HARNESSING PASSIVE COOLING STRATEGIES TO ENHANCE THERMAL COMFORT IN THE DESIGN OF PROPOSED SCHOOL OF ENVIRONMENTAL STUDIES ABDUGUSAU POLYTECHNIC, ZAMFARA STATE, NIGERIA.

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JULY, 2017

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DEPARTMENT OF ARCHITECTURE,
FACULTY OF ENVIRONMENTAL DESIGN
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NIGERIA

JULY, 2017

Declaration

I declare that the work in this dissertation entitled "HARNESSING PASSIVE COOLING STRATEGIES TO ENHANCE THERMAL COMFORT IN THE DESIGN OF PROPOSED SCHOOL OF ENVIRONMENTAL STUDIES ABDUGUSAU POLYTECHNIC, ZAMFARA STATE," has been carried out by me in the Department of Architecture. The information derived from the literature has duly been acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Ibrahim Yusuf Chafe		July 2017
Name of student	Signature	Date

Certification

This dissertation entitled "PASSIVE COOLING STRATEGIES TO ENHANCE THERMAL COMFORT IN THE DESIGN OF PROPOSED SCHOOL OF ENVIRONMENTAL STUDIES ABDUGUSAU POLYTECHNIC , ZAMFARA STATE" by Ibrahim Yusuf CHAFE meets the regulations governing the award of the Master of Science Degree in Architecture of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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Dedication

To my Family. And all disciples Worldwide.

ABTSRACT

Passive design responds to local climate and site conditions in order to maximise the comfort and health of building users while minimising energy use. The key to designing a passive building is to take best advantage of the local climate. Passive cooling refers to any technologies or design features adopted to reduce the temperature of buildings without the need for power consumption. Consequently, Buildings consume large amount of energy in order to achieve thermal comfort for users. To achieve the goal of thermal comfort in buildings, passive cooling is one of the suggested practices emphasized to be adopted in many buildings around the world of which educational facilities have been a major target as an opportunity of achieving thermal comfort. When it comes to educational facilities, end users who are usually students, lecturers and other occupants spend almost 50% of the entire day within the buildings. To add on 50%, occupancy is predominantly during day time when environmental conditions are adverse to human survival hence creating thermal discomfort which in turn leads to low productivity and occupancy dissatisfaction. Many educational facilities mostly in Africa have been built relying on natural climatic conditions for occupancy comfort throughout the year which has brought about discrepancies amongst users. Whilst passive cooling can provide thermal comfort in some climates, a gap of thermal comfort improvement strategies in buildings still exits to enhance suitable thermal condition in buildings thus avoiding occupant dissatisfaction, low productivity and overall building performance. The aim of this study is to test the usefulness of applying selected passive cooling strategies to improve thermal comfort of buildings in hot dry climate of Gusau for the design of School of Environmental Studies Abdugusau Polytechnic, Nigeria. The methodology adopted were case studies and simulation whereby, three 3 case studies

buildings of the same usage type were selected and eight passive cooling strategies were applied. Simulation software – namely ECOTECT – was used to assess the performance of the building. Solar shading performance was also assessed using Sun Cast Analysis, as a part of the ECOTECT software. Result from the simulation indicated that the Mean Radiant Temperature can be reduced and thermal comfort percent can be improved by applying passive cooling strategies. Mechanical ventilation without cooling registered a negligible improvement in occupancy thermal comfort while on application of scheduled cooling thermal comfort improved between slightly warm and slightly cool with a 15% improvement in comfort hours. Also, in respect to indoor temperature, upper rooms are the worse where the temperature reach up to 39°C on peak day hours beside the temperature drop to uncomfortable level during night, the situation is different on ground flat when simulation indicated better performance on ground floor even though the recorded temperature still above the comfort level but not as high as those recorded on top floor. Also the simulation showed that temperature at peak hour (between13:00 and 17:00 O'clock) up to 40°C which is almost 12°C above comfort range. This means that it is impossible to achieve comfort temperature with passive cooling however passive cooling improve significantly temperature within the building. This study can help architects and related stake holders to exploit passive instruments to reduce interior temperature and energy consumption of a building during the design process.

