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GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

MASTER THESIS

ENERGY AND DAYLIGHT PERFORMANCE ANALYSIS OF DOUBLE SKIN FAÇADE SYSTEMS IN HOT ARID CLIMATE: A CASE STUDY IN NIGERIA

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We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

ENERGY AND DAYLIGHT PERFORMANCE ANALYSIS OF DOUBLE SKIN FAÇADE SYSTEMS IN HOT ARID CLIMATE: A CASE STUDY IN NIGERIA

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This research is marked at evaluating the energy and daylight performance and concept of Double Skin Façades established on computational simulations integrated with some relevant examples. DSF is reflected as the greatest solution in realizing the interface between the interior and the exterior building spaces. It also allows some architectural pliability to the design. Double skin façade lately has received much attention being opponent to the more typically glazed curtain wall. This is for its ability on efficiently reducing the thermal transmission (U-Value) and solar heat gain (G-Value). DSF design comprises assessments on building geometric factors, glazing type, ventilation procedures, shading devices, and daylighting, aesthetics, and maintenance expenses.

However, the concept of (DSF) is sometimes complicated, and its use and function influences different parameters of the building, but If the approach is overall and the aims to be realized are distinct, then the stated method is flexible enough to reach climatic variations for greatest types of building use.

Besides the fact that large number of researches carried out on the performance of this facade configuration in moderate climates, it is very vital to recognize its performance and formations in hot and dry climates. It is therefore a chance to learn about this facade arrangement earlier the technology is transmitted into construction in hot arid areas.

Keywords: Double skin Façade Systems, Building Envelopes, Performance, Energy Simulations, and Daylight analysis.

ÖZ

ÇİFT KABUK CEPHE SİSTEMLERİNİN SICAK KURAK İKLİMLERDE ENERJİ VE GÜNIŞIĞI PERFORMANSININ ANALİZİ: NİJERYA'DA BİR ÖRNEK İNCELEMESİ

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Bu çalışmada, Çift Kabuk Cephelerin enerji ve gün ışığı performansı, bilgisayar simülasyonları kullanılarak değerlendirilmiştir. Çift kabuk cepheler, iç mekanla dış mekan arasındaki arasındaki etkileşimin sağlanmasında en iyi çözüm olarak görülmektedir. Ayrıca tasarımda mimari esneklik sağlar. Son zamanlarda çift kabuki cephe sistemleri klasik giydirme cepheye göre daha fazla ilgi görmeye başlamıştır. Bu, termal iletimi (U-Değeri) ve güneş ısısı kazancını (G Değeri) etkin bir şekilde azaltma kabiliyetinden dolayıdır. DSF'nin tasarımı, geometrik parametreler, cam tipi, havalandırma teknikleri, gölgeleme cihazları ve günışığı, estetik ve bakım masrafları oluşturma kararlarını içerir.

(DSF) kavramı karmaşık olduğundan, kullanımı ve işlevi binanın farklı parametrelerini etkiler, ancak yaklaşım genel ise ve ulaşılacak hedefler açıksa, söz konusu sistem, iklim değişikliklerini karşılayacak kadar esnektir.

Ilıman iklimlerde bu cephe sisteminin performansına dair çok sayıda araştırma yapılmasının yanında, sıcak kurak iklimlerde de performans ve konfigürasyonlarını anlamak büyük önem taşımaktadır. Teknolojinin sıcak kurak alanlarda kullanılmaya başlanmasından önce bu cephe sistemlerin incelemek önemlidir.

Anahtar Kelimeler: Çift cepheli cephe sistemleri, bina zarfları, uygulama, performans, zorluklar, enerji ve günışığı analizi, sınırlamalar.

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My sincere appreciation is reserved for *my beloved parents, siblings, friends and relatives* and *my lovely wife*, for their courageous words for being what I become today. Thanks for your great support and static care you render to me words are not enough to express my gratefulness to all of them. That is why I dedicated this thesis solely to *the entire family of late Ibrahim Sha-rubutu Wurma*.

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GAMBO, Wurma Bara'u

İzmir, 2018

TEXT OF OATH

I declare and honestly confirm that this study, titled "ENERGY AND DAYLIGHT PERFORMANCE ANALYSIS OF DOUBLE SKIN FACADE SYSTEMS IN HOT AND ARID CLIMATE: A CASE STUDY IN NIGERIA" presented as a Master of Science Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Gambo Wurma Bara'u

Signature

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07/06/2018

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SYMBOLS AND ABBREVIATIONS:

DSF	Double Skin Façade
DS	Double Skin
U-Value	Thermal transmission
G-Value	Solar heat gain
GF	glazed Façade
DSFs	Double Skin Facades
Mm	Millimeter
Cm	Centimeter
BBRI	Belgian Building Research Institute
USA	United States of America
US	United States
Ft	Feet
EPW	Energyplus Weather Data
SHGC	Solar Heat Gain Coefficient
VT	Visual Transmittance
EU	European Union
KWh	Kilo Watt-hour
LEED	Leadership in Energy and Environmental Design
Sqm	Square meters
NSE	Nigerian Stock Exchange
FCT	Federal Capital Territory
Km	Kilometers
CAD	Computer-Aided Design

SYMBOLS:

%	Percentage
Co_2	Carbon dioxide
^oC	Degree Celsius
N^0	Degrees
M^2	Meter square

CHAPTER -1
INTRODUCTION

1.1 BACKGROUND

Typical building facades (DSF) are said to have quite number of challenges in terms of natural ventilation, thermal comfort, especially in buildings with high ratio of glass in the facade, in arid and hot climate regions. These problems cherish the architects and other building industry professionals to develop techniques of solving these problems through the utilization of new techniques such as shading devices, colour glass among others. The adoption of these techniques has shown a reduction in natural lighting, and the increase in the use of artificial light; which inevitably led to the increase in the interior heat gain. To battle this situation, artificial cooling is used to cool down the heat effect. This results in the increase of energy consumption which leads to the increase the cost (Shameri M.A. et al, 2011).

Double skin façade is mainly used to boost building's thermal efficiency with great glazing facades formations. DSF is mainly adopted for architectural reason and for its transparency properties because it allows close contact with the surroundings of the building, and of the point that it concedes a great amount of daylight to pass in to the building deprived of intense glare. Finally it has attractive aesthetic value which is much desired by architects, developers and owners. Though, there are numerous tasks of using DFS; one of them is the construction expenditures that is vividly much higher equated to a conventional glazed-facade. Moreover, the possibility of overheating during days with relatively high temperature is obvious and consequently excessive need for cooling the interior spaces may arise.

It is quite unfortunate that until now, there are still few buildings which actually patronize the use DSF. Thus it is said that it is somehow difficult to find any objective data on the actual performance of buildings with DSF specifically in hot arid climate. This research will focus on some of the configuration issues in designing a DSF, where the aims of this study is to give a broad overview of double skin facade within the earlier specified climate region (hot and dry).

The task anticipated from buildings with DSF is to attain a harmony between the visual aesthetic, acoustics insulation, and the performance in terms of energy efficiency. The elementary structure of DSF consists of the inner skin, an air cavity, and outer skin. The inner skin and the outer skin can be of a single or double pane glass. The DSF can also be combined with shading elements such as louvers to moderate solar gains and consequently the cooling mandate of the building is reduced. Nevertheless, heat is ensnared in the air cavity of the DSF when the weather is hot, due to solar gains and thermal transfer of the exterior skin. Depending on the design, the gap of the DSF is commonly ventilated naturally or mechanically to drive out the excess of heat gained (Elizabeth Gratia, et al (2004).

The word “Sustainability” is a wide and complex topic with different aspects and definitions (Graber, and Dailey, 2003). The main dimensions of sustainability are environment, economic and society in a local and world wide scale, and in many different sectors such as construction, industry, tourism, etc. (Hoşkara, 2009). Sustainability primarily is environmental well-being, economic and social comfort for human beings and satisfactory of their essential basic needs to have a superiority of life continuously without interrupting the upcoming generation’s well-being for their needs (Brundtland, 1987).

In construction sector, for the past 2 decades, sustainability has been one of the important issues in design concepts. However, buildings are one of the damaging properties for the society and environment in relations to sustainability. They have high energy consumption and they are a huge producer of harmful gasses to the air. Similarly, they consume great amount of energy, and thus cost in order to be facilitated for the users. So the buildings not environmentally and socially nor economically are sustainable (Graber and Dailey, 2003).

Key innovation in GF skills has equipped the architects and experts a chance to integrate the Components of the building envelope within sustainability philosophies but preserving a great level of capability. That is the reason why it is vital that GF construction systems and materials should be planned and fixed appropriately to deliver an exciting living environment, while maintaining a sustainable system for the environment and the society (Winxie, 2007).

1.2. STATEMENT OF THE PROBLEM

Based on the ideas acquired from the investigation of some works, there was huge number of research on the performance of Double-skin building facade formations established in moderate climate. Despite the fact that large number of researches carried out on the performance of this facade configuration in moderate climates (Neveen H. 2007), it is of very vital to comprehend its performance and arrangements in hot and dry climates.

Since the late 1970s, reliance on artificial cooling systems in buildings has been growing, continuously which in consequence increases the maintenance cost of these buildings. The formations of some commercial building facades in hot and dry regions have an excessive impact on dwindling/growing the building's maintenance demand. In hot arid climates, about 45% of the cooling loads emanate from the facade's configuration (H. Elkadi et al, 1999).

1.3. RESEARCH AIM AND OBJECTIVES

The main aim of this research is to discuss the concept and the energy and daylight performance of DSF Systems, in hot and dry climate. Computational design method is anticipated to be adopted for it is of supreme importance to this research in order to overwhelm with difficulty of office buildings with regard energy performance and daylight accomplishment especially in hot and arid climate where cooling load is very high and if not properly designed, double skin façade may not be suitable for hot arid climatic zones. By undergoing through the above process, it is expected that some simplified model would be developed and hence will be useful to support design decision process to realize appropriate building options especially at the pre-design stage. In this case the main research question is: What is the general perspective of DSF system and its performance in hot and arid regions? In order to answer this question there is need of answering the following sub-questions:

The following questions are the main questions expected to be ascertained in this research. They include:

- What is DSF structure?
- Evaluation of energy and daylight performance of DSFs structure in Hot and dry Climatic region; what are the problems? Can DSFs system solve these problems?

1.4. SCOPE OF THE RESEARCH

This research is limited to ascertaining the performance of double skin façade in hot and arid climate and finding some possible ways of improving daylight and energy performance in office buildings particularly in Kano, Nigeria. This study will lay emphasis on assessing the performance of double skin façade envelope precisely energy, daylight and thermal behavior of the façade configuration. It will as well highlight the theoretical framework required to accomplish environmental-friendly thermal level and sufficient daylight within buildings with double skin facades. It is also within the scope of this study to highlight the general concept of double skin façade. The research will also develop a theoretical and design solutions for sustainable commercial buildings in terms of sufficient illumination and thermal comfort in hot and arid climate.

1.5. LIMITATIONS OF THE STUDY

This research is limited to assessing the energy and daylight performance of the double skin façade configuration in office buildings in Kano, Nigeria. The research then identified the most suitable way of enhancing the energy and daylight efficiency in response of the façade composition thru various formations which will be identified from various literatures. The double skin facades element combinations will then be simulated on the energy and daylight simulation program to establish the effect of each unit of the façade in terms of energy and daylight performance which will therefore be recommended as a substitute of classical façade in office buildings specifically in hot arid climatic region. The survey is used to analyze the level of comfort of the users in terms of energy and daylight performance in the office building and some information were obtained from the building users. Secondly, the research improved the energy and daylight performance by modifying the façade configurations.

1.6 RESEARCH DESIGN AND METHODOLOGY

The approaches to be adopted in this research include developing of an intensive literature review within the study area, survey questions, and testing the data collected using computational design approach which could help to the generation of new contemporarily design ideas. The workflow developed in this approach started with the generation of a 3D model of a banking hall using a three dimensional parametric modeler tool named Grasshopper, which works in connection with Rhinoceros. This thesis has been structured and divided into five (5) chapters, each chapter having a sub-heading in the following sequence;

Chapter 1: Introduction (an overview of the research).

Chapter 2: Literature review (Concept of Double Skin Facades, Historical Development, Classification and Relevant case studies).

Chapter 3: Research Methodology (Involve data collection about Double Skin Facades in Hot Arid Climate through survey questions information about the climate of the study area and the base case building and also energy and daylight Simulation process).

Chapter 4; Data presentation, including survey evaluation and energy and daylight simulations base on the suggested methodology in chapter 3 are presented in this chapter.

Chapter 5: This part of the thesis will convey the discussion and summary of findings as presented in the immediate chapter, as well as conclusion, recommendation and contribution to future knowledge.

The figure below is a flowchart showing relationship between chapters.

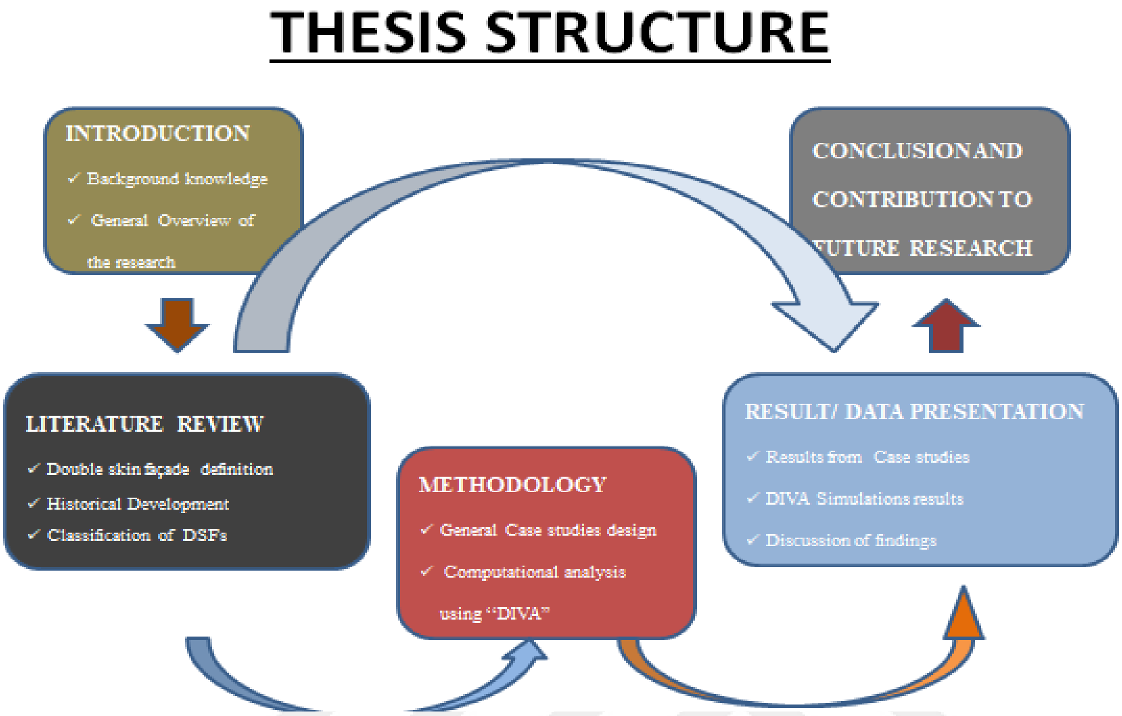


Figure 1.1: Thesis Structure

In the figure 1.1 above, the arrows are showing relationship between chapters how they are correlate to each other. The blue arrow illustrates the connection between the literature review and methodology thus; suitable approaches will be adopted based on the review of relevant literatures. The faded blue arrow illustrates the connection between literature review and the case study building which is presented in chapter four, thereby analyzing and evaluating its performance and how its energy and daylight performance can be improved using the previous relevant examples presented in chapter as a base. The approaches established from the literature review will be tested and their effect will be presented in chapter 4. The orange arrow denotes the connection between the methodology and results and data presentation which implies that the instruments applied for the collection of data were presented and the results were analyzed in chapter four. Further explanation of the thesis structure can be seen in item (1.6) above.

CHAPTER- 2

CONCEPTS OF DOUBLE SKIN FAÇADE SYSTEMS

2.1. LITERATURE REVIEW

This chapter tries to review various literatures on buildings with double skin facades to relate the research with the contemporary state of knowledge. However, a general definition of DSFs was presented by different authors. Below are some of these various definitions of DSFs.

Oesterle et al. gave the most exhaustive meaning of DSF. Based on the explanations he gave, a double skin façade is a façade composed of multi layers, which has an interior and exterior layer that consists of a buffer zone applied as a shield against solar and ventilation control.

Ding et al. has describes DSF is a façade that comprises of an inner facade, an intermediate air space and an outer facade. The external facade (glazing) furnishes a guard against the prevailing weather and enhanced sound insulation from the external. Shading strategies are usually mounted between the two skins in the cavity to foil the internal rooms from high cooling masses.

Kim et al. seconded that: “Double-skin facades are multi-layer skins construction with an interior skin, an intermediate cavity and an exterior skin. These skins could be of either single or double pane glass made of special qualities and characteristics. Shading devices are usually placed at the intermediate cavity for thermal comfort in the manner that these devices can be adjusted. The constructions DSF process could widely be grouped under, Shaft-box facade, Box Window façade, Multi-story façade and Corridor facade”.

Baldinelli pointed out that; “DSF Compared to an ordinary single skin façade, consists of an interior skin separated from an exterior skin composed into a glazing unit. Ordinarily, the external skin is a single layer of specially treated glass against the exterior conditions, while the interior layer consists of single or double pane glass often with windows which are operable".

Chan et al. debated that: "DSF refers to as a building facade enshrouding one or several stories with multilayer glazed skins. The outer facade is usually a toughed single pane glass and can be wholly glazed. The depth of the intermediate cavity ranges amongst 200 mm up to 2 m or even more. DSF which is air-tight can produce increase in building thermal performance thereby minimizing the heat loss during winter season. Similarly, moving air cavity into a ventilated double skin facade can engulf the heat without transmitting it into the building and can relatively minimize the heat gain from solar thus; the cooling necessity of the building is compressed".

Harrison and Boake, (2003), termed the DSF system as "*principally a couple of glass "facades" divided by an air corridor. The prime layer of glass is ordinarily insulating. The air cavity between these layers of glass acts as insulator against extreme temperature, aggressive winds, and sound. Shading elements are often employed amid the building skins. All other elements can be positioned differently both opaque and translucent membranes".*

Arons, (2001) defines the DSF as "*a façade that composed of two prominent flat elements that permits exterior or interior air to move through the system. This is composition is occasionally termed as a twin skin."*

Uuttu, (2001) portrays the DSF as "*a pair of glazed-skins distinct by an intermediate space ranging from 20cm and above. The glass prime layer, usually detached, acts as part of a typical curtain wall, while the additional layer, usually single glazing is placed either in front or at the back of the core facade. These skins aid the cavity amid them work essentially as insulation against temperature excesses and sound."*

Compagno, (2002) labels DSF as *"facade system with additional skin in front of the building core façade. Solar shielding strategies are positioned in the cavity amid these skins, which shields them from the weather influence and polluted air"*

2.2 CONCEPT OF DOUBLE SKIN FACADE

In this part, the DSF concept is extremely illustrated via furnishing with additional knowledge concerning the combination, the role as well as the use of the system mentioned.

