Greening System.

Source: kirhammond.wordpress.com. [Accessed January 2014].

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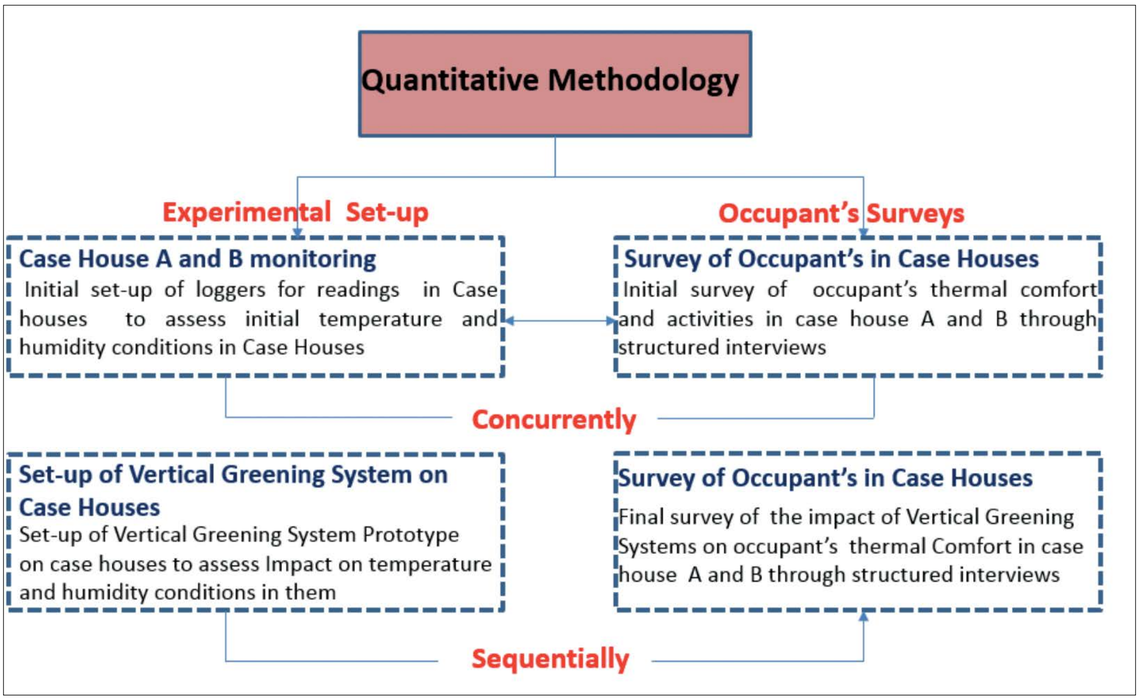

Figure 5.
Quantitative methodology and field experiment,.
Source: Author, 2015.