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Abbreviations

ASHRAE…… American Society of Heating, Refrigerating and Air-Conditioning Engineers

DBT…… Dry Bulb Temperature

MRT …….. Mean Radiant Temperature

RH …… Relative Humidity

PMV……. Predicted Mean Vote

PPD…… Predicted Percentage Dissatisfied

SET…… Standard Effective Temperature

CFS…… Complex Fenestration Systems

DV…… Displacement Ventilation

SHGC …… Solar Heat Gain Control

EPBD…….. Energy Performance of Building Directive

1.0. INTRODUCTION

1.1 Background of Study

The chief goal of building is to provide a healthy and comfortable shelter. Thermal comfort improves concentration, workmanship and enthusiasm (Samuel, Nagendrab, & Maiya, 2013). enhancing productivity and quality (Srinavin & Mohamed, 2003) whereas a poor thermal environment results in sickness (Balaras, Dascalaki, & Gaglia, 2007) and (Wolkoff & Kjaergaard, 2007). Conventionally thermal comfort is achieved by energy intensive mechanical air conditioners. They are associated with sick building syndrome in many cases (Seppanen & Fisk, 2002).

It is important for architects to appreciate the manner in which energy is used in buildings as well as the fuel type employed for its generation. This is particularly important because it will help in identifying ways in which we could attempt to reduce our dependency on fossil-fuel, and thus consider new forms of renewable technologies. (Tukur, 2013).

Passive cooling is a building design approach that focuses on heat gain control and heat dissipation in a building in order to improve the indoor thermal comfort with low or nil energy consumption (Samuel, Nagendrab, & Maiya, 2013). Passive cooling systems are energy-efficient and eco-friendly techniques used to improve the thermal comfort with nil or little power consumption. They work either by removing heat from the building to a natural heat sink or by preventing heat from entering the living space from external heat sources. (Chafe,Tukur,& Sagada,2016).

In Nigeria, most buildings rarely take passive architecture and energy efficiency into consideration due to ignorance, poverty, lack of awareness and/or improper policy on building regulations by Government, use of mechanical devices to achieve thermal comfort in buildings is not only capital intensive but also generate greenhouse gases, air and noise pollution amongst others (Nwofe, 2014).

Wong and Li, (2007) states that, with the global emergence of energy shortages, climatic changes and sick building syndromes associated with the common usage of air-conditioning, authorities worldwide have recognized the necessity in finding strategies that can cultivate a more sustainable design with satisfactory indoor thermal comfort. This has led to the growing interest in passive cooling strategies that take advantage of natural ventilation which has the potential to reduce first costs and operating costs for commercial buildings while maintaining ventilation rates consistent with acceptable indoor air quality. One of the main objectives of designing a building is to provide a comfort condition for the building's occupants, while at the same time minimizing the building's energy consumption. (Chafe, *et al.,* 2016). This research deals with the regulation of thermal comfort and building indoor temperature in school of environmental studies.

According to American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE Standards, 2004), thermal comfort is that condition of mind which expresses satisfaction with the thermal environment. Because there are large variations, both physiologically and psychologically, from person to person, it is difficult to satisfy everyone in a space. The environmental conditions required for comfort are not the same for everyone.

1.2 Problem Statement

Buildings consume large amounts of energy in order to achieve thermal comfort for users. Thermal Discomfort affects the quality of teaching and learning in schools. To achieve the goal of thermal comfort in buildings, passive cooling is one of the suggested practices emphasized to be adopted in many buildings around the world of which educational facilities have been a major target as an opportunity of achieving thermal comfort.

In educational facilities, end users who are usually students, lecturers and other occupants spend almost 50% of the entire day within the buildings (Ibrahim, Baharun, Abdul Mannan, & Abang Adenan, 2013). Furthermore, occupancy is predominantly during day time when environmental conditions are adverse to human survival hence creating thermal discomfort which in turn leads to low productivity and occupancy dissatisfaction.