The BBRI, (2002) portrayed DSF in the sequence below:

- Exterior Skin: Usually it is a toughed single glazing and may be solely glazed.
- Interior Skin: Detached double glazing unit (double and single pane clear, Low e argon among other glasses can be used). Most often this layer is not glazed wholly.
- The cavity amid the two skins: Its ventilation could be exclusively natural or artificial. The cavity width may vary as a function of the applied concept between the range of 200mm to 2m or even more. This width influence upkeep of the façade.

Saelens, (2002) elaborates in his doctorate degree thesis the conception of the Double Skin Façade. Based on his description, "*a multi-skin facade is an envelope construction, which is a product of two translucent surfaces distinguished by an air space, which that acts as an air channel".*

Uuttu, (2001) depicts the DSF concept as "*a duo of glass skins distinguished by an air gap with a depth ranging from 20 cm to several meters"* According to him *"the air space is attached with the outdoor atmospheres so that the windows of the inner façade can be operable, even in the high-rise buildings pending to wind pressures; this system permits cooling at night time and natural ventilation of the building. During winter the air space serves as thermal buffer zone which minimizes heat losses and endows passive heat gain from solar radiation. Generally, double-skin façades provide a protected place within the air space to attach daylight-enhancement gadgets as well as some shading elements such as venetian blinds and louvers.*

When solar radiation is high, the air space has to be efficiently ventilated, to surpass overheating. In this regard, the basic criteria are the cavity depth and the size of the openings in the outer skin. Depending on the wind pressure and the prevailing climatic conditions, the air change within the cavity of the building façade.

These vents can either be left open all the time (passive systems), or opened by hand or by machine (active system). Active systems are very complicated and therefore expensive in terms of construction and maintenance. Advanced philosophies in designing DSF are strategies concerning fire and noise protection. Adopting these factors as a base, several resolutions were established for double-skin façades."

Lee, Selkowitz, Bazjanac, Inkarojrit and Kohler, (2002) have endorsed in the adoption of the DSF System as stated below: "*The paramount performance of DSF as quoted by design engineers of (EU) is sound insulation. A second skin of glass positioned in fore of a conventional façade minimizes acoustic levels at specifically around noisy locations, such as airports or high traffic urban areas. However, the presence of operable windows at the back of this all-glass layer compromises this sound control benefit, specifically if openings in the external layer are adequately large enough to enable ample ventilation from the ecosystem".* The authors stated another benefit of this façade configuration. Based on their findings, "*double skin facades permit the renewal of notable buildings or the upgrading and renovation of buildings where new zoning ordinances would not allow a new building to replace the existing old one with the same size due to more stringent height or volume restrictions".*

The authors' concentration was on the ability of DSFs in the extraction of heat. In accordance to their view, *"double-skin façade's heat extraction relies on the solar shading elements placed in the intermediate space between the exterior and interior skin façade to restrain solar heat gain. The notion is identical to external shading systems in that solar radiation loads are halted prior entering into the building, except that heat absorbed by the between-pane shading element is released within the air cavity, then extracted off through the external skin by mechanical ventilation or natural means.*

This idea is evidenced with a single external layer of laminated safety or heat-reinforced safety glass, with external air inlet and outlet openings which can be manually controlled or automated with throttling flaps. The second internal skin façade layer is composed of an operable or fixed single or double pane, hopper or casement windows. Within the air cavity are fixed Venetian blinds or retractable or roller shadings, which can be automated or manually operated.

2.3 CLASSIFICATION OF DSF SYSTEMS

2.3.1 ACCORDING TO AIRFLOW/ VENTILATION MODE

Double Skin Facades composition may be categorized in diverse directions. It can be classified based on construction mode, target and method of air flow within the intermediate space, etc.

The DSF is usually a glass entity "skins" with an air space between them. The prime coat of glass is usually insulating. The intermediate cavity acts as insulator against outdoor temperature, wind-loads, and acoustic. Shading elements are often placed between these two facades. These elements are organized separately into numbers of permutations and combinations of both opaque and translucent membranes.

There are many distinctions in the double skin facades construction types, it is required to design a logical system of classification in order to assess and make evaluation of the benefits of the plentiful systems as well as the "environmental success" of one building's formation to another. Three basic types of systems were cited by Lang and Herzog, they include: Extract Air System, Twin Face System and Buffer System. These systems vary considerably with respect to process of ventilation and their abilities to minimize overall energy consumption.

Moreover, Saelens (2002) defined the double-skin facade as an envelope which is composed of two diaphanous surfaces distinct by an air cavity, which is served as an air duct." The additional skin provides improved thermal performance, which consequently minimize both cooling demand in summer and heating demand in winter. Shadings can be mounted within the air space, for extreme solar heat gain avoidance. Shading systems can absorb solar radiation especially when connected into the air space. The prevailing whether determine the need for heating or cooling, this extracted air can be drawn either into the internal building spaces or ventilated out to the outside the building.

Based on this procedure, DSF was classified into; Buffer system, Extract air, Twin faces and Hybrid DSF systems.

1. BUFFER DSF SYSTEM:

The insulating glass adopted in this method is to domain natural daylight into buildings as well as upgrading its thermal insulation. Two layers of single glazing are used at an interval ranging from250mm to 900mm or more, enclosed and permitting uninterrupted air into the building thru openings that can be opened. The figure below shows an example of a buffer DSF system.

Figure 2: *Buffer DSF: Business promotion centre Germany. (*Source: www.fosterandpartner.com)

2. EXTRACT AIR DSF SYSTEM:

This involved of an extra glazing layer positioned on the interior of a core façade of double glazing which makes the intermediate air space to partake in cooling the building. The unwanted used air is extracted through the intermediate space using mechanical means (fans), which moderates the interior glazed skin while the exterior skin of insulating glass decreases thermal transmission. Solar shading elements are also placed within the air cavity with depth ranging between 150mm-900mm. This synthesis is often used in regions where natural ventilation is precluded or places with acoustic discomfort, aggressive wind loads, among others. (See figure: 3 below):

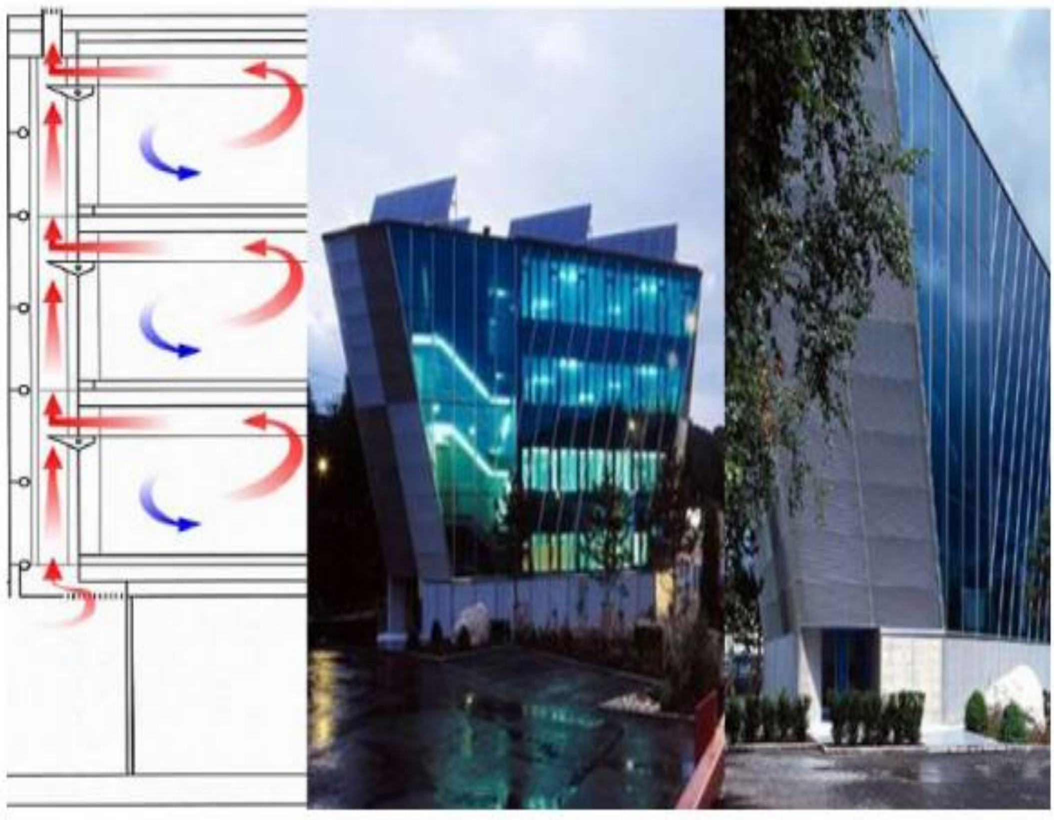


Figure 3: *Extract Air DSF (Bürogebäude Felbermayr, Salzburg, Austria.* Source: www.architecten.at

3 TWIN FACE DSF SYSTEM:

This is composed of ordinary curtain wall system within a single glazed building skin. The exterior skin may be made with specially treated glass to blend with the intended function. Sun shading elements may be incorporated. This synthesis should have an intermediate air space of at least 500mm-600mm to allow for cleansing. Natural ventilation is allowed in the twin faced DSF due to the presence of an opening which distinct it from the buffer and extract air DSF system. The internal skin gıves insulation for minimizing loss of heat from the interior, whereas the external skin functions as a guard to the air cavity contents (shading elements).

Figure 4: *Twin Face DSF Daimler Benz (Debis) Building, Berlin.* Source: www.coltinfo.net

4. HYBRID DSF SYSTEM:

This system of DSF is the association of any two of the above mentioned DSF systems used in a situation where any among the systems prior mentioned does not accommodate to the building system involved. The buildings may use a unit of any material or screens on either of the sides of the basic environmental barrier. Best example of hybrid DSF system to be cited is the Renzo Piano's designed structure "Jiao center" located in New Caledonia.

Figure 5*: New York Times Building and Detail of ceramic shading elements*
Source: www.brianrose.com & architecture.co

2.3.2. ACCORDING TO CAVITY PARTITIONS

Oesterle et al., (2001) reflects mostly the type of the air cavity to classify the Double Skin Facades. Most comparable is the Saelens' (2002) and E. Lee et al. The of DSF typology are portrayed in the following sequence:

- **Box window type**: In this case horizontal and vertical partitioning divide the façade in smaller and independent boxes.
- **Shaft box type**: In this situation, a set of box window elements are mounted on the skin. These elements are mounted alongside the vertical shafts situated in the façade to ensure effıcıency in stack effect.
- **Corridor façade**: This system shows horizontal demarcation for fire prevention, ventilation and acoustic reasons.
- **Multi storey Double Skin Façade**: In this situation, there is no division vertically or horizontally within the air gap. The large openings within the building provide ventilation within the air cavity.

According to Uuttu, (2001);

- **Building-high double-skin façade**: *the air space is not partitioned at each floor; rather it proceeds over the whole building height. The following is the primary notion behind a building-high cavity: air that accumulates at the top of the intermediate air space is likely to generate heat during summer. Openings in the external façade and at the edge of the roof extract away the heated air, while drawing from near the base of the building the cooler air as a replacement to the extracted heated air."*
- **Storey-High Double-Skin Façades**: *"This system contained air straits horizontally partitioned at each intermediary floor."*
- **Box Double-Skin Façades**: *"In this façades system there are ventilated façades often stockwise in nature with horizontal demarcations on each floor and vertical demarcation on each window. Outlet and inlet vents are positioned at each floor. Hence the lowest degree of air heating and therefore the most effective level of natural ventilation are to be expected."*

The concept of "diagonal air transmission" is portrayed both by Uuttu and the journal "Space Modulator", (1999). *"In box double-skin façades, a unique sash termed a "fish-mouth" planned to allow inside and exhaust outside air is usually* *built in between storeys. This idea also has air channels in and out. Air from outside intake via "fish-mouth" is heated within the double-skin and conveyed upward to be exhausted from the outtake "fish mouth" at the neighbouring sash. If both the "fish mouths" are placed out vertically, a considerable part of the exhausted air would have been reabsorbed. This system also precedes the dissemination of fire to other levels".*

- **Shaft Façades:** *"This system is a composition of a double skin façade with a building-high air corridor and the other with a storey-high air corridor. The building-height air cavity produces a central vertical shaft as an outlet for the exhaust air. The exhaust air drains from the storey high air space into the main vertical shaft. Then it ascends, due to the stack influence and escapes thru the top outlet. This air flow is supported due to optimism in the shaft at the lower floors level as the trapped air is ascends to be drained after being heated".*

Arons, (2000) labels two distinct facade compositions namely:

- ***Airflow facades****: this façade system is continuous for at least one storey with its inlet at or below the floor level of one storey and its exhaust at or above the floor level.*
- ***Airflow window****: a façade with double leaf that has an inlet and outlet distanced at an interval of less than the vertical spacing between floor and ceiling.*

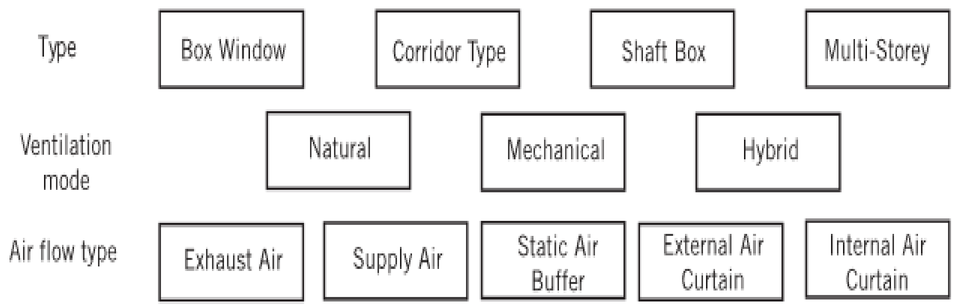


Figure 6: *Graphical methods of double skin façade classification*

2.4. ADVANTAGES OF DOUBLE SKIN FACADES

There are numerous merits behind using Double Skin Facades over the conventional

Facades portrayed in the sequence below:

- Lower Construction Cost:

In comparison to various solutions that can be furnished via employing specially treated glasses like thermochromic, photochromic, electrochromic among other panes (their qualities transform according to environmental and the climatic conditions of the region). Although these panes can be very promising, they are very expensive. Inversely, Double Skin facades can attain a quality of variability thru a coordinated combination of components which are both known and available.

- Acoustic Insulations:

Based on some authors' perception, the acoustic insulation can be one of the highly important rationales to use a Double Skin Façade. Degree of the interior nuisance can be minimizing inside an office building decreasing both the room to room sound transmission (interior nuisance) and the transmission from exterior sources (external nuisance). The acoustic insulation concerning the internal and the external nuisance can be attained by adopting this Double Skin Façade especially if incorporated with the quantity of openings which can be indeed very vital.

Jager, (2003) stated that for an acoustic insulation, 100 mm has to be proposed as minimum value. Faist, (1998) indicated in a report written about calculating acoustic aspects of Double Skin Facades. Both calculations and real measurements are presented in this report. Finally, acoustic performance was thoroughly reported in Oesterle et al., (2001).

- Thermal Insulations:

Many authors cited that the DSF System can produce with optimum thermal insulation for the presence of its outer skin both in winter and in summer periods.

- ❖ **During the winter**, the exterior supplemental skin provides improvement; during the heating period the results will improve if the intermediate space (cavity) is closed (partially or completely). The reduced speed of the air flow and the increased temperature of the air inside the corridor drop the degree of heat transference on the surface of the glass which results in heat losses reduction. Has the effect of maintaining higher temperatures on the inside part of the interior pane. Oesterle et al., (2001) depict how the thermal performance can be enhancing by portraying how the best proportion of the opening area should be.

During summer, the heated air within the intermediate corridor can be removed when it is mechanically or naturally ventilated. As Lee et al., (2002) label it, *"as re-emission of the heated air from absorbed radiation is discharged into the air space, a natural stack effect results, which causes the air to rise, taking with it supplemental heat"* For the cavity to be properly ventilated, it is very vital to carefully select the combination of the type of the panes and the type of shading elements so that the air cavity is not overheated and hence the interior space.

- The cavity should be carefully designed for the role it plays, in terms of its width and height and also the openings ratio can be essential for the intermediary temperatures and for the airflow (in situation whereby the cavity is to be ventilated naturally). Shading elements should be properly mounted for effeciency. Lee et al., (2002) depicts the best position of the shading elements (as they claim, it should be placed in the outer half of the intermediate space).

Stec et al, (2000) claim that "*half of the inner façade should be insulated if comfort with natural ventilation is the objective. Otherwise mechanical cooling should be applied".*

- Night Time Ventilation:

During the hot summer days, when the external temperature is more than 26°C there is a possibility that the interior spaces may be easily overheated. In this situation, the offices at the night can be naturally ventilated, thus the pre-cooling energy is saved. During the early morning hours, the temperatures within the indoor spaces will be little, hence increased air quality for the occupants producing thermal comfort. The utilization of natural night time ventilation as well, affects the reservation of heat of the surrounding materials (walls, ceilings, and other furnishings). If windows and doors are closed and on the other hand mechanical ventilation systems cease to work at night, the heat will be trapped inside causing distress within the interior during early morning hours. The prime merit of the Double-Skin Facades is that natural night ventilation can be realized, and protected against the outdoor weather.

"Double-skin facades have been configured to allow for night time ventilation, with the reasons of security and rain protection cited as main advantage", Lee et al, (2002).

"Natural cross ventilation during the night cooling demands large openings in the exterior façade (for example open junctions between the panels with at least 2% of the floor area an operative opening)", Stec et al, (2000).

- Energy Savings:

Fundamentally, Double-Skin Façades can save energy when efficiently designed. Habitually, energy savings that can be achieved due to the additional facade may seem inspiring when the conventional insulation of the exterior wall is reduced. *"Where DSF constitute window ventilation possible, energy savings can be largely attained or where the period in which natural ventilation can be achieved was substantially extended. By avoiding a mechanical air supply, costs for electricity can be reduced. This will greatly exceed the savings mentioned before"* Oesterle et al., (2001).

Arons, (2001), cited that *"energy savings attributed to Double Skin Facades are attained by minimizing heating load at the area of buildings. Providing low solar factor and low U Value minimizes cooling load of adjacent spaces".*

- Thermal Comfort:

Compared to the outdoor air temperature, the air within the DSF cavity is warmer during the winter period; the internal ration of the façade can upholds heats that are more close to the levels of thermal comfort. Likewise, during the summer it is really crucial that the system is well planned so as the temperatures within the intermediate space will not increase excessively. Appropriate composition of DSF configuration and type, size of openings, type as well as the location of sun shading elements and pane types can assure enhanced results for all climatic regions and all types of building.

Low Solar Heat Gain and Thermal Transmission:

The two principle merits of the DSFs are; the effective thermal transmission (U-Value), and the little solar heat gain (g value), Kragh, (2000).

Table 1 below highlighted some advantages of DSF as mentioned earlier in different literature sources.