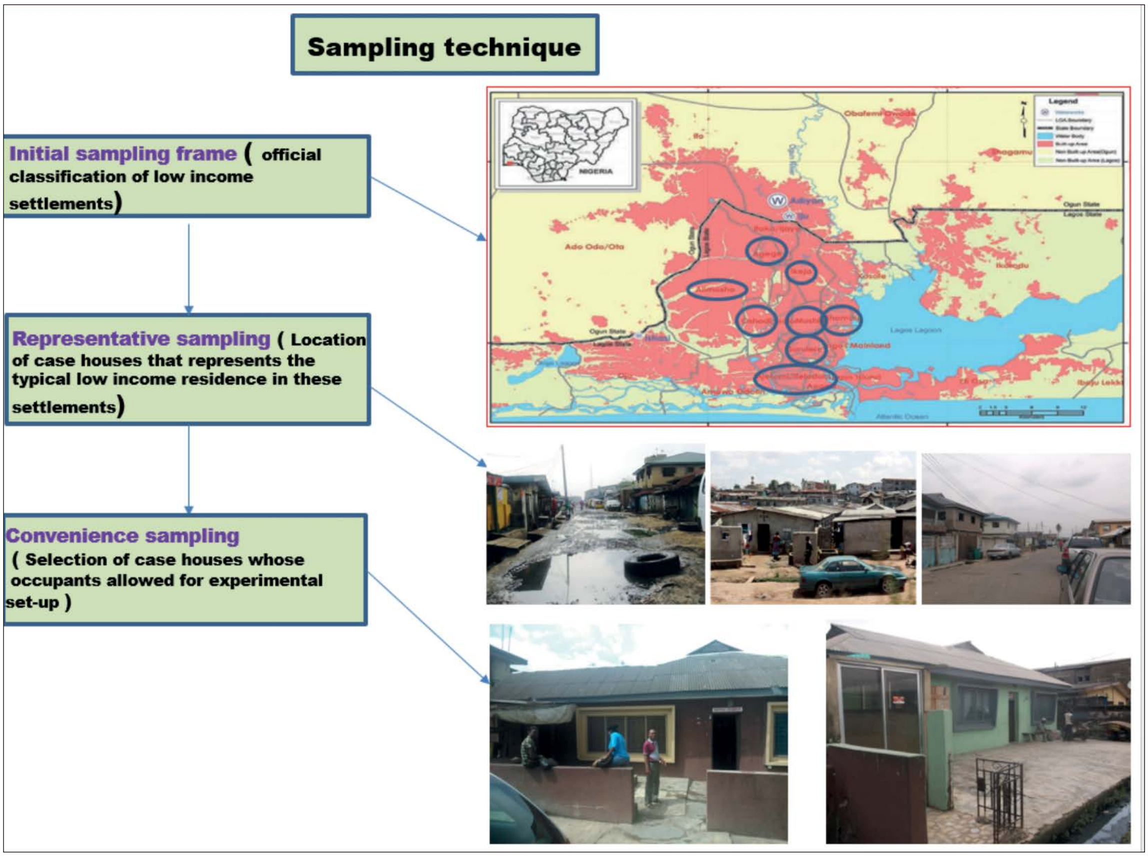

Figure 6.
Sampling technique.
Source: Author, 2015.

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4.1 Research setup

The total number of 'residences' were 10, 5 arranged on a long row or corridor and the other 5 arranged opposite it. The implications of this was a long dark poorly lit corridor and only 1 of the 10 rooms were cross ventilated, (Room 5) and this caused the residences to be overheated and uncomfortable for the residents (this was confirmed through the measurement and subsequent interviews). Each room was approximately 3m x 3m in size, 9m2 in area. Each room was populated by a minimum of 4 people (Details on this are given later in this chapter).

At the back of the building, a small kitchenette and bathroom was located at the left side of the house and a small 1 bedroom apartment was located on the right side of the house. Total length of the main building was 15m, while the total width was 7.5m.

Room 1 and 10 were used for the experimental set-up. Room1 was set-up with the VGS while Room 10 was used as the 'control room', as done in similar studies by Wong et al, 2010: Price, 2010 and Susorova, 2013. This was due to the walls receiving the most solar radiation (in this case, the westerly solar exposure as it entails that the wall receiving this is conducting heat into the interior space). This was also used as basis for experimental set up in studies by Eumorfopoulou and Kontoleon (2009): Price (2010): Susorova et al (2013): Chen et al, 2013.

Measurements of the surrounding environment (both indoors and outdoors) and within the VGS of temperatures and humidity was continuously recorded for a total of 5 months (with data mea-