Whilst passive cooling can provide thermal comfort in some climates, a gap of thermal comfort improvement strategies in buildings still exists to enhance suitable thermal condition in buildings thus avoiding occupant dissatisfaction, low productivity and overall building performance. The research seeks to study the passive cooling strategies that suit the hot dry climate of Talata Mafara and also to find out the effect of each strategy applied in the design of School of Environmental Studies AbduGusau Polytechnic, Zamfara State Nigeria.

1.3 Aim and Objectives

The aim of the research is to evaluate the effect of passive cooling strategies for achieving indoor thermal comfort in Design of School of Environment Studies building for AbduGusau Polytechnic Talata Mafara.

The aim of this work has been achieved through the following objectives:

i. Identify various passive cooling strategies that enhance thermal comfort suitable in hot dry climate of Talata Mafara.

ii. To use of computer simulation software to find out the improvements that can be achieved by modifying building components and design elements that enhance thermal comfort for the geographical conditions of Talata Mafara.

iii. To design a proposed school of environmental studies building that will provide a suitable environment for users' comfort.

1.4 **Research Questions**

The main research questions of this study are:

i. What are the appropriate passive cooling strategies which enhance thermal comfort that are suitable in the hot dry climate of Mafara?

ii. What are the possible improvement in indoor temperature and comfort that can be achieved by applying passive cooling strategies?

iii. How can passive cooling be improved through design processes that will provide thermal comfort in the design of school of environmental studies in Mafara?

1.5 Scope of the Study

The research is limited to improving passive cooling in delivering indoor thermal comfort in school of environmental studies, specifically, in hot-dry climate of Mafara. This research focused on evaluating the effect of each strategy on specific factor of thermal comfort. It highlighted the theoretical framework necessary to achieve environmentally-friendly indoor environment. This was coupled with the assessment of existing principles and the consideration of the study area climate. It is also within the scope of this research to highlight the concept of designing for thermal comfort. Finally, the research will develop a theoretical as well as design solutions for enhancing thermal comfort in hot-dry climate of Mafara.

1.6 Justification of the Study

There were several researches about overall passive cooling strategies for buildings and there are various researches about simulations focusing on various particular passive cooling. However, there is a lack of such studies in terms of Mafara climate and built environment. The research will help to get better understanding about the interactive relationship between the buildings' envelop shape and the surrounding environment.

2.0 LITERATURE REVIEW

2.1 Introduction

Humans can and do survive in a range of climates from tropical to high latitude; this ability of humans to acclimatize to different conditions has led to different concepts of the ideal climate. Therefore, what may be considered an ideal climate in one region could be considered uncomfortable in another region. Accordingly, the thermal comfort differs from region to region. Over the last few decades' researchers have been examining the physical, physiological and psychological responses of people to their environment with the aim to develop an effective model to define and predict comfort temperature.

Until the early 20th century, the only way to control the indoor climate was through passive strategies. With the introduction of mechanical building services, it became a separate profession (Alvarado & Martınez, 2008).The evolution of technology and the development of new artificial systems for lighting and air conditioning, for example the air conditioning equipment developed by Willis H. Carrier in 1902 were great contributions for the internal thermal comfort of buildings. However, for some time, these new systems and the availability of cheap energy made the architects ignore the climatic characteristics of each region, resulting in dependence and indiscriminate use of such systems.

Building form, materials, orientation and urban patterns are the most important design parameters affecting indoor thermal comfort and energy conservation in building scale (Leylian, Amirkhani, Bemanian, & Abedi, 2010). Intelligent configuration and moulding of

the built form and its surroundings can considerably minimize the level of discomfort inside a building, and reduce the consumption of energy required to maintain comfortable conditions (Nayak & Prajapati, 2006).

This chapter reviews the definition of thermal comfort, the process of thermal comfort, physiological, psychophysical, and emphasising physical approaches. In addition, it intends to review the 'adaptive' school of thought where adaptive factors are added. Also this chapter review how passive cooling can be applied to enhance thermal comfort. Finally this chapter develop a conceptual frame work of this research