Table 1: Advantages of DSF

Advantages mentioned by author	Oesterle et al., (2001)	Compagno, (2002)	Claessens et al.	Lee et al., (2002)	B.B.R.I., (2002)	Arons, (2000)	Faist, (1998)	Kragh, (2000)	Jager, (2003)
Lower construction cost (comparing to electrochromic, thermochromic photo-chromic panes)	√								
Acoustic insulation	√			√		√	√	√	√
Thermal insulation during the winter	√	√		√	√		√	√	
Thermal insulation during the summer	√	√		√			√	√	
Night time ventilation	√	√	√	√		√			
Energy savings and reduced environmental impacts						√			
Better protection of the shading or lighting devices	√	√		√					√
Reduction of the wind pressure effects	√	√	√						√
Transparency – Architectural design				√	√	√		√	
Natural ventilation	√	√		√		√	√		√
Thermal comfort – temperatures of the internal wall	√	√		√	√	√	√	√	
Fire escape	√								
Low U-Value and g-value		√				√		√	

Source: Harris Poirazis (2006) "*Double Skin Facades*"

2.5. DISADVANTAGES OF DSF

The demerits of DSF system mentioned in literature are highlighted in the sequence below:

- Higher Construction Cost:

In comparison to a conventional façade, *"there is no any dispute in saying that* *double skin facades are more costly than single skin forms: the process of construction of the external skin and the intermediate space between the two skins forms the former type more sophisticated"* Oesterle et al., (2001).

- Supplementary Maintenance Cost:

Equating the Double Skin to the Single Skin type of façade, one can easily see that the Double Skin type much costly in terms of construction, operating, and maintenance expenses. Oesterle et al., (2001) highlighted method of estimating the costs and expenses and described it extensively.

- Overheating Problem

As earlier highlighted, if the Double Skin Façade system is not properly designed there may be tendency that the temperature in the air cavity to rise, thereby excessive heating the internal spot. To defeat excessive heating, the distance between the intermediate air cavities should not be less than 200 mm according to Jager, (2003). Compagno, (2002) mentions that, the crucial criteria to be stick to include: cavity width and the extent of the ventilation openings.

- Daylight

The daylight features of DSF are identical to other types of glazed facades (i.e. single skin façade). Oesterle et al., (2001) moreover differentiate Double Skin Facades from others by concentrating specifically on the points below. As the authors describe, *"these include*:

- *The reduction of the quantity of light entering the rooms as a result of the additional external skin and*
- *The compensatory effect of huge surfaces of glazing".*

Table 2: Disdvantages of Double Skin façade

Disadvantages mentioned by author	Oesterle et al. (2001)	Compagno (2002)	Claessens et al.	Lee et al. (2002)	B.B.R.I. (2002)	Arons (2000)	Faist (1998)	Kragh, (2000)	Jager (2003)
Higher construction costs	√				√	√			√
Fire protection	√				√				√
Reduction of rentable office space	√								√
Additional maintenance and operational costs	√		√		√				√
Overheating problem	√	√			√		√		√
Increased air flow speed					√				
Increased weight of the structure			√						√
Daylight	√								
Acoustic insulation	√				√				√

Source: Harris Poirazis (2006) *"Double Skin Facades"* A literature Review

2.6. EXAMPLES OF DOUBLE SKIN FAÇADE IN HOT ARID CLIMATE

Heat prevention is of prime concern in warm climates as a means to moderate energy usage and deliver comfort to dwellers. The office building in Dubai for example uses horizontal shading to cut down on solar gain. Abu Dhabi, for instance, is situated at 24.43^{0} north of the equator. The prediction necessities for south façade screening are marginal when equated to the desires for latitudes advance north. It is probable to realize good veiling safeguard for the façade by basically expending the annoyed cleaning and preservation platform that is customarily delivered in wide-ranging air corridor double façades, without necessitating supplementary louver shading elements in the cavity as is more common in northern regions. The west and east façades of tower type buildings in specific posture a greater tricky as they cannot be functioned by meeker horizontal methods that are effective for glazing facing south with excessive sun angles (when reflect structures in the north of the equator).

Double façades in hot climate can be roughly distributed into two types (Terri Meyer Boake, 2012):

1. Those that employ shielding screen as the exterior face combined with a extraordinary performance screen wall method as the interior sheet of the façade, in which;

- A subsequent layer of glass is not used to offer the exterior layer.
- The sheets are likely to be detached by a widespread air corridor to offer access for spring-cleaning.
- The exterior shielding layer is either fixed or responsive.
- The shielding layer must be very strong to endure acquaintance to the components as well as dusting.

2. Those that practice a more customary approach (twin-face, extract-air or buffer,) where the outer sheet glazed and where;
    - The air passage is typically extensively sufficient to permit dusting access without intrusion in the inner spaces.
    - The air passage is used to shield the temperature excesses.
    - The air passage may not or may produce part of the freezing organism.
    - The screening devices are not customarily situated in this cavity if it is not closed.

Somewhere the cavity or air corridor is not airtight and outdoor air would be tolerable to move in the corridor, this would allow airborne sand particulates to accumulate and would result in cleaning issues. The open nature of the new screen type exterior layer that is situated between one and 1.5 meters starting in the main curtain wall aids stress-free access for core cleansing, which will be necessary as the exposed nature of the curtain will permit expressively more deposits to occur.

The absenteeism of shading strategies in the air corridor distinguishes the warm climate double façade type from moderate or cold climate consequences where some shielding materials are purposefully positioned in the cavity as a means to protect them.

Subsequently, here are various examples of inventive uses of double façade methods in hot climate places, primarily in the Persian Gulf area, nevertheless without numerical data to support their performance as nothing is available and is doubtful assumed the nature of the private ownership of the buildings.

2.6.1. ARCAPITA BANK HEADQUARTERS, MANAMA, BAHRAIN.

Table 3: Arcapita Bank Headquarters

Building:	Arcapita Bank Headquarters,
Architect:	SOM Associates.
Project Location:	Manama, Bahrain.
Project Year:	2009
Building Illustrations:	
Building Façade(s) / Building skins	Interior skin: Glass curtain wall, fully glazed. Exterior façade: glazed curtain wall.
Building type:	Commercial /Office Building
Building Size	10-storey building, Height =(48 meters) Area: 42,000 square meters.

The Arcapita Bank headquarters, Manama, Bahrain designed by SOM Associates uses a double façade system to simultaneously provide an exterior system and shading.

In this occasion, the building offers dwellers with the impress of a wholly glass façade building without the extreme heat gain.

In the upper part of this building accommodates some offices covering the area of 18,500 square meters with intense glazing that provide pleasant view to the outdoor activities. Benefit can be derived from this solution for its easiness in installation and consequently inferior maintenance costs. The louvres are placed between double-skin air gaps to help in mitigating solar heat gain.

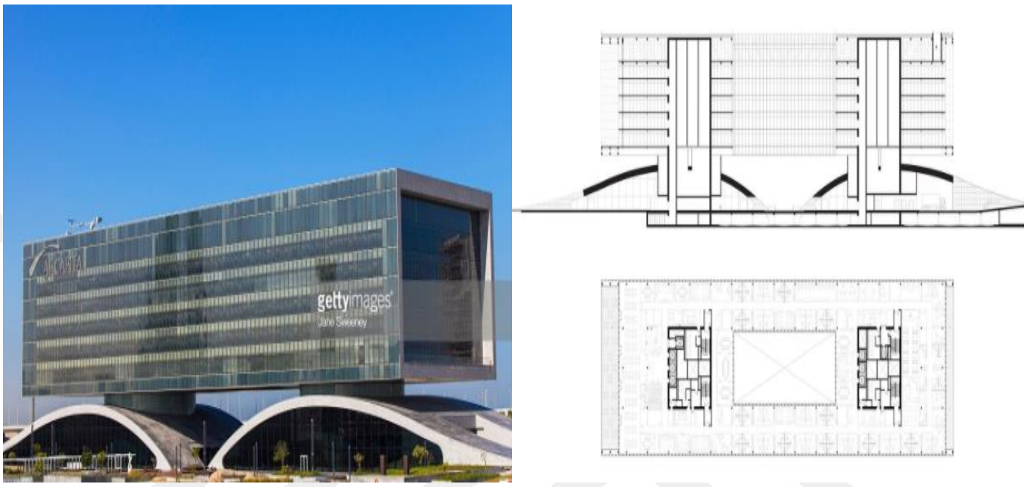


Figure 7: The Perspective view of the building and the bank layout, and the longitudinal section at the top of the floor plan. **Source:** SOM Associates.

2.6.2 CLEVELAND CLINIC, ABU DHABI | HDR ARCHITECTURE

The double façade system used on the Cleveland Clinic in Abu Dhabi differs from others in the region in that case; it is not aimed to lay emphasis on the donation of shading and utilizes a distinction of an extract-air and a buffer double façade system. The facility has been planned agreeing to LEED Gold TM philosophies and the designers feel that this specific double façade presentation to be the first ever used in a hospital. The double façade cavity should be designed in such a manner a free opening is provided to form a duct effect, so that the building has an inlet and outlet for airflow along the cavity. The technique works by employing the mechanical floor at the lowermost of the hospital tower, draining cool air earlier used inside the hospital from the bottommost of the tower to the chimney between the double screen wall which warms and increases by chimney effect thru to the roof. This exhaust generates a defensive buffer between outdoor air and the inside of the building. The air within the building is cooled in a triple approach via sea water, heat retrieval, and used cool air exhausted thru the 1.5 m wide-ranging air corridor space.

The shielding system in this situation is not located in the cavity but moderately on the interior for easy inhabitant control. The double façade method is identical on all directions of the hospital to offer shielding of the great temperatures to entire façades.

The double façade method is anticipated to moderate the cooling expenses of the patient tower building by nearly 33% due to a decline in the cooling masses.

The dusting and maintenance of the air corridor will take place from within the corridor as the 1.5 m width will accommodate this activity.

Figure 8: Cleveland Clinic, Abu Dhabi.

Figure 18b: *The Cleveland Clinic, Abu Dhabi.*

Table 4: Cleveland Clinic, Abu Dhabi

Building:	Cleveland Clinic, Abu Dhabi
Architect:	HDR Architecture
Project Location:	Business Bay, Dubai, United Arab Emirates.
Project Year:	2012
Building Illustrations:	
Building type:	Hospital (Clinic)
Building Size:	Area: 409,234 m^2 Height: 23- floors
Building skin:	Interior skin: Fairly standard sealed rectilinear glass curtain wall System. Exterior façade: Diamond shaped glazing layer which is connected to the cable.
Cavity depth	Building-height (1.5meters)

2.6.3. TEL-AVIV UNIVERSITY NANOSCIENCE CENTRE

Tel-aviv University Nanoscience Centre is a compressed building of cubic form, similar to a diamond and revolved at 45^o. A cost-effective land mark structure well-assimilated into the predominant green environment and the confined urban context. Sitting on a crucial spot, a cross point at the main pedestrian axes, and a reference for the East gate to balance the whole area together with the Natural History Museum. A building that will function as a firsthand place for Nanoscience and Nanotechnology that will involve inspire and inspire diverse spectators and re-define the model of the laboratory building by crafting flexible and modular laboratories enhanced by a substantial space for communication and cooperation.

The Façade was a glazed envelope sheltered and enclosed by a second white external skin, comprising of an effective grid of vertical and horizontal constituents intermingling utilizing the core configuration of the building.

Basically, it consists of reinforced concrete rectangular 25 cm columns systematized in two crowns, one on the exterior incorporated with the façade, and an internal one; use of a post-stressed configuration declines the total weight, pressure on foundations and the structural expenses by escaping virtually any kind of vertical structure.

Figure 9: Tel-aviv University- Nanoscience Centre. OAB-FERRATER & ASSOCIADOS (2012)

Figure 10: Tel-aviv University- Nanoscience Centre. OAB-FERRATER & ASSOCIADOS (2012)

The façade geometry is motivated by a shape made up of a medium of similar features and vertical lines forming a skin nearby the building that acts as a load-bearing exoskeleton and a means to control sunlight and the connection between the interior and the exterior.

Figure 11: Tel-aviv University- Nanoscience Centre. OAB-FERRATER & ASSOCIADOS (2012)

Figure 12: A cross-section- Tel-aviv University- Nanoscience Centre. OAB-FERRATER & ASSOCIADOS (2012)

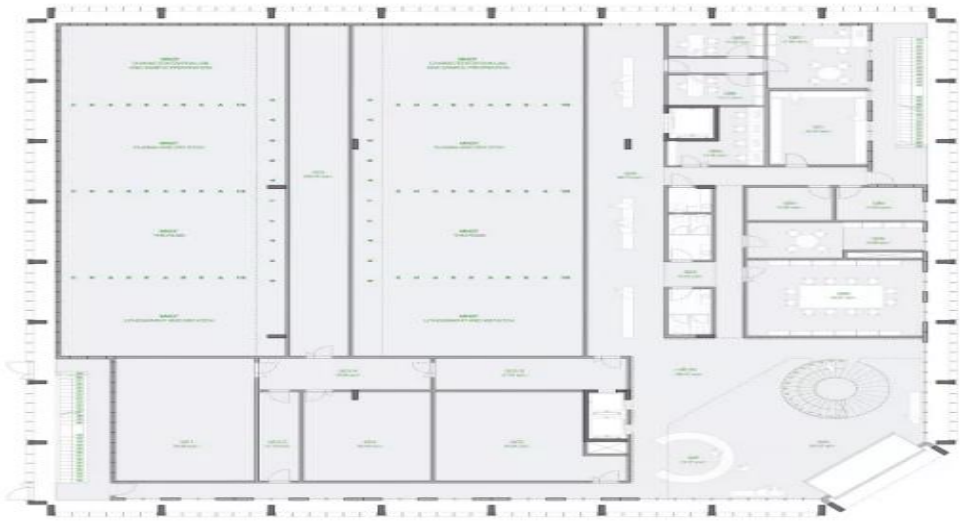


Figure 13: Ground floor plan- Tel-aviv University- Nanoscience Centre. OAB-FERRATER & ASSOCIADOS (2012)

Table 5: Tel-aviv Nanoscience & Nanotechnology Center

Building:	Tel-aviv Nanoscience & Nanotechnology Center
Architect:	QAB-FEERATER & ASSOCIADOS
Project Location:	Tel-aviv University, Israel.
Project Year:	2012
Building Illustrations:	
Building type	Academic / Research Building
Building size:	5-Storey building and a basement floor
Building Skins	Interior skin: Glazed curtain wall Exterior façade: White exterior skin consisting of an efficient grids that form load bearing exoskeleton.

2.6.4. SOWWAH SQUARE, ABU DHABI, UNITED ARAB EMIRATES

Goettsch Partners has designed a 529,360 m^2 development with climate response strategies for the envelope. The building utilizes a double skin façade system with cavity mechanically ventilated to create a shield zone to provide guard from the severe outdoor environment in Abu-Dhabi. At Sowwah Square (Figure 19) the double skin façade type is a multi-story starting from the fourth floor to the top of the building. An active solar shading system is integrated on the exterior surface of the cavity and can track the sun to optimize the shading. The shading system helped to prevent the intermediate space from overheating because it has minimized the projected solar energy on the intermediate space. “Utilizing an outboard lite with a very high shading coefficient, the design team was able to effectively block 76 percent of the solar energy from ever entering the air cavity.” (Soberg, 2008)

Taking the exhaust air from office spaces and injecting it back to the cavity to flush out the warm air was used to achieve getting the intermediate buffer zone. According to (Soberg 2008) “Through these efforts, the design team expects the double-skin cavity to be an average temperature of 89º F (31 ºC) when the exterior temperature extents 115º F (46 ºC). This will permit the great U-value of the shielded internal glazing to more simply block the air cavity’s radiating energy.

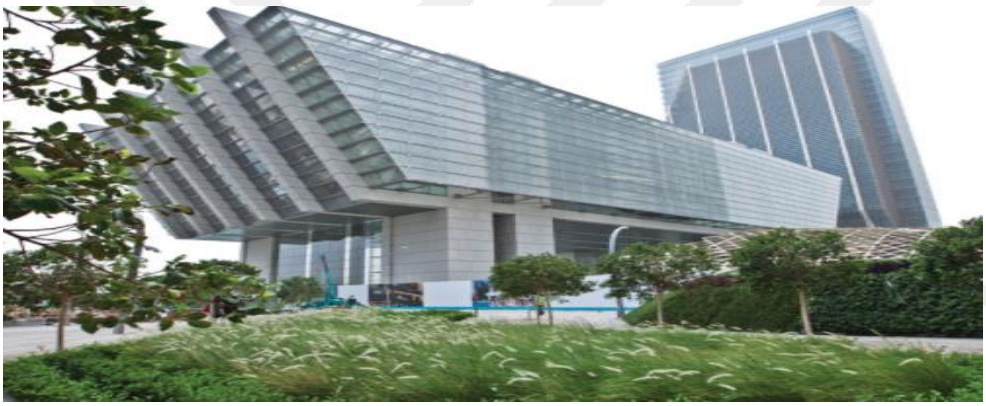
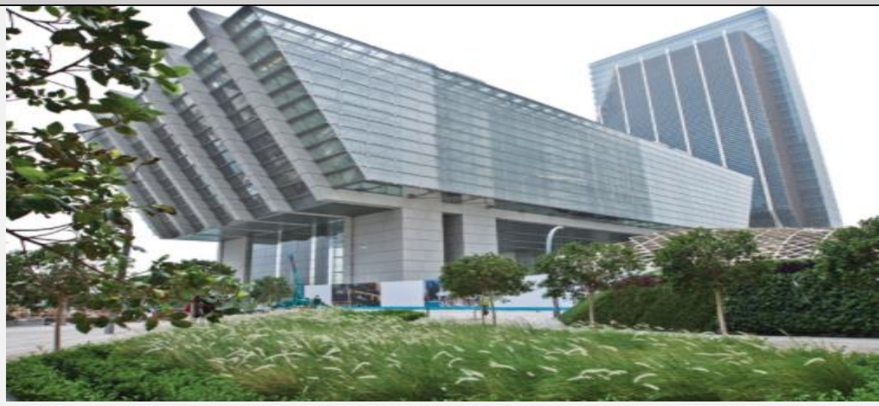


Figure 14: Sowwah Square Building, Abu Dhabi UAE. **Source:** Soberg, 2008.

Figure 15: Sowwah Square Building, Abu Dhabi UAE. **Source**: Soberg, 2008

Table 6: Sowwah Square Building

Building:	Sowwah Square Building
Architect:	Architects Goettsch. Partners
Project Location:	Abu Dhabi United Arab Emirates
Project Year:	2013
Building Illustrations:	
Building type	Commercial Building
Building size:	Area = 450,000 sqm.
Building Skins	Interior skin: Glazed curtain wall Exterior façade: High performance glazed curtain wall with sun shades (louvres).

2.6.5. JOHN HANCOCK-601 CONGRESS, BOSTON MA, USA.

This building is attractive on several accounts. The building was the first illustration of this type of double skin structure in the US, the whole envelope is a double skin as contrasting to one elevation of the building, and it is purely a very attractive object in person.

The facade structure made-up by Permasteelisa is an 8 inches "energetic" facade. The outdoor light is a 1 inch shielded glazing unit. The inner is a single 3/16 inches unit. Air Condition drawn from the engaged space thru a sieved slot in the base of the wall at every floor, moves up between the glass entities and drawn out through a hole to the reoccurred air plenum. Through periods of great hotness gain, operable shades which inhabit the space between the 2 glass entities seize solar radiation afore it reaches the engaged space. The heat is carried out through the flow created by the plenum draw.

A six storey foyer takes up the bulk of the south façade of the building. The outdoor glazing of the foyer is shielded entity and the walls of the office space opposing the foyer are the single glazed entities, as if the distinctive wall had peeled apart to constitute the occupiable space.