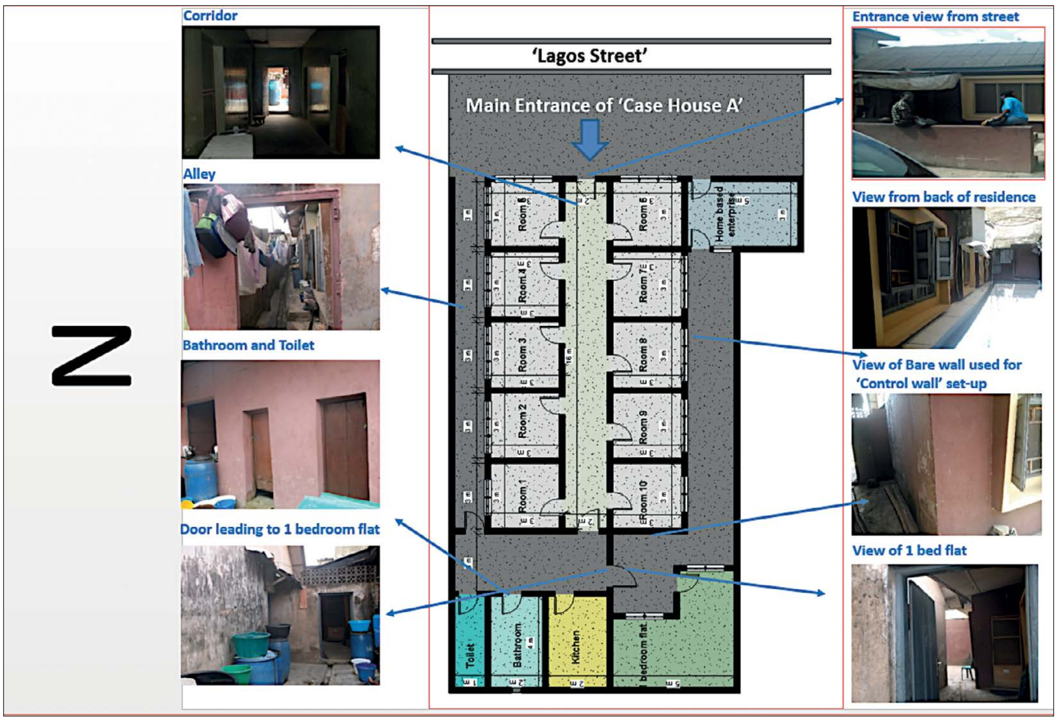

Figure 7.
Floor plan of Case House A.
Source: Author, 2015.

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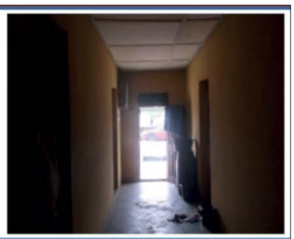
Details of Building Morphology , Case House A				
Wall	• 225mm thick • Hollow concrete block • Plastered with 5mm of cement.	The walls were 225mm thick, built from hollow concrete block and plastered with 5mm of cement. On confirming the age of the building with the landlord and caretaker, it was listed as 55 years. This was apparent in the decay of the façade located at the back of the building		
Floor	• Built of concrete and screeded with cement • Depth of 20mm	The floors were built entirely of cement. This was through 'screeding' of cement. The same material Was used on the exterior floor		
Ceiling	• Built from suspended ceiling tiles	The ceiling finish was built from suspended asbestos tiles, some of which were missing		
Roof	• Aluminum roofing sheet	The roofing material was aluminum roofing sheet discolored with age. The roofs project outwards by 450m (eaves). This provides some shading from the sun. However, solar radiation still falls on part of the building at different times of day, thus the shading provided by the roof was not significant enough to prevent the sun ray from hitting all parts of the building. A 300mm fascia board was also used on the façade of the building		
Doors	• Treated hardwood	The doors were built from treated hardwood		
Windows	• Louvre windows	The windows were 600mm X600mm .The rooms at the entrances had windows of 1800mm and 2400mm in width at the façade respectively, while the windows in the rest of the houses were 1800mm in width. Apart from one residence at the façade, none was cross ventilated. The windows used are called louvers		

Figure 8.
Details of Building Morphology,.
Source: Author, 2015.

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sured and gathered during specific times (every 10 minutes), diurnally and nocturnally alongside with ambient climatic data.
An optimized experimental installation was set up on the selected residences (typical low income houses) in Lagos, Nigeria. In each location, two residences were selected side by side with the exact number of rooms and same number of occupants (with a minimum of 3 occupants in each room), same materials used in construction (concrete blocks), same morphology and plan layout as well as building orientation. Consideration was given to the times in which the rooms were fully occupied. The west side of each of the two apartments was set up with a VGS. This is due to both walls receiving westerly solar radiation.

Indoor temperatures, mean radiant temperatures and humidity were recorded concurrently from May 2014 (to establish that the two rooms used for the experimental set-up were similar) to September 2014 (When the VGS was fully grown and Leaf area index was maximum). Particular focus on the readings presented here is on those taken between July-September, with particular attention in the month of August when the plants were fully grown and the ambient temperature was at its highest. This involved the design and assembly of two appropriate low cost VGS prototypes. The appropriate VGS prototype to the Low income group is characterized by

- Financial affordability
- Ease of erecting the systems
- Sustainable Material choices
- Edible plant types to provide an alternative of vertical farming and possible financial succour through selling of fresh vegetables. These included west indies plants, Fluted pumpkin plants (Telfairia occidentalis), Cymbopogon citrates (Lemongrass/ antisnake), Corchorus plants and sanseviera trifasciata
- Insect repelling plants

The VGS were located on surfaces with direct solar access as the situation permitted. A partnership with a horticulturist ensured appropriate planting was selected and well maintained. Measurements of the surrounding environment (both indoors and outdoors) and within the VGS for temperatures and humidity were continuously recorded for a total of 3 months and across the two major seasons in the city, wet and dry . Data was collected continuously at 10 minute intervals with attention paid to when occupants where in the rooms at the same times, alongside with collection of ambient climatic data. This ensured that adequate data during various times in the day was well documented.

4.2 Assembling of Prototypes (HDPE plastic VGS)

A design and assemble of an appropriate low cost VGS prototype with valuable financially saving ideas from the Residents and neighbors (Which was the intention of adopting the holistic research approach) was achieved. The HDPE pipes were sourced from a nearby construction site as recommended by the residents. that would anchor the HDPE pipes to the hardwood.

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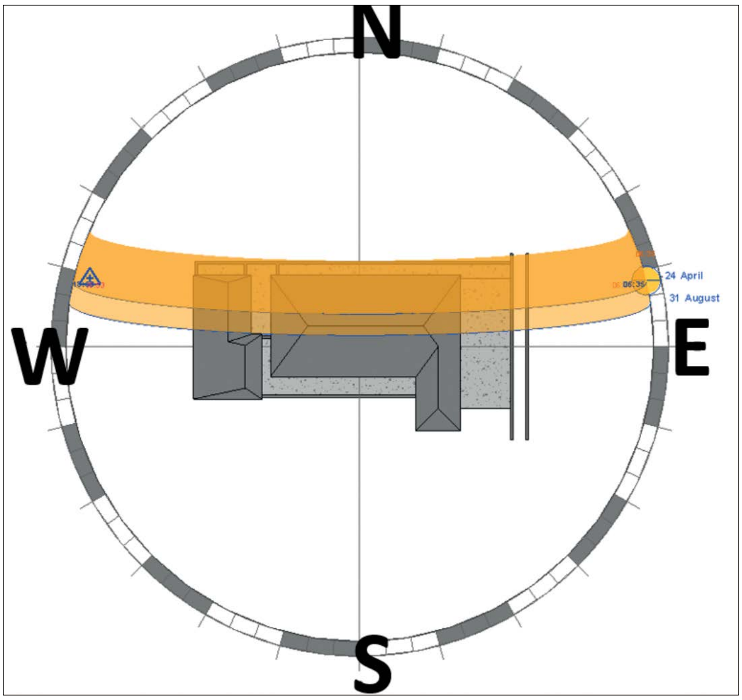

Figure 9.
Sun path movement in Lagos, Nigeria.
Source: Ecotect, 2015.

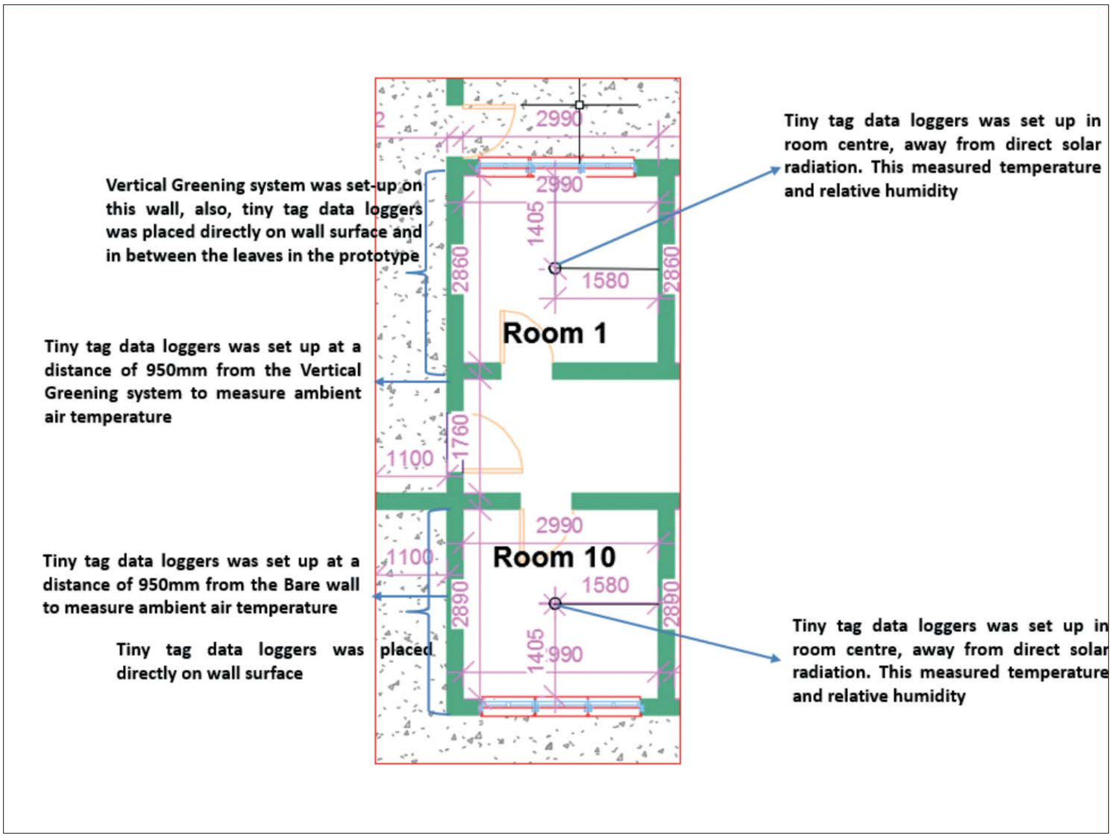

Figure 10.
Location of Loggers in rooms used for experimental set-up.