Table 7: John Hancock- 601 Streets Congress

Building:	John Hancock -601 Street congress
Architect:	HDR Architecture
Project Location:	Boston MA, USA.
Project Year:	2003
Building Illustrations:	
Building type:	Office Building
Building Size:	Area: 617,253 square feet Height: 6-storey building
Building skin:	<u>Interior skin</u>: The interior is a single 3/16"glass unit <u>Exterior façade:</u> The exterior skin is a 1" insulated glazing unit.
Cavity depth	Building-height (1.5meters)

Figure 16: John Hancock 601 street, Boston MA, USA. **Source:** HDR Architecture

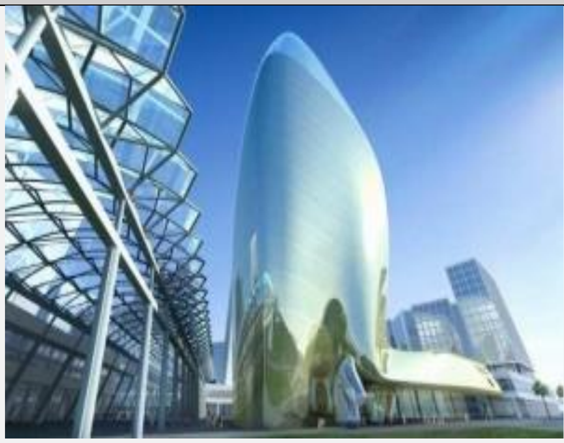
2.6.6. ZAHA HADID ARCHITECT'S BUILDING, ABU DHABI, UAE.

The new building in central Abu Dhabi is a building with a double skin façade in either of the internal and the external skin. This building is glazed fully and curved in shape and comprises a 17 storeys with an approximate floor area of 15,000 square meter designed by Zaha Hadid Architects and the upper most floor of the building is designed as a special restaurant.

The exterior skin is single glazed with special properties. The interior skin is double glazed with a gap in between (60 cm – 80 cm) incorporated with motorized blinds to reduce the solar gains. (Yagoub, Appleton and Stevens 2010)

Figure 17: Zaha Hadid Architect's Building, Abu Dhabi United Arab Emirate. **Source:** Yagoub, 2010.

Table 8: New office building, Abu Dhabi

Building:	New office building, Abu Dhabi.
Architect:	Zaha Hadid Architects
Project Location:	Abu Dhabi, United Arab Emirate
Project Year:	2003
Building Illustrations:	
Building type:	Office Building
Building Size:	Area: 15,000 square meters Height: 17-storey building
Building skin:	Interior skin: The interior skin was 8mm thick clear laminated glass Exterior façade: The exterior skin was 10mm thick pyrolithic Coating with gold.
Cavity depth	Building-height (60 cm – 80 cm)

2.6.7. SUPREME AUDIT COURT, TEHRAN, IRAN:

According to a study carried out by (Hashemi, Fayaz and Sarshar 2010) on the 12-storey Supreme Audit Court building in Tehran, Iran, which has a double skin throughout its four facades (as shown in figure 28 below) by adopting onsite measurement for the period of fourteen days during summer and winter to examine the behavior of double skin façade during the fore mentioned seasons. The outcome of the finding indicated that the surface temperature differences between the exterior and the interior and the air in between these skins can reduce required heating energy in winter. Cooling loads in summer can be decreased by applying additional techniques such as night ventilation and utilizing shading devices.

Table 9: Supreme Audit Court

Building:	Supreme Audit Court
Architect:	
Project Location:	Tehran, Iran
Project Year:	2007
Building Illustrations:	
Building type:	Court Building
Building Size:	Area: ….. Height: 12-storey building
Building skin:	Interior skin: The interior skin clear laminated glass Exterior façade: The exterior skin was glazing
Cavity depth	Building-height (1.2 meters)

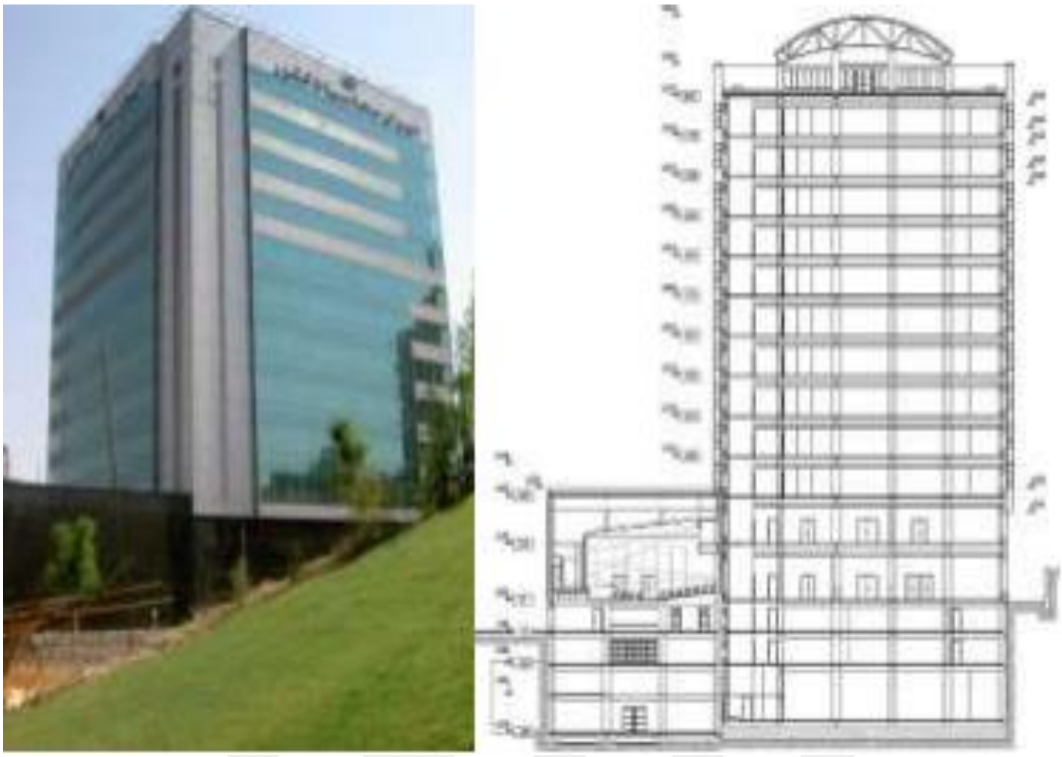


Figure 18: Supreme Audit Court, Tehran, Iran (on the left is the Perspective view and the cross-section by the right). **Source:** Hashemi et al. (2010)

CHAPTER – 3
THESIS METHODOLOGY

This research is based on quantitative and observational approach for evaluating the performance of office building with double skin façade in hot and arid climate. This chapter furnishes us with knowledge on how the study was conducted in order to meet the earlier mentioned aim and objectives (1.3). This chapter covers the research design, strategy and method adopted in accomplishing this dissertation thereby contextualizing the methodology and justifying their use to the research. This chapter also conveys issues like reliability, validity, replicability, limitations, constraints and how these negative effects could be minimized in the research process.

To realize the optimistic configurations for double skin facades in hot and dry climatic regions, a dynamic thermal and daylight simulation analysis should be used to enquire about the double-skin façade performance and its operating components. The study tested several effective variables on a hypothetical building model in Kano city, Nigeria. The research aimed at evaluating the illumination and energy performance of a baseline double skin façade case with and with multiple configurations.

3.1. DESIGN STRATEGIES IN HOT AND ARID CLIMATE

Climatic factors greatly influence on the building performance specifically daylight as well as its energy consumption. Decreasing energy consumption, via natural resources and producing healthier, comfortable, and sustainable living functions are the aims of a climatic- responsive sustainable building design (Hui 2000). Viable design and construction approaches are of pronounced importance these days. One may say that sustainability was previously a motivating potency, revealing its rationality thru the various forms and procedures used. Consequently, from those days till today, there are no sufficient transformation in difficulties and necessities encountered in design and construction environment; however several developments have been realized in terms innovative technologies and modernization of materials. Consequently, all-inclusive deliberation on building process should be ensured. Moreover, climatic- responsive design, choice of materials and building performances need to be assessed together and the final product should accomplish well during its lifespan.

3.2. DATA ACQUISITION

Data is acquisition for this research was according to (Gliner, Morgan & Leech, 2000) approach, they categorized research design into:

i.) Exploratory (user perception)

ii.) Descriptive (case studies)

iii.) Experimental (simulation)

Personal interview practiced and questionnaires were administered as basic source of data to determine the indoor conditions within the selected building under study. Data in relation to building location, materials configuration were gathered through the earlier mentioned mechanism. To achieve the targeted results, the workflow indicated in figure below should be adhered to while conducting the simulation experiment.

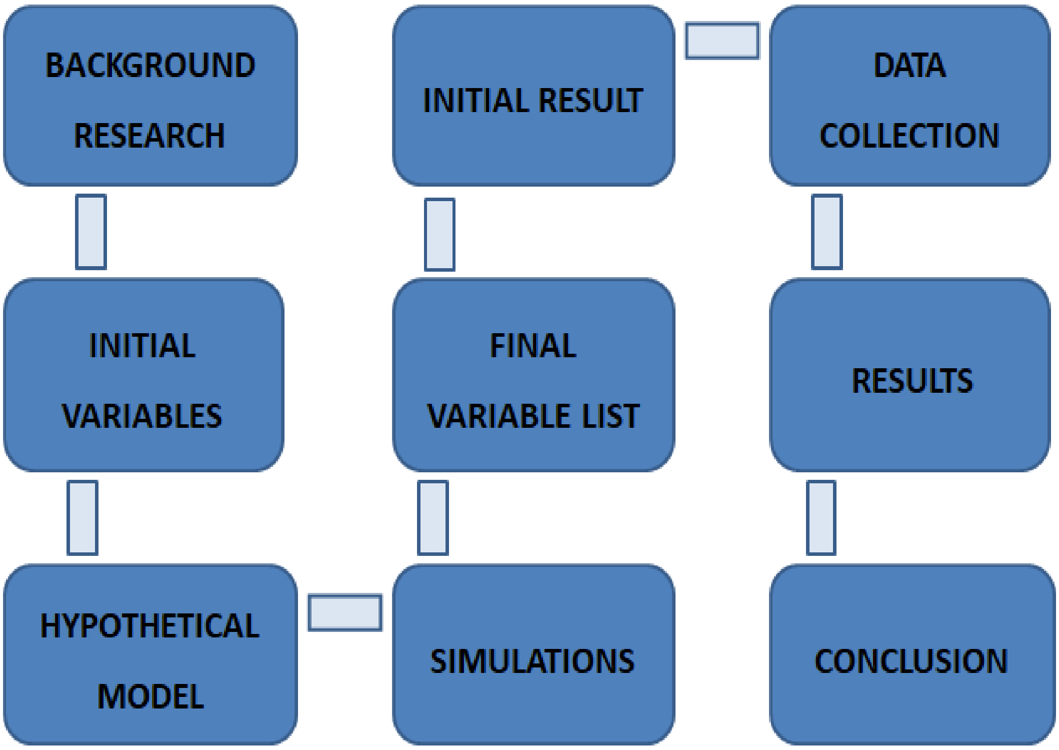


Figure 19: Methodology Workflow

3.3. INSTRUMENT OF DATA COLLECTION

In Architecture, case for theoretical research may require the adoption of general methods of data collection (Oluigbo, 2010). During the data collection process, it is vital do adopt as many instruments as possible. The instruments used for data collection include:

1.) Physical survey

2.) Drawings

3.) Interview / Survey Questions

4.) Computational tools (simulations)

3.3.1. QUESTIONNAIRE DESIGN PROCESS

Before the questionnaire administration, it is necessary to carefully plan and design it logically. The figure below shows the sequence of developing the survey questions;

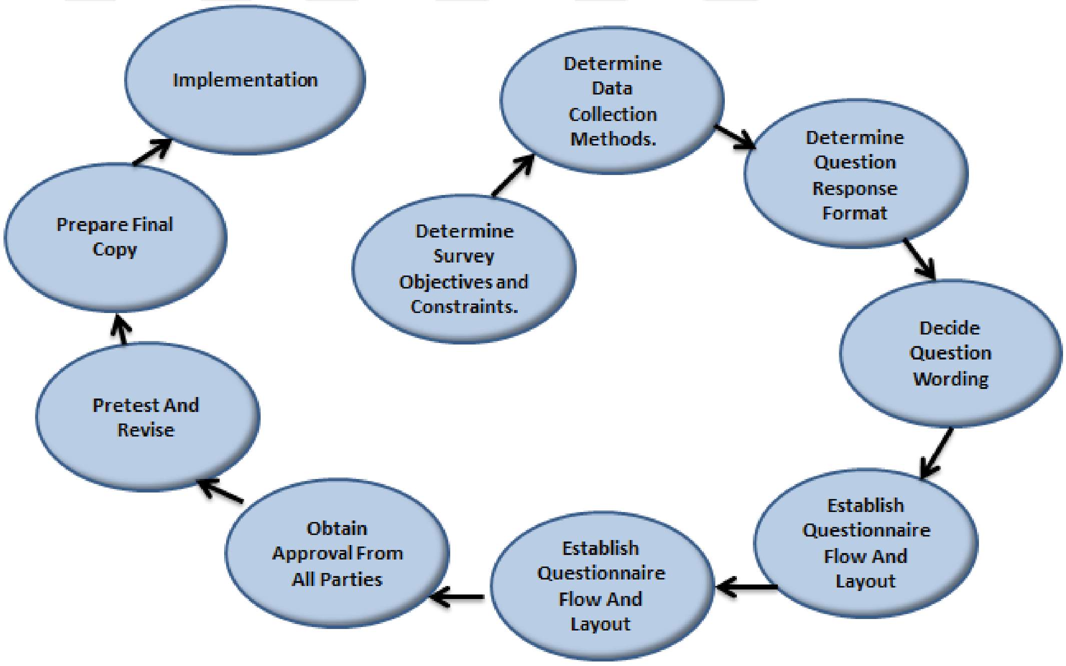


Figure 20: Questionnaire Design Process.

3.3.2. SURVEY QUESTIONS ADMINISTRATION PROCEDURE

Based on the final stage of the above mentioned Figure, one hundred and fourteen (114) Questionnaires were administered to both the Staff and Customers using the building under study. These Survey questions were successfully shared by the Researcher with the aid of one other person who happens to be a staff within the building under study. After reasonable period of time, responds were obtained from various respondents only twelve (12) out of one hundred and fourteen (114) questionnaires were not received yet bringing the total number of questionnaires returned to one hundred and two (102).

Some challenges encountered in the course of administering the survey questions include the difficulty of some respondents especially the customers' side to respond to the survey questions, although the survey questionnaire was designed in such an interesting way that can easily be answered and be filled logically. Some of the respondents were not willing to accept the survey questions and to some extent some of the staff also refused to welcome the survey. Moreover, in the course of this survey some of the respondents exhibit some degree of misunderstanding the aim of the survey but notwithstanding, they responded to the questions as much as possible though there were some of them who required interpretation of some questions before they were able to respond to them.

3.4. LADYBUG + HONEYBEE SIMULATION TOOLS

The method to be adopted for evaluating the energy performance and natural daylight within the office building under study is Honeybee and Ladybug which also would allow for the visualization of Energy and daylight Simulations results as well as some visual information about the study location in terms of Temperature, Sun paths Relative humidity among others.

3.4.1. ENERGY SIMULATIONS

The methodology embraced in this investigation aimed to show the efficiency of employing the parametric approach in generating diverse alternatives, assessing and donating their performance. This method could overlay the way to the generation of inventive and exceptional design ideas. The workflow established in this research began with the generation of 3D model of the office building by means of a three dimensional parametric modeler tool called "Grasshopper", which is plug-in for Rhinoceros. Other environmental analysis plugins adopted are Ladybug + Honeybee. Ladybug Apparatuses is an association of free computer applications that upkeep environmental design and application of all existing environmental design software parcels. Ladybug tools help in connecting 3D Computer-Aided Design (CAD) interfaces to the prior stated simulation engines. Ladybug Tools uses weather data analysis to aid the parametric workflow of innovative simulation process and is very vital in analyzing the energy performance of a building.

3.4.2. DAYLIGHT SIMULATIONS

Ladybug and Honeybee are important design tools that permit designers to have answers to very significant environmental questions in the initial phases of a project when there is the greatest design flexibility and potential impact. Via these tools permits the design teams to demonstrate composite environmental features and visualize how our designs react to those factors. This iterative parametric procedure is crucial to meet each project's distinctive performance goals where form follows performance and is used to determine daylight performance of a building.

3.4.3. DIAGAMMATIC FLOWCHART OF GENETIC ALGORITHM

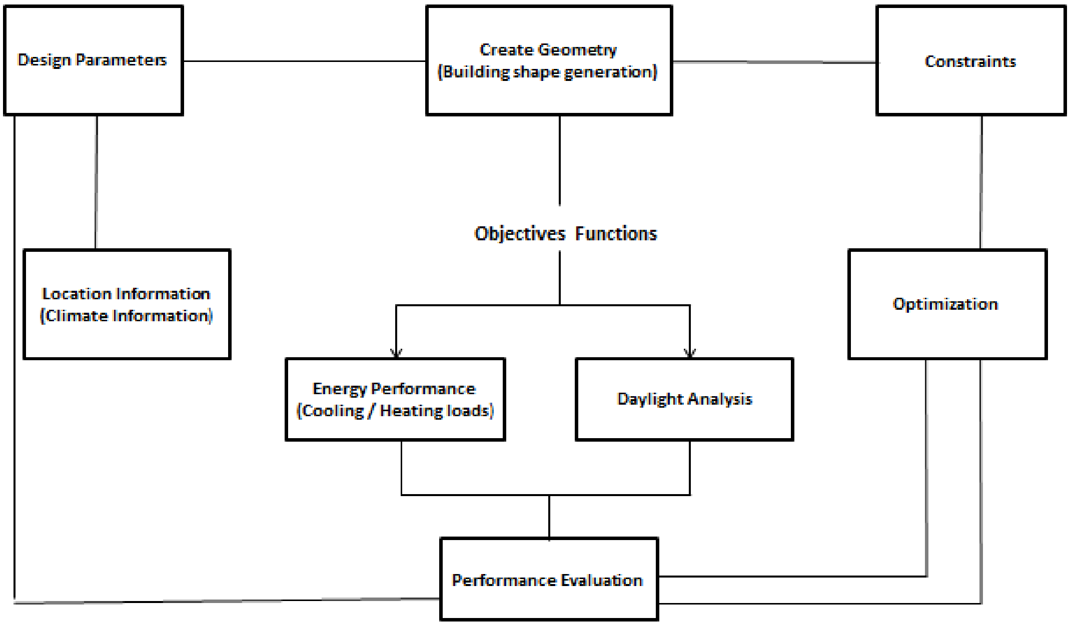


Figure 21: Ladybug + Honeybee Energy/Daylight Genetic Algorithm flowchart

3.4.4. DESCRIPTION OF PARAMETRIC MODEL AND DECISION VARIABLES

The Parametric model developed for an office building comprised Double-skin glazed facades with aluminium mullions with an air cavity between them. The parametric model allows for changing the glazing configuration (glazing type and ratio), and the change of different time that produce different values based on the predominant weather. All the decision variables are changeable using some intervals and were fixed with minimum and maximum values limits as indicated in the (Table 10) below. These variables allow for the Month, Day and Time to be adjusted. The glazing properties were made in such a way that they can be changed based on the glazing type including the thermal transmission (U- Value), the Solar Heat Gain Coefficient (SHGC) and the Visual Transmittance (VT).