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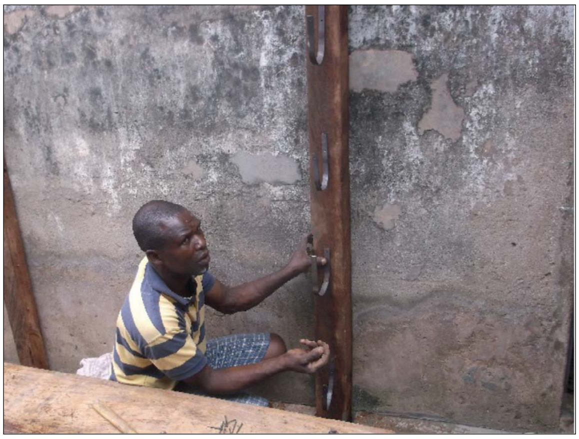


Plate 2. Vertical Greening System assembly
Source: Author, 2014.

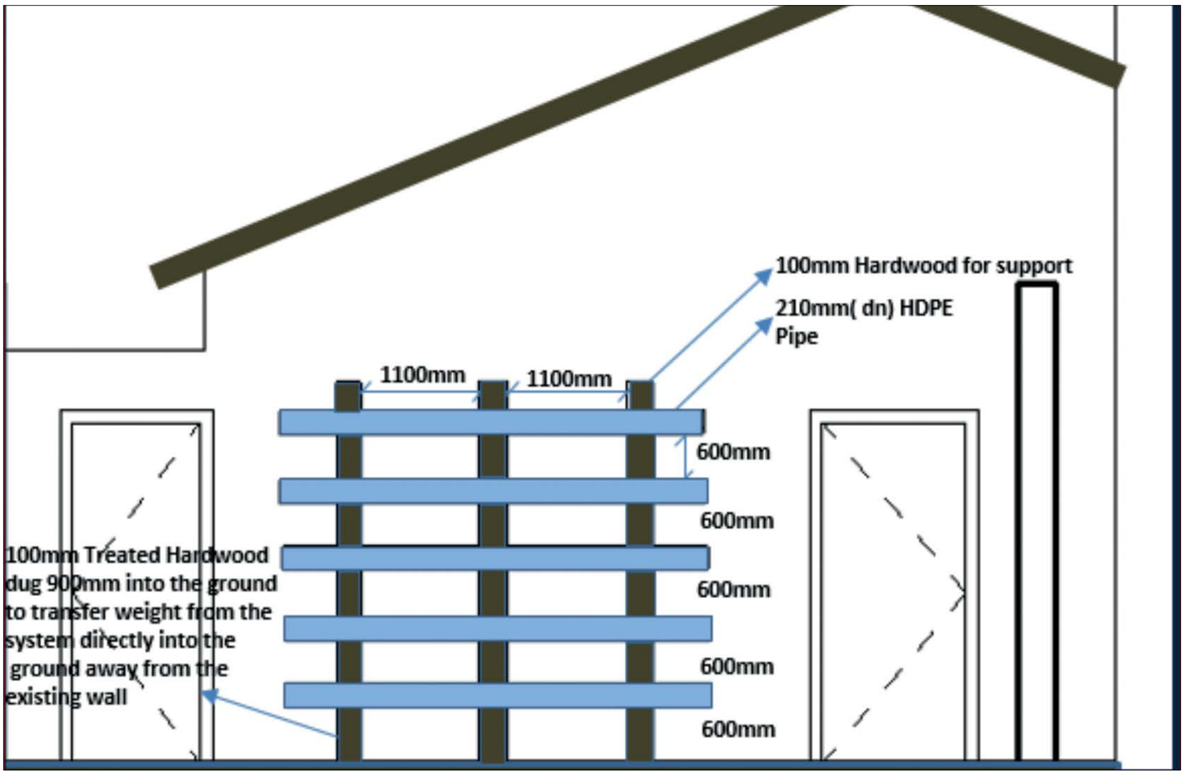

Figure 11. Detailed elevation view of the HDPE VGS prototype
Source: Author 2015

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Plate 3. Plant growth in prototype, July 1st 2014.
Source: Author, 2014.

Plate 4. Close up view of Corchorus plant (another edible plant type).
Source: Author, 2014.

Plate 5. View of fully grown plant in Prototype, August 2nd.
Source: Author 2015

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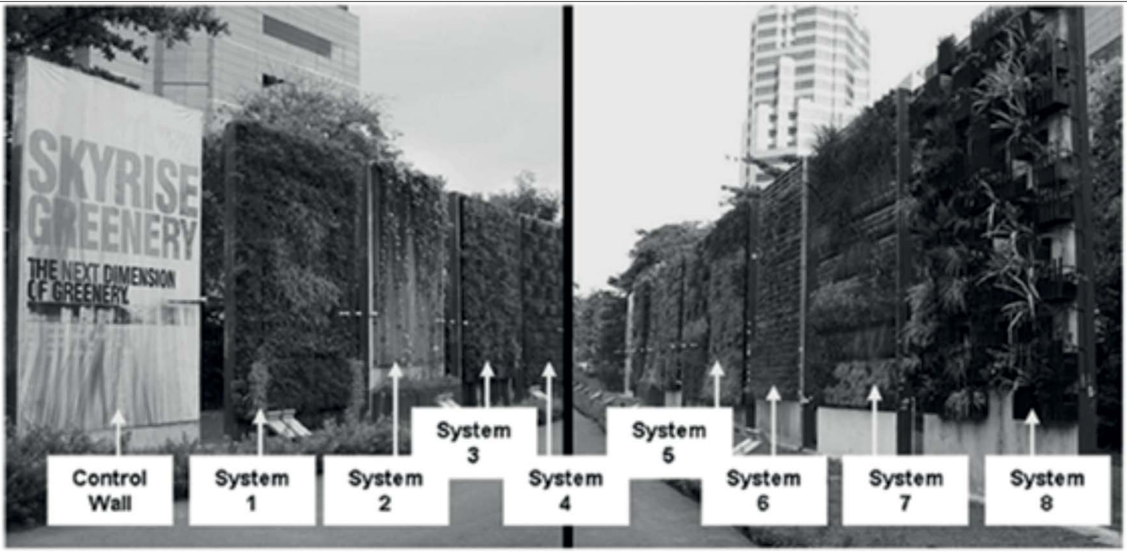

b

VGS	System typology	Description	Plant size
1	Living wall – Modular panel, vertical interface, mixed substrate	Combination of 2 systems: the versicell-based and 'plug-in' slot planter system. Versicell planters have drainage cells with selected mixture of green roof and soil planting media wrapped in geo-textile membrane while the slotted planters are mainly planter cages system.	Small to medium
2	Green façade – Modular trellis	Climber plants in planters forming green screens across mesh panels on the wall.	Climber plants
3	Living wall – Grid and modular, vertical interface, mixed substrate	Plant panels embedded within stainless steel mesh panels inserted into fitting frames.	Small
4	Living wall – Modular panel, vertical interface, inorganic substrate	Employed the Parabienta system with a patented growing medium (composite peat moss) as a planting media inlay. The peat moss panel encased in a stainless steel cage is hung onto supports lined with integrated irrigation.	Small
5	Living wall – Planter panel, angled interface, green roof substrate	This system uses a UV-treated plastic as a molded base panel with integrated horizontal planting bays.	Small
6	Living wall – Framed mini planters, horizontal interface, soil substrate	Individual mini planters placed and secured onto stainless steel frame.	Small
7	Living wall – Vertical moss-tile, vertical interface, inorganic substrate	Patented ceramic tiles shipped with pre-grown moss species. Suitable for creating tiling designs	Small, custom-grown on tiles
7a	Living wall – Flexible mat tapestry, horizontal interface, soil substrate	Lightweight panel comprising 2 layers of moisture retention mats secured onto a supporting grating or mesh. Plants slotted and pre-grown in between mats. Suitable for flat and curved surfaces. Allows ease of change.	Small to medium
8	Living wall – Plant cassette, horizontal interface, soil substrate	Use of planters to hold wider variety of plant types and of larger sizes. Planters are secured onto the wall through hinges. Lightweight growing medium is used.	Small to medium-large

Figure 12. Overview of VGS prototypes.
Source: Perez, 2014.