Table 10: Parametric decision variables and extent of their values

Variables	*Minimum Values*	*Maximum Values*
Glazing Type	1	3
Cavity Depth	500 cm	2M
Month	January	December
Day	Day 1	Last Day of the Month
Time	8:00 AM	6:00 PM

3.4.5. HONEYBEE:

Similar to Ladybug, it is an open and free basis plugin to link Grasshopper3D to Energyplus, Daysim, Radiance and OpenStudio for building Daylight and Energy Simulations. Comparable to Ladybug, Honeybee is intended to run the analysis based on building masses though for more innovative studies. The workflow is aimed for designers so comparable to several other tools and their values are set as default even though for some other tools, user can overwrite all the default inputs.

The connection between Grasshopper as the graphical user interface design environment and the validated simulation engines was made possible via Honeybee. These Simulation appliances as mentioned earlier include; EnergyPlus, OpenStudio, Radiance, and Daysim which assess the energy consumption of the building, daylighting and thermal comfort. Honeybee also facilitated connectivity between these validated (Daysim, Radiance, EnergyPlus and OpenStudio) simulation engines and, Grasshopper graphical programming interface.

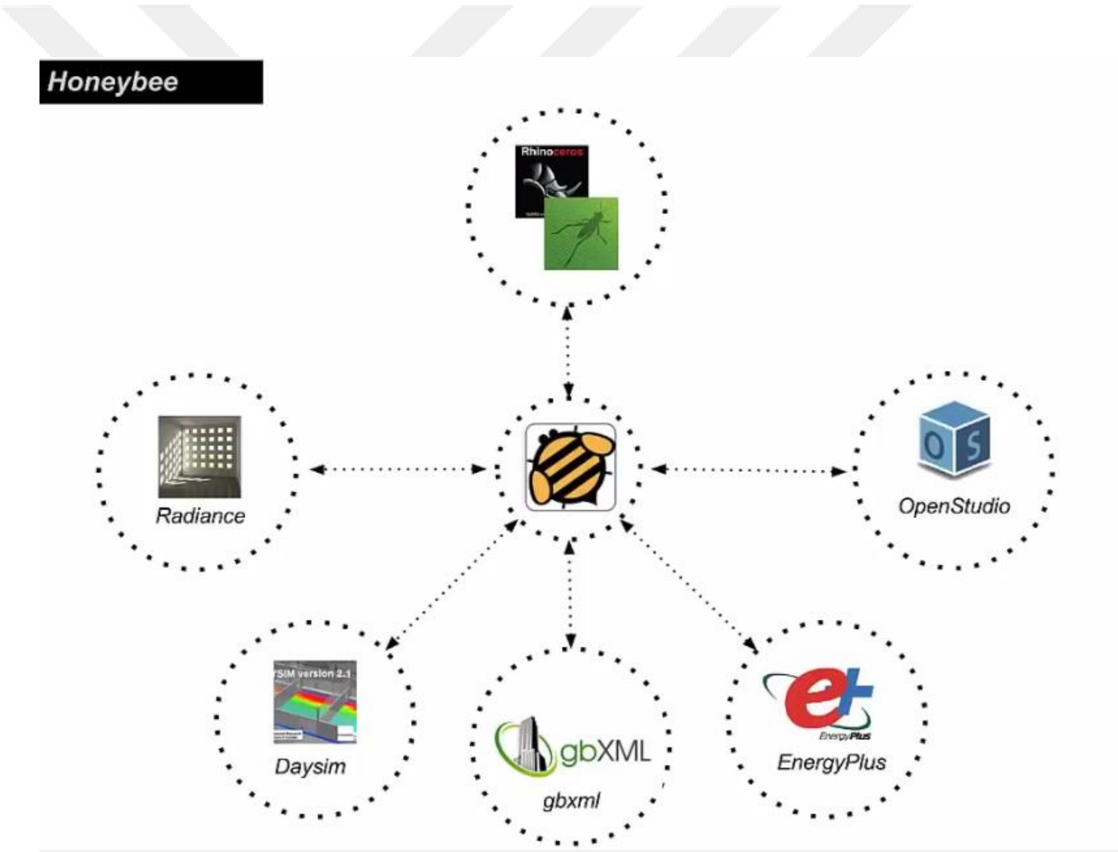


Figure 22: Ladybug + Honeybee connectivity to Energy and Daylight Simulation Engines. *Source: www.mebd-penndesign.info/honey.*

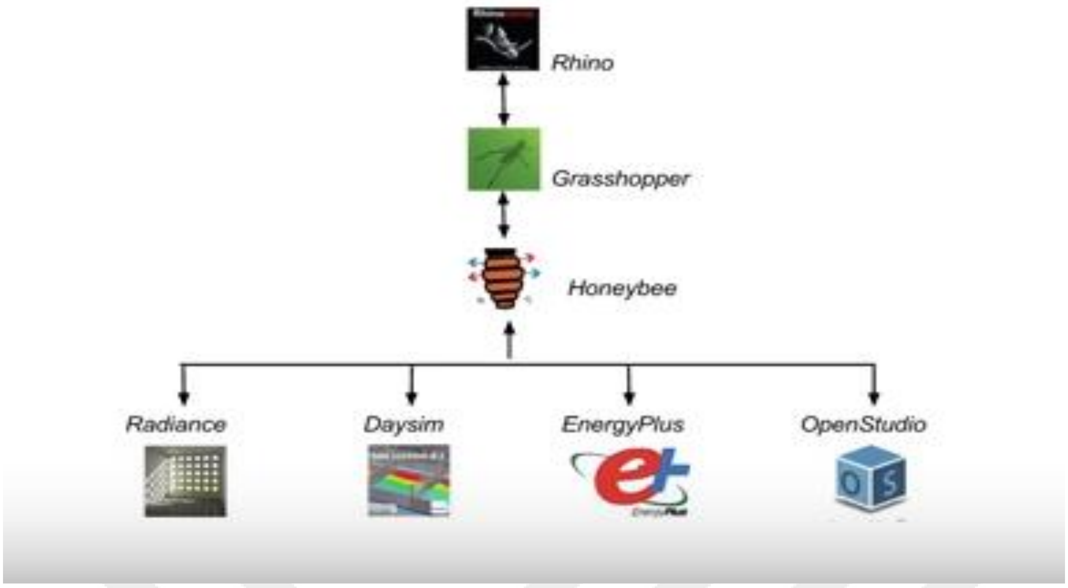


Figure 23*:* Ladybug + Honeybee connectivity to Energy and Daylight Simulation Engines. *Source:* *www.mebd-penndesign.info/honey*.

3.5. LADYBUG: (VISUALIZATION)

This is an open and free basis environmental-friendly plugin for Grasshopper3D. Grasshopper3D, is a "graphical algorithm editor" (grasshopper3d.com) plugin for Rhino, a 3D modeling apparatus which is increasingly becoming a desired modeling instrument for architects, designers, and students. Ladybug profits the parametric strategy of Grasshopper to permit the designer to discover the direct relationship amongst environmental data and the generation of the design thru graphical data outputs that are extremely assimilated with the building geometry.

Ladybug supports the download and the importation of standard EnergyPlus Weather files (EPW) into Grasshopper. It offers a diversity of 3D communicative climate graphics that back the decision-making progression during the initial stages of design. Thru solar radiation studies, sunlight-hours modeling view analyses, Ladybug play a crucial role at the early design stage, it also aid in data and results visualization. It is integrated with visual programming environment that allows instantaneous feedback on design modifications and a high degree of customization.

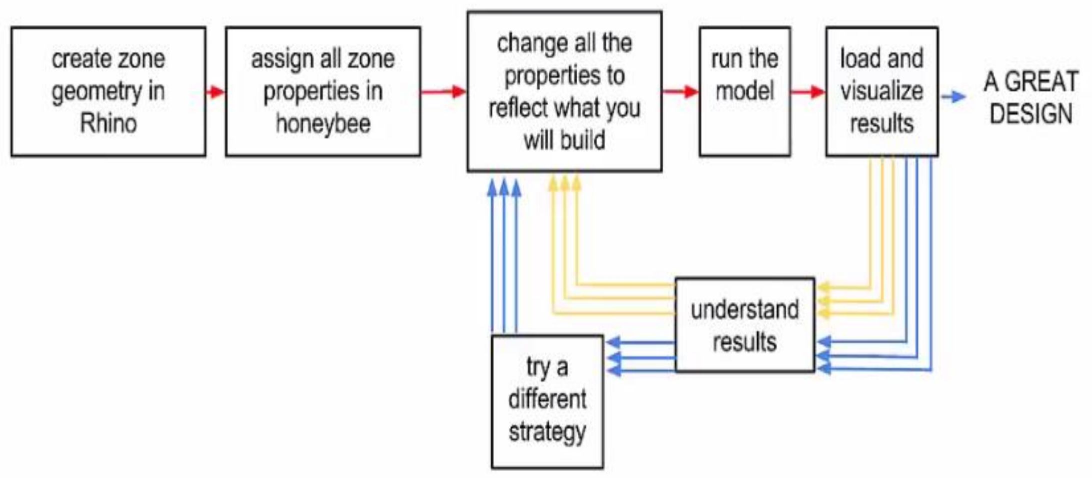


Figure 24: Ladybug + Honeybee Diagrammatic Flowchart

Source: www.mebd-penndesign.info/honey.

CHAPTER-4

CASE STUDY: ZENITH BANK KANO, NIGERIA

4.1 NIGERIAN CLIMATE

The fundamental operate of all buildings is to fit to the predominant climate and furnish with an internal and external environment that is comfortable and conducive to the dwellers. Nevertheless, in this era of global warming and drastic climate change, comfort provision for the occupants of a building is quite challenging and very fundamental. This is in consequence of growing series of challenges confronting professionals presently to produce buildings that will be fit and comfortable for the 21st century. This chapter presents climatic condition of hot arid climate within the study area, as well as its effect on the building facades. This study looks into the climate condition of Nigeria in relation with climatic zones for architectural design. Nigeria's climate, as it is in most West African countries, is identified by strong latitudinal zones, becoming drastically drier as one moves north from the coast.

The adaptable microclimate key is the rainfall, and there is a noticeable fluctuation of dry and rainy seasons in utmost areas. The two air multitudes that regulates rainfall-moist arid mainland air coming south from the African landmass and northward-moving maritime air coming from the Atlantic Ocean. Topographic liberation plays a substantial part in confined microclimate only along the eastern boundary moorlands and nearby the Jos Plateau.

The wet season customarily starts in February or March as humid Atlantic air, famous as the southwest monsoon, occupies the country in the coastal and southeastern portions of Nigeria. The commencement of the rains is often manifested by the prevalence of high winds and dense but scattered squalls. The dispersed quality of this rainstorm is exclusively manifest in the northern regions, though there may be plentiful rain in some minor regions while some other places remain dry. Toward the end of April to the first week of May in most occasions, the raining season begins through the southern part of the Niger and Benue river basins. Habitually in far north of Nigeria, it is mostly toward May end or early June when rains indeed commence. The uttermost of the rainy period befalls over utmost of northern part of Nigeria in August, as soon as air from the Atlantic shields the whole country. In southern districts, this era indicates the August dip in rainfall. Even though hardly absolutely dry, this dip in precipitation, which is particularly marked in the southwest, can be beneficial agriculturally, for it allows a momentary dry period for grain harvesting.

Beginning of September up to November, the northeast trade winds largely convey a season of flawless skies, modest temperatures, and lesser humidity for utmost of the country. Beginning of December through February, nevertheless, the northeast trade winds blow intensely and every so often bring with them a lot of fine sand from the Sahara. These dust-loaded winds, recognized locally as the harmattan, habitually seem as a compressed precipitation and shelter entirety with a deposit of fine elements. The harmattan is more common in the north however touches the whole country excepting a slim strip along the southwest coast. An intermittent strong harmattan, nevertheless, can curve as far south as Lagos, providing liberation from great wetness in the capital and aggressive clouds of dust ready to sea.

Certain about this climatological sequence and the magnitude of the country, there is a substantial range in over-all annual rainfall thru Nigeria, equally from north to south too, in some districts, from east to west. The ultimate overall precipitations are largely in the southeast, along the coast nearby Bonny (south of Port Harcourt) and east of Calabar, where means yearly precipitation is exceed 400 centimeters. Utmost of the left-over of the southeast gets between 200 to 300 centimeters of rain per year, and the southwest (lying farther north) obtains lesser total rainfall, largely amongst 125 and 250 centimeters annually. Mean yearly rainfall by Lagos is approximately 190 centimeters; by Ibadan, merely near one hundred and forty km northern part of Lagos, mean yearly precipitation drops to around 125 centimeters. Moving toward north from Ibadan, mean yearly precipitation in the west is in the series of 120 to 130 centimeters. The over-all precipitation and the span of the raining season drop gradually in Kaduna state toward the northern region, thru the northern Guinea savanna and then the Sudan savanna regions. The Guinea savanna begins in the middle belt, or north-central region of Nigeria. It is distinct from the Sudan savanna for the reason that it has more trees while the Sudan few trees. Raining seasons drop compatibly in interval as one moves toward north, with Kano having an average raining period of approximately one hundred and twenty to one hundred and thirty days, with Katsina and Sokoto have rainy seasons 10 to 20 days shorter. Middling annual rainfall in the north specifically Kano is in the series of 50 to 75 centimeters.

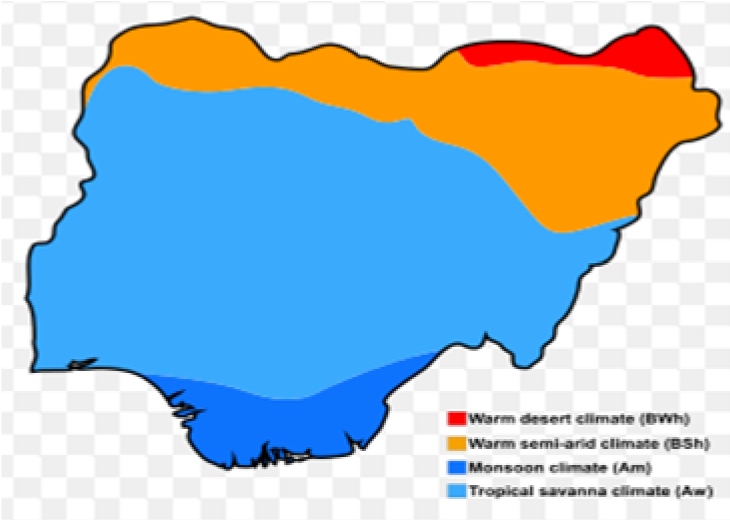


Figure 25: Nigeria Climatic Zones.

In Nigeria, temperatures all through are mostly high; daily variations are more definite than periodic ones. Maximum temperatures befall thru the dry season; rains adequately afternoon highs thru the wet season. Middling lows and highs for Kano are 27° C and 33° C respectively in January and 33° C and 28° C in June respectively. Even though average temperatures differ slightly from coastal to inland regions, inland regions, specifically in the northeast, have larger excesses. There, temperatures extent as high as 44° C afore the onset of the rainfalls or descent as low as 6° C during an invasion of cool air from the northern part from December to February.

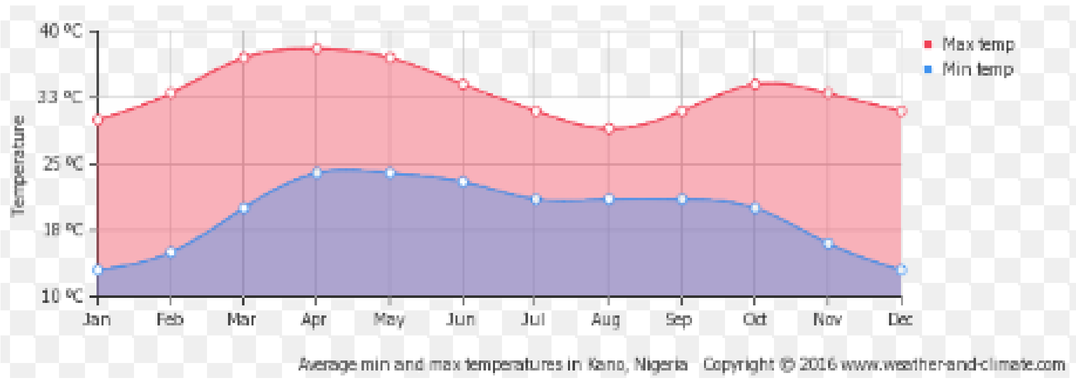


Figure 26: *Average temperature of Kano, Nigeria.*

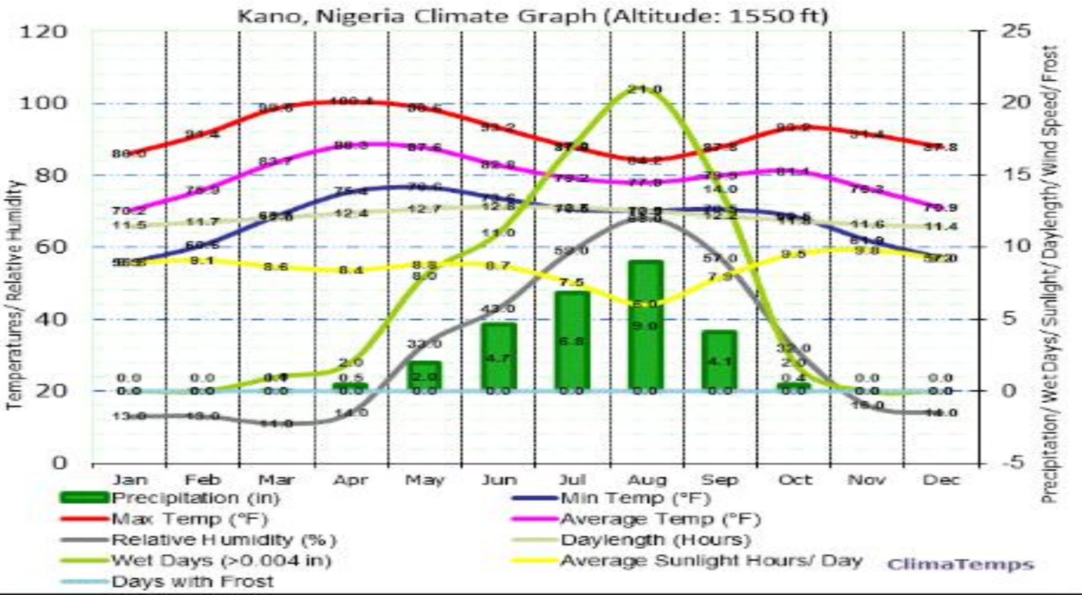


Figure 27: Climate Graph of Kano, Nigeria.

4.2 SURVEY ANALYSIS

According to the survey, the total respondents were ninety two for both of the two categories, where the males constituted 67.65% and the females constituted the remaining 32.35% with their ages ranging from eighteen years upward. Information in this survey were obtained from one hundred and two (102) respondents stratified into two groups of sixty (60) Customers and forty two (42) staff completed returned questionnaires. Most of these respondents were between the ages of eighteen (18) to seventy (70) years in the customer's category and between twenty one to sixty (21-60) years in the staff category. From these age distributions, 3% were from the age of 18 to 20 years, while 24.5% were from the age of 21 to 30 years, and 37.25% were from the age of 31 to 40 years, and 22.5% were from the range of 41 to 50 years, then 9.8% were from the age group of 51 to 60 years, then 2.95% were from the age group of 61 to 70 years.

The information obtained from this field work was gathered by the means of properly planned and designed questionnaires constituted of ten (10) items for the customers and eleven (11) items for the staff in general composed of twelve (12) items. Most of which were multiple choice, rating scales and bipartite scales questions. It should be understood that the first part of the survey question which consist of item 1, 2 and 3 was aimed at identifying the group sample item 5 was aimed at assessing respondents view about the building in terms of level of comfort within its interior. The survey question also try to find the respondents feelings in terms of their thermal sensitivity as this could pave way in rating the building based on its thermal performance in both summer periods. In fact this survey also raised an awareness about the importance of adopting double skin façade in our buildings in hot and arid climates without interrupting the ample supply of natural daylight as well as maintaining the thermal comfort in one hand and conforming to the features of contemporary Architecture that suggest the use of massive glazing for the facades. For the purpose of this research, Bar and Pie charts were used as a graphical medium for the representation and for visual analysis through observation and comparison of the information obtained from the survey (questionnaires).

4.2.1 SURVEY RESULTS

The graphical representation of the survey above is presented in the sequence below with some highlights about each outcome.

1.) What is your age?

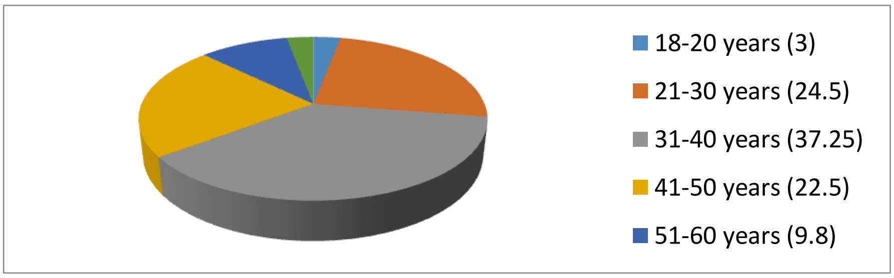


Figure 28: Age distribution of the respondents (%)

2.) What is your gender?

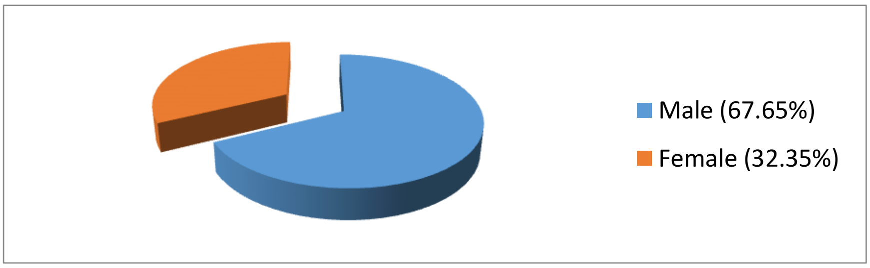


Figure 29: Gender status of the Respondents

3.) What is your highest educational qualification?

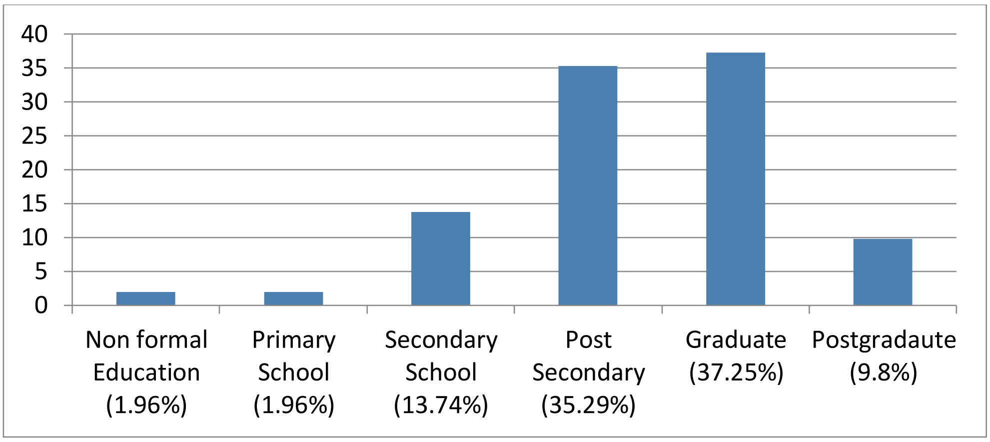


Figure 30: Educational status of respondents

According to the above survey result, it shows that about 37% of the respondents with the highest percentage were graduates and the lowest percentage which is 1.96% fell under those respondents who had Non formal and primary certificates.

4.) What is your occupation?

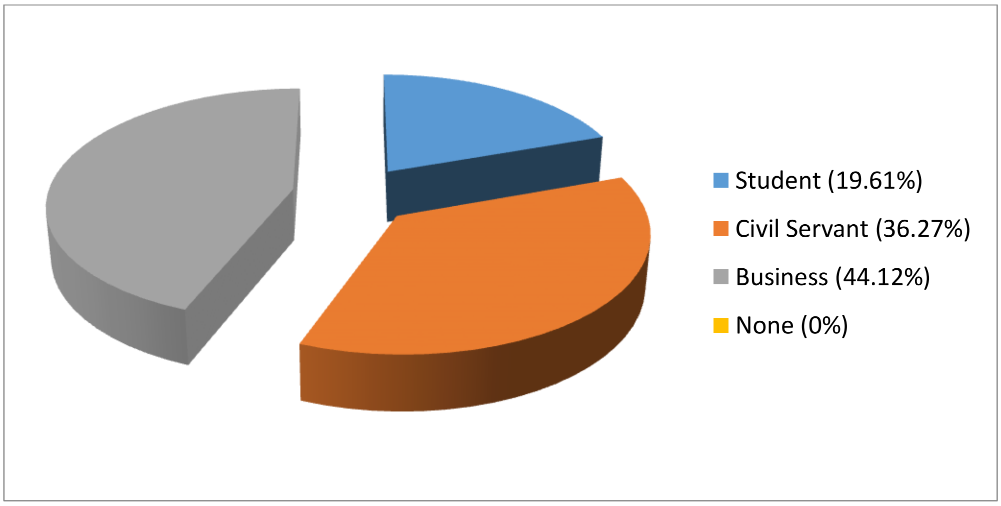


Figure 31: Educational statuses of respondents

5.) How would you rate this building in terms of comfortability?

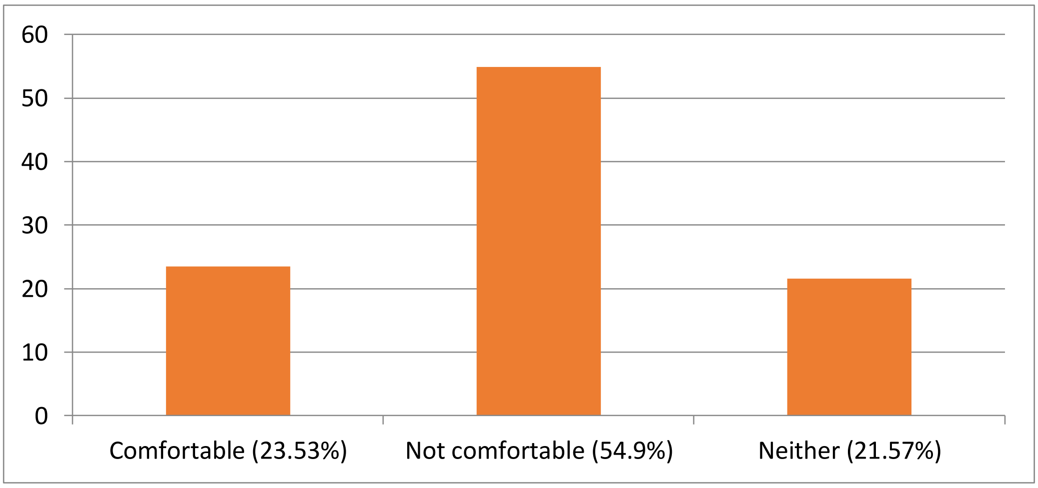


Figure 32: Comfort level rating

Figure above shows the general overview of the building under study by the users in terms of comfortability. Their response indicates that most of them were not comfortable.

6.) How would you rate your thermal sensitivity?

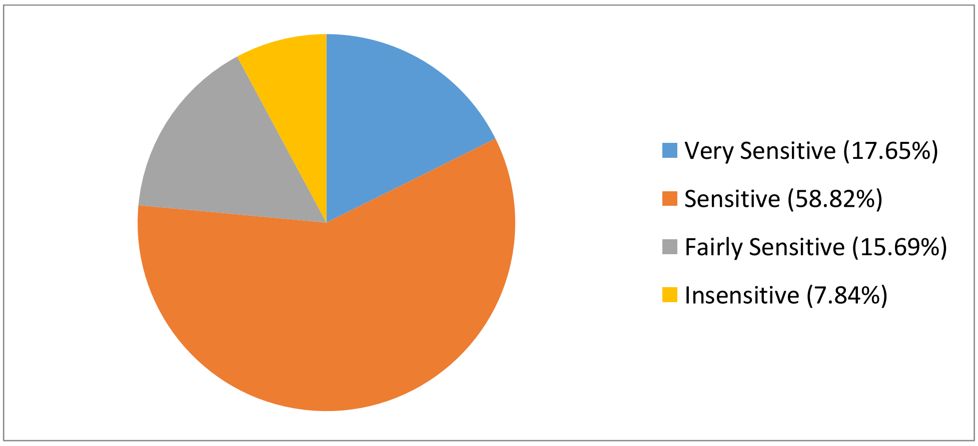


Figure 33: General rating of the respondents' thermal sensitivity.

According to the figure above, the survey shows that about 60% are sensitive to thermal with about 18% who are very sensitive to thermal as such proper consideration should be adhered to during the pre-design stage to ensure adequate thermal insulation materials were used as well as taking measures in designing the air cavity and other shading materials.

7.) How would you rate double skin façade as an important aspect to this environment?

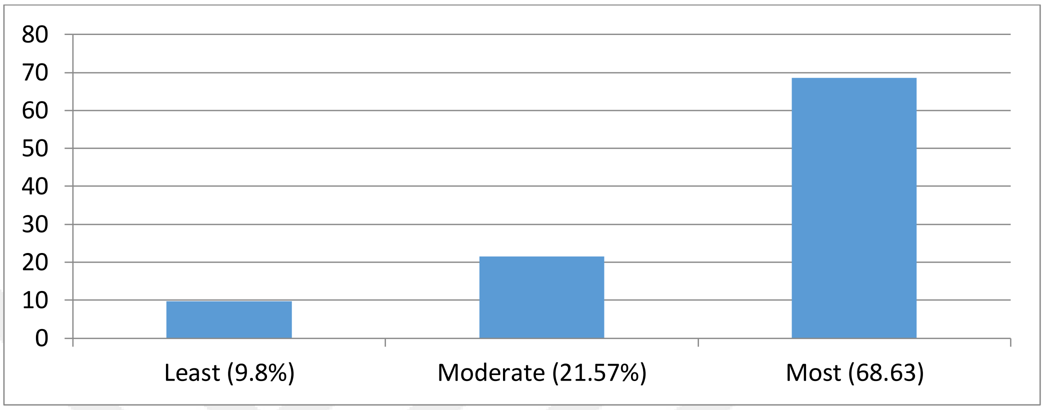


Figure 34: General rating of the Double Skin Façade in terms of its importance.

The figure above indicates that about 69% of the respondents perceive double skin façade as an important aspect of the environment based on their experience of both buildings with single and double skin with glazed façade. Only 9.8% of the respondents view it (DSF) as least important, leaving 21.57% with intermediate opinion about the importance of the double skin façade application in buildings.

8.) Generally, how would you the level of natural daylight in this environment?

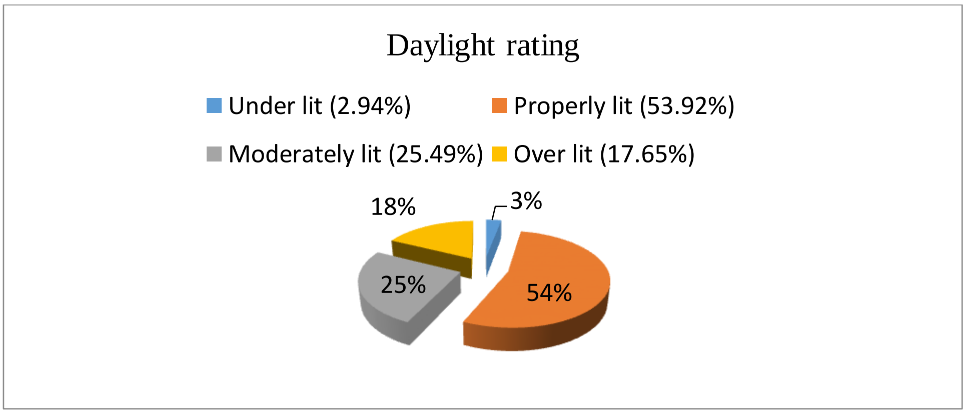


Figure 35: General rating of the environment in respect to daylight

Natural daylight delivery to the inner spaces of the building is of supreme importance. Nevertheless, due to some improved curiosity in the use of daylight in the strategy of low-energy, viable buildings are leading numerous architects and engineers to reflect inventive ways of developing the profits of daylight. It is very vital that the positive benefits of daylight were not compromised and do not become flummoxed with the negative impacts related to the intense solar radiation, thereby adopting the use of contemporary architecture building materials (glazing) and properly configuring them through the concept double skin façade that that can efficiently provide the required interior illumination and can relatively reduce the thermal transmission (U-Value) as well as solar heat gain (G-Value).

9.) How would rate the level of heat during summer in this environment?

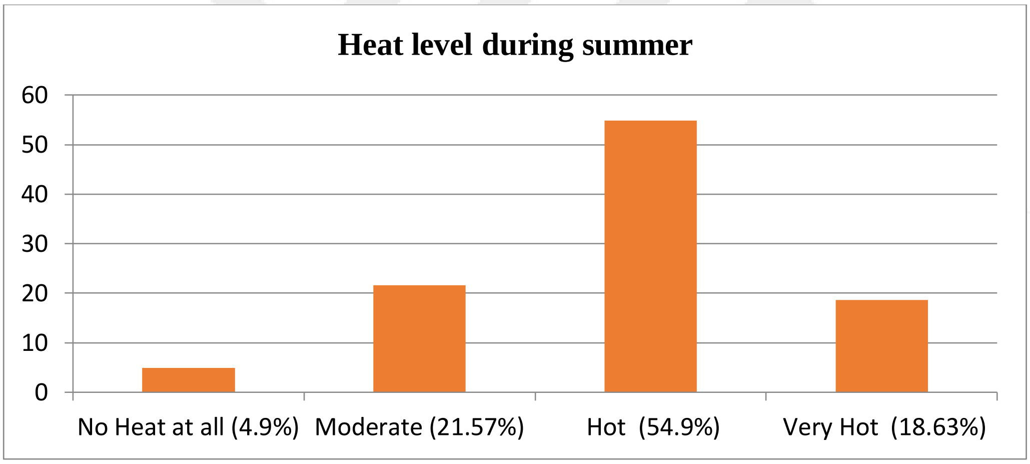


Figure 36: General rating of heat level during summer

The above figure indicated that about 55% of the respondents consider the building as hot environment, and about 21% consider it as moderate in terms of hotness during summer, and only about 5% consider it as efficient in terms of heat and about 19% consider it as very hot environment and consequently cooling load may be high hence, energy consumption will be relatively high. In view of that, there is need to evaluate the performance of the façade configuration so as to find the best or suitable façade formation so as to minimize the cooling load and consequently decrease the energy consumption.

10.) How would rate the level of cold during winter in this environment?

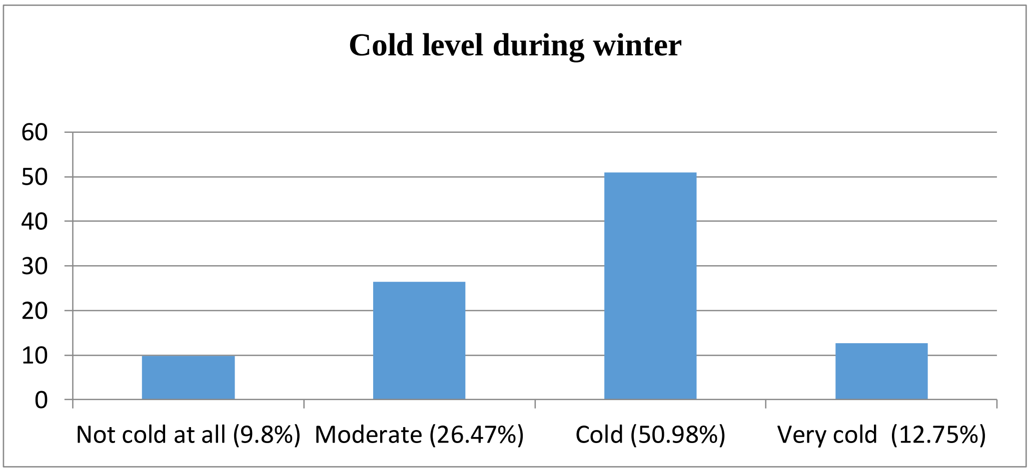


Figure 37: General rating of cold level during winter

According to the responses obtained as represented in figure xx and Figure xx above, majority of the occupants are not comfortable both during summer and winter, therefore this research will try to find the genesis behind it and suggest some possible solutions using computer energy and daylight simulation tools precisely Ladybug + Honeybee.

4.3. THE CASE STUDY BUILDING

Building: Zenith Bank Plc

Location: Kano, Nigeria.

Project Year: 1990

Client: Jim Ovia

Building Type: Office Building (Commercial)

Building Size: Area = 672 sqm.

Height = 11 meters

Building Skin: Interior = Single pane glazing

Exterior = Double pane glazing

Cavity Depth: 50cm

Zenith bank Nigeria plc was founded in May, 1999 and begins its operations in July the same year but then as a commercial institution. On June 17, 2004 the bank became a public limited company and was counted on October 21, 2004 on the Nigerian Stock Exchange (NSE) In consequence of the vastly prosperous Initial Public Offering (IPO).

The building is a prototype to all Zenith bank branches across the nation. Zenith bank is headquarter is located in Lagos, Nigeria; Zenith Bank has more than 500 branches and financial offices nationwide, it exists in all state capitals including Abuja (FCT). United Kingdom Financial Service Authority befitted Zenith bank as the first Nigerian bank to be certified by the (FSA) In April 2007, resulting to Zenith Bank (United Kingdom) Limited. Zenith bank correspondingly has divisions in some African countries comprising; Sierra Leone, Zenith Bank (Sierra Leone) Limited; Ghana, Zenith Bank (Ghana) Limited; Gambia, Zenith Bank (Gambia) Limited still has a symbolic office in Johannesburg, South Africa. And various representative offices in Asia located in Beijing, China. The building under study is located Along Maiduguri Road, Kano State within Kano city as a financial institution which many people patronize and visit daily during the five working days (Mondays to Fridays, 7 ‘o clock in the morning to 6 ‘o clock in the evening.