4.3 VGS prototype as compared to previous studies

The figure above compares various VGS prototypes derived from various studies as put together by Perez, 2014. In relation to the target group in this research, the need to invent a system that was relatively simple to erect, maintain and whose materials was extremely cheap and easy to obtain was paramount. The VGS prototypes eventually used in the study was put together by the Author and certain construction ideas were proposed by the residents while this was being erected. It is safe to say that inputs by the target group while erecting them made the VGS a lot cheaper than the initial budget. This is another factor that distinguishes the study from previous works that have included simulations etc. All instruments were heat friendly in order to minimize errors/discrepancies in reading data. They were protected from rain by a water repelling material (Nylon) to avoid damages which might lead to errors in data recordings. The readings were recorded at 10 minutes intervals. They included the temperature data loggers and humidity loggers. They were located in the exact areas in the spaces, within the VGS and hung in the centre of the rooms. For the wall surfaces, they were embedded on the surface with the same concrete materials of the walls. Sources of heat gain in the rooms include: Human body heat, Convective heat Gain from aluminum roof and building materials and Heat Gain from solar radiation.

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5. Results

There was a maximum reduction of 4oC in the interior temperature of the room with the VGS mounted on the wall surface as compared to the room without the VGS. The readings were noted when activities in both rooms were nearly equal, i.e. the occupants were in the rooms as at the time of the readings and the number of occupants were the same in number. The Occupants also confirmed a slight difference in temperature in the room through the separate structured interviews which is not reported here.

The difference in indoor temperature was likely due to the photosynthetic activities of the plants in the VGS absorbing solar radiation before the remaining heat is gained into the walls subsequently entering the rooms, hence the lower temperatures recorded in the room with the VGS. Also, the Leaf area index forming a shading to the wall thus preventing the solar radiation from penetrating the walls directly,

This result is promising in that questions like if more VGS prototypes were set up around the rest of the building, would the reduction in the room temperature be more significant? This will be further explored by simulation.

6. Discussion and conclusions

For architecture in the tropics, the key to achieving thermal comfort in buildings (without mechanical cooling devices) has been through basic design rules such as cross ventilation, building orientation, roof overhangs etc, however, overpopulation and overcrowding has limited the efficacy of following such design principles.

The need to research on alternative sustainable ideas particularly on passive cooling for free running houses is important. The results of the small set up of the VGS show its potentials to offer passive cooling. Further analysis will be explored using simulation to review multitude of scenarios the VGS prototype can influence thermal comfort in free running buildings. This will also involve analysis of the microclimate around these residential buildings. Further investigation on user acceptability among Low income Groups and Professional Architects was also conducted to assess if VGS will be accepted to be used on large scale within the city of Lagos. The results showing the Plastic VGS prototype offering the best results could direct further research on the development of the plastic VGS prototype for low income Houses. Also, further analysis on Humidity and wall surface temperature has been done in the research which was not discussed in this paper due to the focus on temperature differences in interior spaces.

ISSN 2309-0103
www.enhsa.net/archidoct
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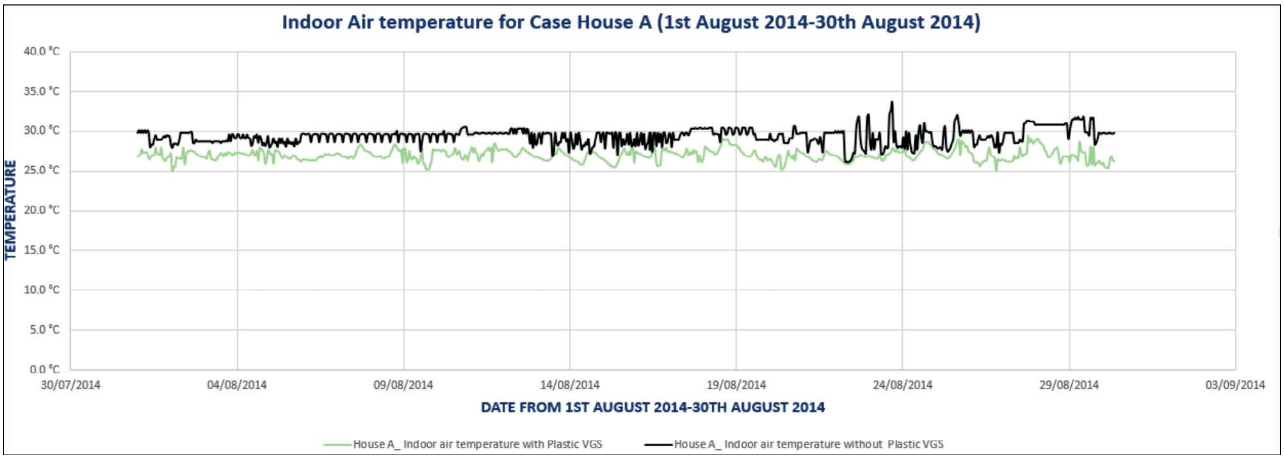

Figure 13. Indoor air temperature of Room1 (without VGS and Room 10 with VGS)

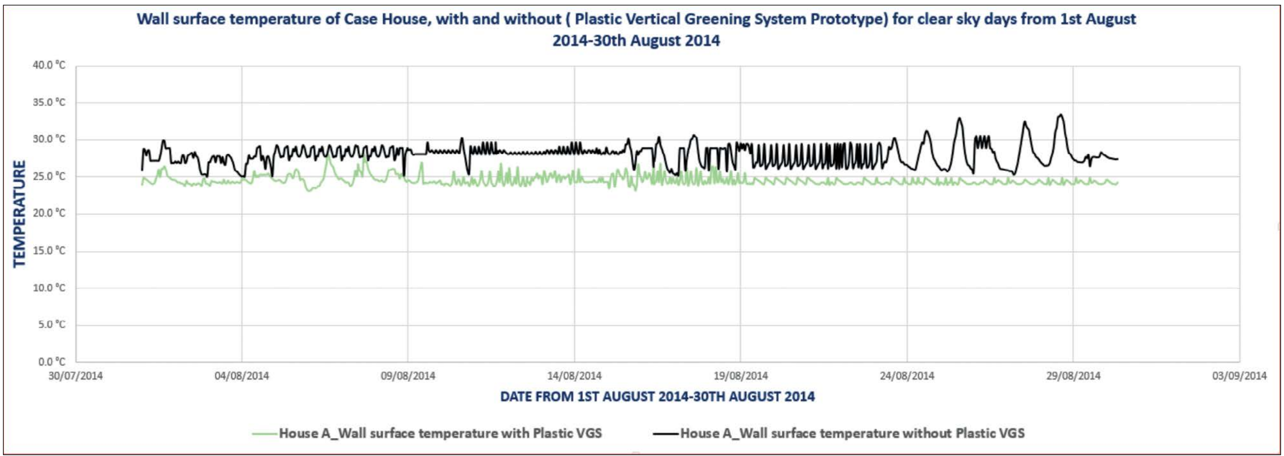

Figure 14. Wall surface temperature of Room1 (without VGS and Room 10 with VGS)

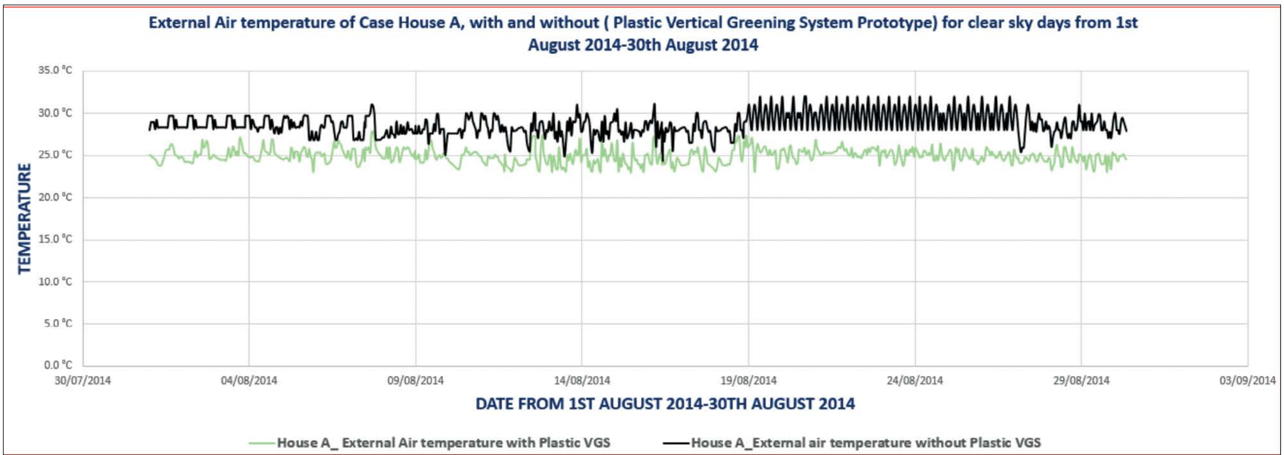

Figure 15. External air temperature of Room1 (without VGS and Room 10 with VGS)

ISSN 2309-0103
www.enhsa.net/archidoct
Vol. 3 (2) / February 2016

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