Figure 38: Showing the study area location.

The figure above illustrates the location of the case study building which is located in

Kano city, Kano state in the north-west part of Nigeria bordering Jigawa, Katsina, Zamfara and Kaduna states.

Figure 39: Showing minimized study area location

Figure 39 above, illustrates the entire Kano metropolitan, where the case study building is located in Tarauni LGA coloured in light-brown colour in the lowest part of the Map.

Figure 40: Zenith Bank Nigeria Plc. Headquarters, Lagos, Nigeria.

4.3.1. CASE STUDY BUILDING DESCRIPTION AND LAYOUT:

The selected building is a two-storey building, with a double skin glazed facade. Each floor area is 672 m^2 excluding the cavity depth. The cavity depth is 500mm. It has a length of 28 m and a width of 24 m and 11 m storey height.

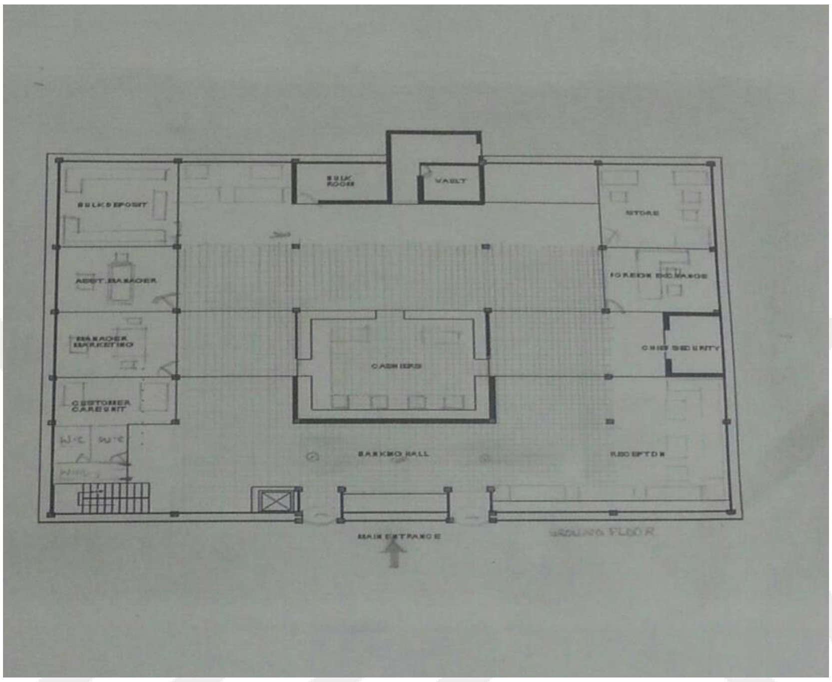


Figure 41: Floor Plan of the Building under study (Ground floor)

The floor plan above shows the layout and the interior arrangement of functions within the building. The building has double skins with double entrances which serve also as exits and are automatically operated to control the people's movement in and out for ensuring proper security. The banking hall is situated in the ground floor, as well as some auxiliary functions like; the customer care unit, the cashiers, foreign exchange, the vault, assistant manager, bulk room, storage among other functions. The building has an ample circulation space that allows free movement from one point to another with restriction to vault, bulk room and storage areas.

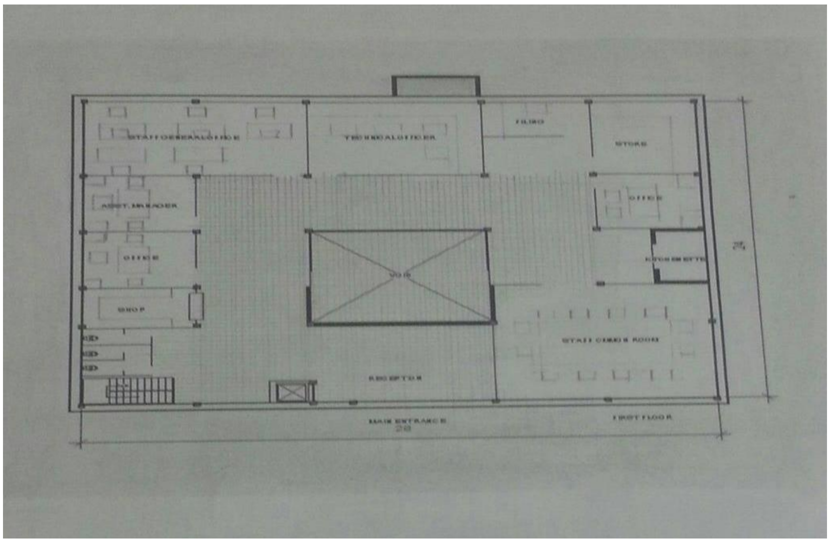


Figure 42: Floor Plan of the Building under study (First floor)

The figure above as labeled is the first floor plan that represents the layout and the internal arrangement of functions within it. People gain access to this place though either the lift or the staircase situated immediately after entering the building by your left so as to be easily accessible. Offices are also located in the first floor as well as some conveniences including the Manager's office as well as the staff meeting room and a kitchenette as well a small shop.

Figure 43: Approach View of Zenith Bank Nigeria Plc. Maiduguri Road, Kano, Nigeria.

The hypothetical building is intended to resemble the typical size and construction type of commercial buildings in Nigeria specifically in Kano city. The building adopt the norm of "**Cubism**" which was defined according (Random House, Inc. 2018) as concept developed in the early twentieth century, distinguished mainly by an emphasis on formal structure rather than their natural forms by transforming them to their geometrical peers, and unifying the planes of the signified objects independently of representational necessities.

The façade of the building was made up of double skin glazing for both interior Skin and the exterior Skin. Glazing is usually installed without proper provision shading devices and other responsive measures.

Figure 44: Showing inside the Banking hall

The interior view shows that the building is lit by both natural daylight and electricity supply especially in the early and late working hours (around 7:30 am and 5:00 to 6:00 pm), this indicate that there is need for ensuring ample supply of the natural daylight through various design configurations.

4.3.2 BASE CASE MODEL

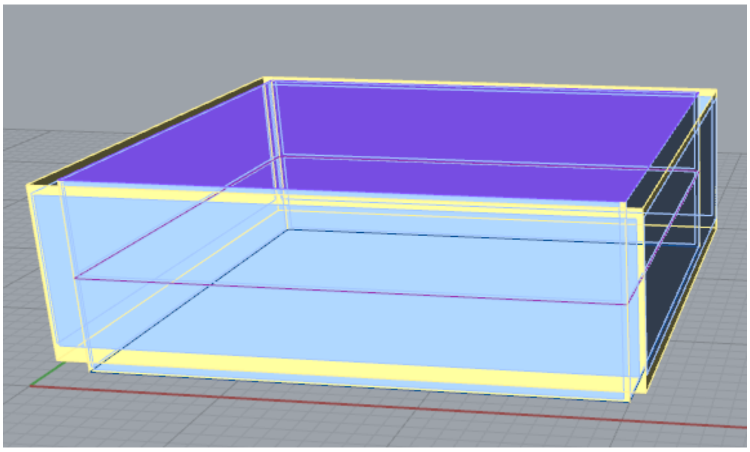


Figure 45: Base case model

The dimensions of the model are; 28 m long, 24 m wide and 11 m high with 50 cm air cavity between the interior and the exterior skins.

4.4. LADYBUG + HONEYBEE SIMULATION TOOLS

The objective function of the process is aimed at utilizing parametric workflows to achieve optimum energy saving and natural daylight within the office building under study. Ladybug permits in showing different outcome for both Energy and daylight Simulations as well as some visual information about the study location in terms of Temperature, Sun paths Relative humidity among others.

4.4.1. HONEYBEE ENERGY SIMULATIONS

As earlier mentioned in the immediate chapter, Honeybee links the graphical user interface design environment of Grasshopper to four basic validated simulation devices precisely; EnergyPlus, OpenStudio, Radiance, and Daysim which assess the energy consumption of the building, daylighting and thermal comfort. In this research, honeybee was used to evaluate the energy performance of the hypothetical building using some variables that validate the results.

Table 11 below shows some energy simulation values for Cooling and Heating loads as well as the artificial lighting requirements of the selected hypothetical model with different glazing configurations at different times. The depth of the air cavity between the interior and exterior skin also serves as a decision variable.

Table 11: Energy Simulation results

S/NO.	INNER GLAZIN	DEPTH (Centimeters	INNER GLAZING	U-VALUE BTU/h.ft².°F	SHGC W/m²	VT (W/m²)	THICKNESS (cm)	MONTH	COOLING LOADS Kwh/m²	LOADS Kwh/m²	LIGHTING Lumen/watt
1	Single_Pane	50 cm	Double_Pane	0.85/ 0.83	0.73/0.65	0.69 / 0.63	0.25	January	107.04	16.28	448.59
2	Single_Pane	50 cm	Double_Pane	0.85/ 0.83	0.73/0.65	0.69 / 0.63	0.25	February	196.98	22.88	843.25
3	Single_Pane	50 cm	Double_Pane	0.85/ 0.83	0.73/0.65	0.69 / 0.63	0.25	March	325.77	26.16	129.19
4	Single_Pane	50 cm	Double_Pane	0.85/ 0.83	0.73/0.65	0.69 / 0.63	0.25	April	1949.21	26.22	169.53
5	Single_Pane	50 cm	Double_Pane	0.85/ 0.83	0.73/0.65	0.69 / 0.63	0.25	May	1741.98	26.25	214.39
6	Single_Pane	50 cm	Double_Pane	0.85/ 0.83	0.73/0.65	0.69 / 0.63	0.25	June	1494.79	26.25	257.45
7	Single_Pane	50 cm	Double_Pane	0.85/ 0.83	0.73/0.65	0.69 / 0.63	0.25	July	1081.19	46.25	299.59
8	Single_Pane	50 cm	Double_Pane	0.85/ 0.83	0.73/0.65	0.69 / 0.63	0.25	August	473.72	27.11	344.45
9	Single_Pane	50 cm	Double_Pane	0.85/ 0.83	0.73/0.65	0.69 / 0.63	0.25	September	890.76	46.25	386.39
10	Single_Pane	50 cm	Double_Pane	0.85/ 0.83	0.73/0.65	0.69 / 0.63	0.25	October	894.96	46.25	429.65
11	Single_Pane	50 cm	Double_Pane	0.85/ 0.83	0.73/0.65	0.69 / 0.63	0.25	November	973.75	46.25	472.71
12	Single_Pane	50 cm	Double_Pane	0.85/ 0.83	0.73/0.65	0.69 / 0.63	0.25	December	819.19	26.25	514.85
13	Low_E_Argon	50cm	Double_Pane	0.64/ 0.83	0.38/0.65	0.56 / 0.63	0.25	April	1350.82	33.11	169.53
14	Low_E_Argon	50cm	Double_Pane	0.64/ 0.83	0.38/0.65	0.56 / 0.63	0.25	May	1205.03	32.58	214.39
15	Low_E_Argon	50 cm	Double_Pane	0.64/ 0.83	0.38/0.65	0.56 / 0.63	0.25	August	269.44	33.29	344.45
16	Low_E_Argon	50 cm	Double_Pane	0.64/ 0.83	0.38/0.65	0.56 / 0.63	0.25	September	820.98	32.58	386.39
17	Low_E_Argon	50 cm	Double_Pane	0.64/ 0.83	0.38/0.65	0.56 / 0.63	0.25	November	850.32	32.58	472.71
18	Low_E_Argon	50 cm	Double_Pane	0.64/ 0.83	0.38/0.65	0.56 / 0.63	0.25	December	605.71	32.58	514.85
19	Single_Pane	100 cm	Double_Pane	0.85 / 0.83	0.73 /0.65	0.69 /0.63	0.25	April	1734.36	30.34	132.67
20	Single_Pane	100 cm	Double_Pane	0.85 / 0.83	0.73 /0.65	0.69 /0.63	0.25	May	1237.38	28.15	193.25
21	Single_Pane	150 cm	Double_Pane	0.85 / 0.83	0.73 /0.65	0.69 /0.63	0.25	August	400.34	29.71	323.68
22	Single_Pane	150 cm	Double_Pane	0.85 / 0.83	0.73 /0.65	0.69 /0.63	0.25	September	534.22	54.79	295.79
23	Single_Pane	200 cm	Double_Pane	0.85 / 0.83	0.73 /0.65	0.69 /0.63	0.25	December	624.81	34.38	457.81

In the Table 11 above, about 23 scenarios were analyzed thereby assigning various configurations of the glazing type: (Single Pane, Double Pane and Low E Argon) in the interior and exterior façade, Cavity depth: (50 cm, 100 cm, 150 cm and 200 cm) at different time throughout the year. Base case was analyzed based on each month of the year (January to December) having the same glazing configuration and the cavity depth and the results were obtained and recorded as in the table above. The results revealed that glazing configuration has a greater influence in the energy consumption of the building as well as the depth of the cavity. It is also observed that due lack of shading elements within the cavity increases the cooling loads of the building, therefore some shading elements should be mounted amidst the air cavity.

The analysis also revealed that wider the cavity the less cooling load is required; therefore one should be cautioned enough in designing the air cavity. Hottest and coolest period is also very vital in the provision of the shading elements that may be adjustable or removable when required. Comparatively, from the above table, three different configurations were compared to evaluate the best formation in terms of energy performance at the same time (August) and the best formation was found to be; Low E Argon in the interior skin, double pane in the exterior skin with an air cavity of 50 cm. The second best option was that with Single pane in the inner skin, double pane in the outer skin with an air cavity of 150 cm. Then the third one was that with façade configuration of single and double pane in the inner and outer skins respectively and the air cavity of 50 cm.

4.4.2. HONEYBEE DAYLIGHT SIMULATIONS

Honeybee associates the graphical user interface design environment of Grasshopper to four basic validated simulation devices as stated earlier which include; EnergyPlus, OpenStudio, Radiance, and Daysim which assess the energy consumption of the building, daylighting and thermal comfort. Consequently in this research, honeybee was used to evaluate the daylight performance for the hypothetical building using some variables that validate the results.

In the Table 12 below, about 22 scenarios were analyzed thereby assigning various configurations of the glazing type: (Single Pane, Double Pane and Low E Argon) in the interior and exterior façade, Cavity depth: (50 cm, 100 cm, 150 cm and 200 cm) at different time throughout the year. Base case was analyzed based on each month of the year (January to December) at different day and a specific time, having the same glazing configuration and the cavity depth and the results were obtained and recorded as in the table below. Comparatively, from the table below, two different configurations were compared to evaluate the best formation in terms of daylight performance at the same time (August) and the best formation was found to be; single pane in the interior skin, double pane in the exterior skin with an air cavity of 150 cm compared to the second option which was Single pane in the inner skin, double pane in the outer skin with an air cavity of 50 cm.

Table 12: Daylight Simulation Results (illuminance "Lux")

S/NO	Glazing Type Inner Skin	Cavity Depth Cm	Glazing Type Outer Skin	Visual Transmittance W/m²	Month	Day	Time	Illuminance value (lux)
1	Single_Pane	50 cm	Double_Pane	0.69/ 0.63	January	12	10:00 AM	878.44
2	Single_Pane	50cm	Double_Pane	0.69 / 0.63	February	12	9:00 AM	518.77
3	Single_Pane	50 cm	Double_Pane	0.69 / 0.63	March	15	3:00 PM	1108.23
4	Single_Pane	50 cm	Double_Pane	0.69 / 0.63	April	28	6:00PM	1239.49
5	Single_Pane	50 cm	Double_Pane	0.69 / 0.63	May	12	8:00 AM	915.37
6	Single_Pane	50 cm	Double_Pane	0.69 / 0.63	June	9	12:30 PM	1447.87
7	Single_Pane	50 cm	Double_Pane	0.69 / 0.63	July	15	1:00 PM	1221.08
8	Single_Pane	50 cm	Double_Pane	0.69 / 0.63	August	5	9:00 AM	579.52
9	Single_Pane	50 cm	Double_Pane	0.69 / 0.63	September	20	4:00 PM	673.45
10	Single_Pane	50 cm	Double_Pane	0.69 / 0.63	October	17	1:45	1008.76
11	Single_Pane	50 cm	Double_Pane	0.69 / 0.63	November	10	5:00 PM	603.34
12	Single_Pane	50 cm	Double_Pane	0.69 / 0.63	December	12	6:00 PM	573.08
13	Low_E_Argon	50 cm	Double_Pane	0.56 / 0.63	October	1	1:00 PM	1252.39
14	Double_Pane	50 cm	Single_Pane	0.63 / 0.69	May	12	8:00	1541.33
15	Double_Pane	50 cm	Single_Pane	0.63 / 0.69	January	28	11:00 AM	936.88
16	Double_Pane	50 cm	Single_Pane	0.63 / 0.69	January	1	6:00 PM	962.26
17	Tripple_Pane	50 cm	Single_Pane	0.37 / 0.69	March	11	2:00 PM	1101.37
18	Double_Pane	50 cm	Double_Pane	0.63 / 0.63	September	11	9:00 AM	539.51
19	Single_Pane	100 cm	Double_Pane	0.69 / 0.63	April	25	5:00 PM	1344.67
20	Single_Pane	100 cm	Double_Pane	0.69 / 0.63	May	11	9:00 AM	1008.78
21	Single_Pane	150 cm	Double_Pane	0.69 / 0.63	August	12	9:00 AM	784.28
22	Single_Pane	200 cm	Double_Pane	0.69 / 0.63	December	13	6:00 PM	821.04

The results revealed that glazing configuration has a greater influence in efficient provision of Daylighting to the building as well as the depth of the cavity and the period of time. It is also observed that due lack of shading elements within the cavity influences the illumination of the building interior thereby causing intense glare and consequently causing discomfort to the occupants of the building, therefore some shading elements should be mounted amidst the air cavity.

4.5. LADYBUG DATA VISUALIZATION

As stated in the previous chapter, Ladybug offers a diversity of 3D communicative climate graphics that back the decision-making progression during the initial design stages. Ladybug was used for the visualization of some basic climatic data which very vital in ascertaining the energy consumption of a building as well as the daylighting. The figures below visualize different climate-based information including the Sun path, Relative humidity, Outdoor temperature, cooling and heating loads among others.

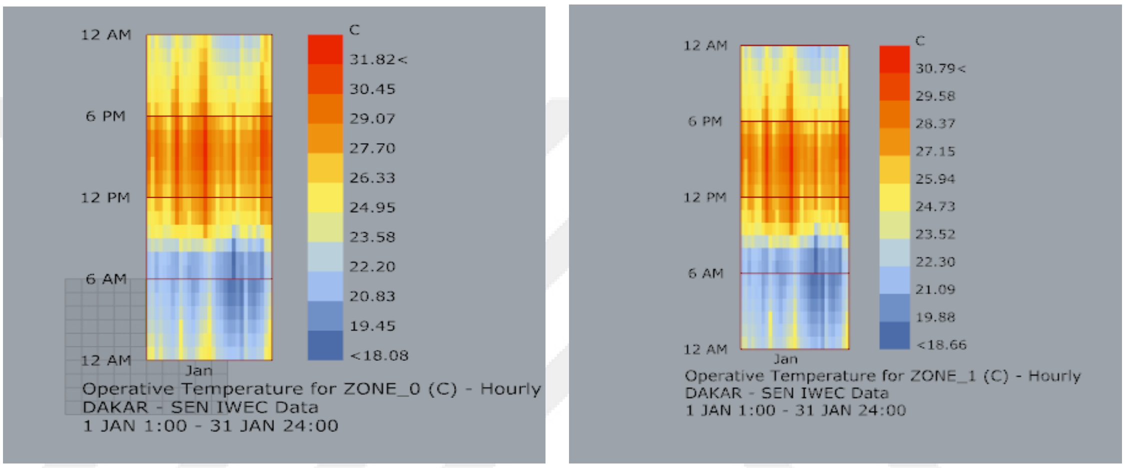


Figure 46: *showing the operative temperature for Zone_0 and Zone_1 respectively.*

It is stated earlier that Ladybug allows for the visualization of data about the prevailing weather with the aid of some components like the import epw weather component, 3D colour chart, legend par, analysis period among other components. The figure 46 above illustrates the operative temperature from the first day of January to the last day of the month. From the map, we can observe that the temperature begin to rise from around 10:30 in the morning up to 6:00 in the evening. The highest temperature is 31^0C and the lowest at 18^0C and this can help tremendously in evaluating the façade suitable configuration.

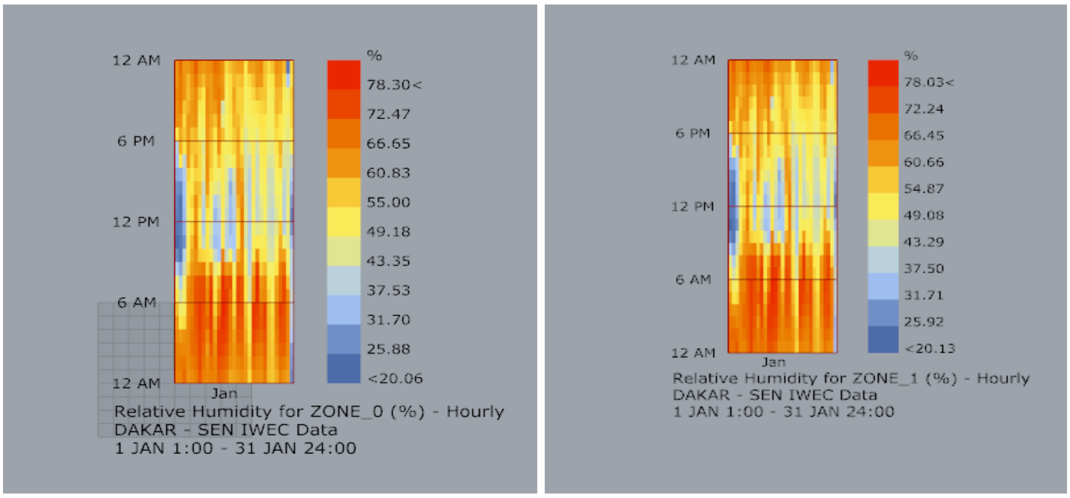


Figure 47: Showing the Relative Humidity for Zone_0 and Zone_1 respectively.

The figure 47 above illustrates the percentage of the relative humidity within the building and based on this we can evaluate some comfort level within the interior of the building. According to some review of literatures, the relative indoor humidity should be within the range of 40 to 60% for health and comfort.

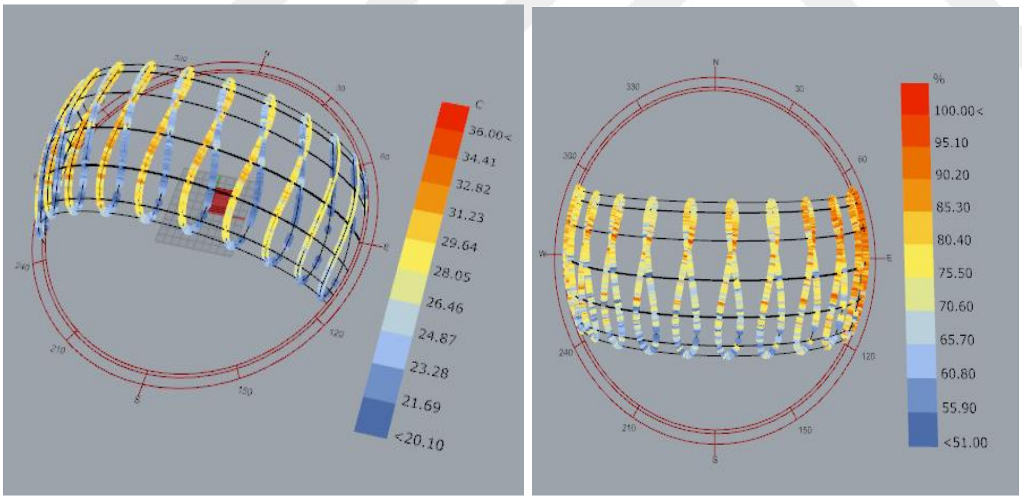


Figure 48: showing the Sun Path in relation to Temperature as well as Relative Humidity respectively.

The figure 48 above illustrates the sun path, it shows the position of the sun as it rose and move along the meridian at different time of the year and its relationship to the building, how it affect the building in terms of solar radiation and from there, we can evaluate the suitable shading elements and its best position on the façade.

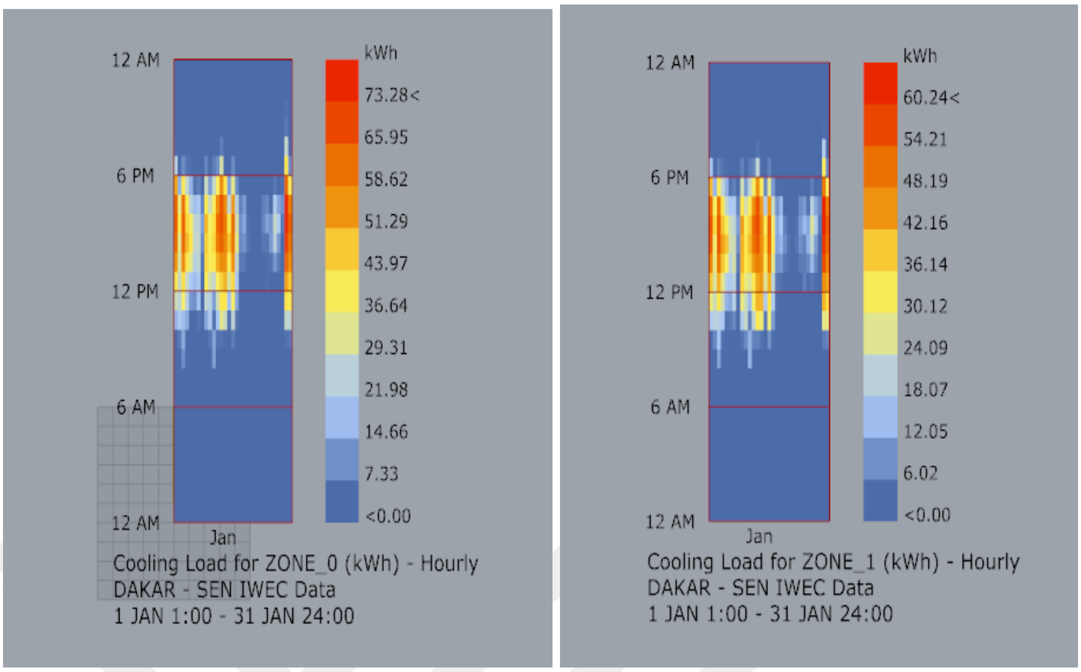


Figure 49: showing the Cooling Loads for Zone_0 and Zone_1 respectively.

The figure 49 above illustrates the energy required for the cooling of the interior of the building under study in January to maintain the indoor temperature in an acceptable range. And from the figure it is observed that the cooling load is high from around 10:30 in the morning up 6:00 in the evening.

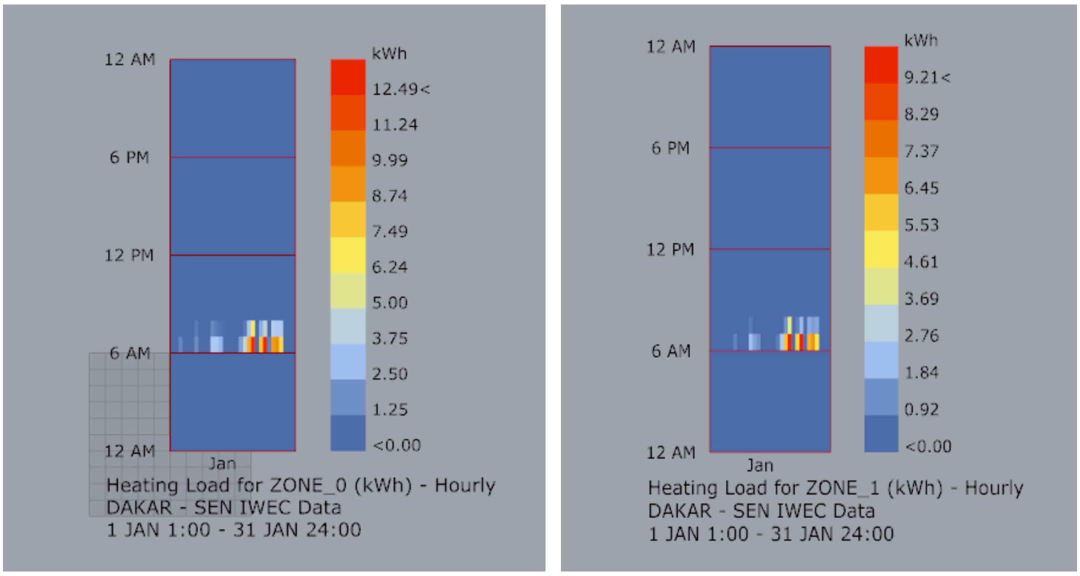


Figure 50: showing the Heating Loads for Zone_0 and Zone_1 respectively

The figure 50 above illustrates the energy required for the heating of the interior of the building under study in January to maintain the indoor temperature in an acceptable range. And from the figure it is observed that the heating load is manageable since it is relatively low. The heating is just required from around 6:00 up to 10:00 in the morning in the month of January.

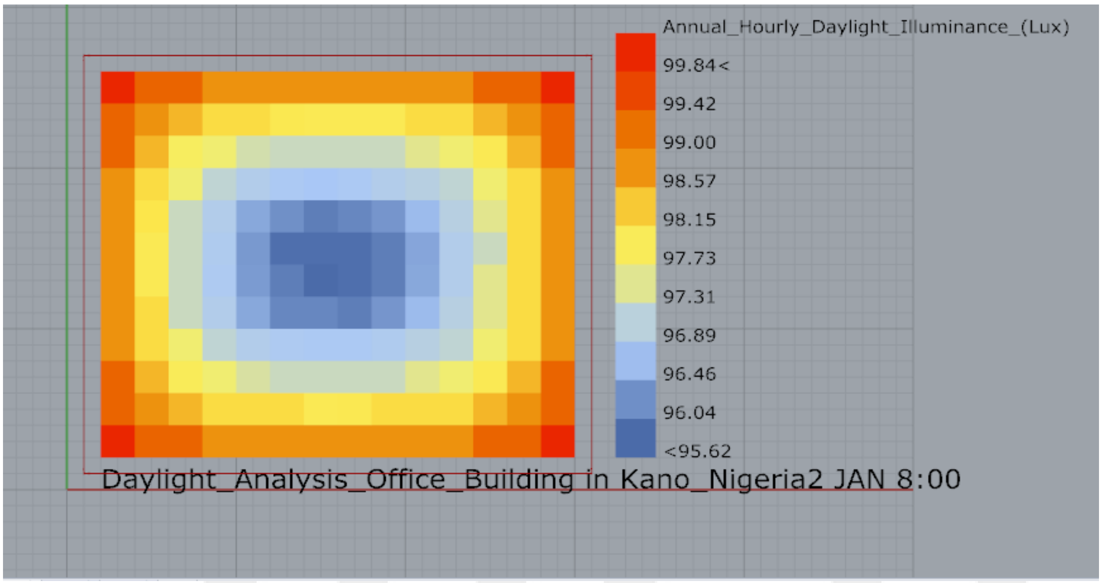


Figure 51: The Annual hourly Daylight Illuminance Map (02/Jan. at 8:00 AM)

Figure 51 above illustrates the illuminance map within the building. According to the legend, the blue portion indicates the area that lack sufficient illumination and the darker the blue colour become; the darker the portion is in terms of lighting. And the Reddish part represents the highly lit portion, and then the brownish portion is less illuminated compared to the reddish portion then followed by the yellowish portion.

CHAPTER-5
CONCLUSION

The study endorses the hypothesis within the range and restraints tested. Peak of double skin façade scenarios revealed the effectiveness of using the proposed parametric approach in identifying various unconventional designs that validated decrease in energy consumption and conserved maximum daylighting performance compared to baseline cases. Results differ between diverse scenarios based on their observed variables. This arrangement provided extra protection compared to single skin facades and reduced of the amount of solar gain in the rooms adjacent to the cavity, thus cooling loads were decreased.

As ultimate of the reviews in this thesis validate intensely, there is a necessity to study energy effectiveness. There are marks that energy efficiency is now being extra valued and considered by the community. The consciousness and the different operations helped appeal for more devotion to the matter of the growth of carbon dioxide. Hence buildings should be planned to improve energy in use at the early design stage.

The current research initially introduced the aim to predict the energy consumption and daylighting performance of an office building in Kano, Nigeria. These goals were achieved by investigating on the energy consumption and daylight performance of the building by consideration of different sets of parameters. These variables established as the main responsive aspect for the energy use intensity. Adopting the parametric model, several simulations were conducted computationally. In these tests, we calculated different solutions with altered values of independent variables under study. The computer parametric approach performed most of the process in an automated fashion. The investigation of the energy performance for the office building is remaining constant between 8 to 18 hours of the five working days (Mondays to Fridays).

Attentive to energy use in buildings necessitates substantial amounts of data opinions. These data are needed to evaluate the possible effects of energy efficiency and daylight improvements. Much less detailed information is available on energy consumption in office buildings, which includes different types of working hours and variants of activity within buildings. Buildings want energy space for heating, water heating, lighting, refrigeration, ventilation and auxiliary facilities. These uses collectively with restrained utilizations and office equipment, interpretation for about half of total request for energy and a comparable ratio of all energy related CO_2 releases. Enhancements to the effectiveness with which energy is used in buildings could offer substantial chances for reducing emissions.

Performance base design approach offers a great potential for investigating alternative designs in a timely efficient manner. When coupled with performance simulation tools, the approach becomes even more powerful. Although the nature of performance-based design approach is very suitable for energy usage, after a comprehensive review of the literature, we had the opinion that there is a basic lack in utilizing the full potential of the approach in conceptual design of energy usage in the Nigerian region.

It can be seen clearly that the change in value by certain degrees and alteration of some parameters has a change in effect of energy as well as the illuminance values. Within the scope the research, we examined around 22 different options having different glazing types and cavity depth. However, further research can easily apply the method to all several other options especially by incorporating the air cavity with some suitable shading elements. In this way, the energy performance of the building and efficient daylighting can effectively be achieved. It is very vital to study further but deeply about the best and suitable shading devices that can efficiently be incorporated in the double skin facade air cavity especially those that can be movable or changeable according to the prevailing weather.

Moreover, the best formation in terms of energy performance in the month of August was found to be; Low E Argon in the interior skin, double pane in the exterior skin with an air cavity of 50 cm. Hence, the best formation in terms of daylight performance in the month of August was found to be; single pane in the interior skin, double pane in the exterior skin with an air cavity of 150 cm.

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APPENDIX 1: SURVEY QUESTIONS (1)

Dear Respondent;

My names are Gambo Wurma Bara'u; I am presently undergoing a Master degree in the Department of Architecture, in the faculty of Natural and Applied Sciences, Yasar University Izmir, Turkey. The main aim of this questionnaire is to ascertain through your response your sensitivity in a building with a double skin façade (DSF) both during winter and summer periods.

I am therefore requesting you to kindly fill all the questions which are very vital in the success of my research and I assured you that all data collected from you will be used only for the purpose of this research and nothing else and will be treated confidentially.

Kindly tick the appropriate answer that you believe in.

SECTION A: PERSONAL PROFILE

1. Which category of age group do you belong to?

18-20 years { } 21-30 years { } 31-40 years { } 41-50 years { }

51-60 years { } 61-70 years { } >70 years { }

2. What is your gender? Male { } Female { }

3. What is your highest level of education?

Non formal education { } Primary { } Secondary { }

Post-Secondary { } Degree { } Post graduate { }

4. How long have you been working in this environment? { } years

5. Do you generally work in a comfortable environment?

Yes { } No { }

SECTION B: SUBJECTIVE EVALUATION

1. How would you rate Double skin façade as an important aspect of your environment?

i. Least { } ii. Average { } iii. Most { }

2. Generally, how would you rate the level of Daylight in your working environment?

Under lit { } fairly lit { } properly lit { } Over lit { }

3. How would you rate the level of heat during summer in your working environment?

No heat at all { } moderately { } Hot { } Very hot { }

4. How would you rate the level of cold during winter in your working environment?

Not cold at all { } moderately { } Cold { } Very cold { }

5. Which of the HVAC system used in your working environment?

Natural ventilation only { } Mechanical system only { } Combination of both { }

6. When is the opening-closure time? { } am/pm - { } am/pm

APPENDIX 1: SURVEY QUESTIONS (2)

Dear Respondent;

My names are Gambo Wurma Bara'u; I am presently undergoing a Master degree in the Department of Architecture, in the faculty of Natural and Applied Sciences, Yasar University Izmir, Turkey. The main aim of this questionnaire is to ascertain through your response your sensitivity in a building with a double skin façade (DSF) both during winter and summer periods.

I am therefore requesting you to kindly fill all the questions which are very vital in the success of my research and I assured you that all data collected from you will be used only for the purpose of this research and nothing else and will be treated confidentially.

Kindly tick the appropriate answer that you believe in.

SECTION A: PERSONAL PROFILE

1. Which category of age group do you belong to?

18-20 years { } 21-30 years { } 31-40 years { } 41-50 years { }

51-60 years { } 61-70 years { } >70 years { }

2. What is your gender?

Male { } Female { }

3. What is your highest level of education?

Non formal education { } Primary { } Secondary { }

Post-Secondary { } Degree { } Post graduate { }

4. What is your occupation?

Civil Servant { } Business { } Student { } None { }

5. How long have you been coming to this environment?

{ } years

6. Do you generally view it as a comfortable environment?

Yes { } No { }

7. How would you rate your thermal sensitivity?

Very sensitive { } Sensitive { } fairly sensitive { } Insensitive { }

SECTION B: SUBJECTIVE EVALUATION

1. How would you rate Double skin façade as an important aspect to this environment?

i. Least { } ii. Average { } iii. Most { }

2. Generally, how would you rate the level of Daylight in this environment?

Under lit { } fairly lit { } properly lit { } Over lit { }

3. How would you rate the level of heat during summer in this environment?

No heat at all { } moderately { } Hot { } Very hot { }

4. How would you rate the level of cold during winter in this environment?

Not cold at all { } moderately { } Cold { } Very cold { }

ILLUMINANCE STANDARD TABLE

S/No.	FUNCTION / BUILDING	ILLUMINANCE STANDARDS
1	Office Building	500 Lux
2	Stores / Kitchen	500 Lux
3	Stairs	150 Lux
4	Car Park	15 Lux