2.2 The Definitions of Thermal comfort

In 1979, Heschong described 'thermal uniformity' in his book 'Thermal Delight in Architecture'; this led to rigorous field studies on defining thermal comfort. Over recent decades the terminology of thermal comfort has evolved. Initially it was limited to physiological factors then evolved to include physical and psychological aspects. Fanger defines thermal comfort as a function of physiological strain factors, stating that "the sensation experienced by a person was a function of the physiological strain imposed on him by the environment" (Fanger, 1970). The influence of these environmental factors, such as temperature, humidity and air velocity on the human body, are varied and depend on each other. As noted by Givoni, it is impossible to express human responses to the thermal environment as a function of a single environmental factor. Rather he defines thermal comfort as "the absence of irritation and discomfort due to heat or cold" (Givoni, 1981). This definition is similar to that used by the German Institute for Standardization,

the "Deutsches Institute für Normung", (DIN), who defined thermal comfort thus: ‘Thermal comfort for humans being is when the temperature, moisture and movement of the surrounding air are agreeable and neither hotter nor colder, drier nor moister, interior air is desired’ (Hegger, Fuchs, Stark, & Zeumer., 2008)

As a function of psychological factors, ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) defines thermal comfort as “the condition of mind that expresses satisfaction with the thermal environment” (ASHRAE, 2009). This definition is the most internationally recognized definition of thermal comfort. However, this definition has been questioned by Heije, through the view of the definition, it is clearly embraces factors beyond the physical/physiological, it indicates that thermal comfort will be influenced by individual differences in mood, personality, culture and other individual, organizational as well as social factors. Heije states that “This description seems to be quite precise but it is not” and explains that “when comfort is regarded as solely as a subjective mental state it seems elusive, both because it cannot be measured objectively and because it is continuously changing” (Heije, 1994).

Apparently, ‘thermal comfort’ has more than one definition; however, it can be argued that the common ground for all definitions is that a range of environmental and personal factors have to be taken into account for people to feel comfortable (Parsons, 2002). As a ‘physical and psychological approach’, Nicol argues that there is no temperature at which everyone will feel comfortable; comfort is a psychological state defined by climate, culture and economics (Nicol, 2008). In conclusion, the definition of thermal comfort is the condition in which the highest possible percentage of a group is in thermal comfort, with respect to the

physiological, psychological and physical aspects. Therefore studying these factors may offer a better understanding of the notion of thermal comfort.

The thermal comfort, complex interaction between man and the environment has led to numerous studies by researchers from different disciplines; physiologists, psychologists, social scientists, environmental engineers and physicists (Nicol, 2012). Each discipline has its own approach to defining thermal comfort. Thus, thermal comfort, as it is based on human subjective perception of a number of external influences such as physiological, psychological, and physical factors, can be perceived as a comprehensive context of the notion of thermal comfort. For the purposes of this research, this comprehensive definition is adopted. Thermal comfort is introduced as a status that is basically influenced by physiological, psychological and physical factors. These three factors influence the thermal comfort level through various aspects as summarized in the diagram shown in figure (2.1).

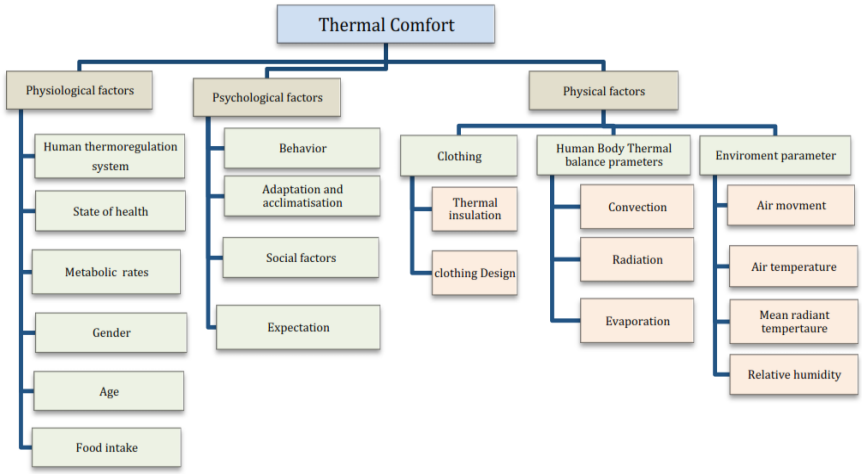


Figure 2.1: Factors that influence human comfort.

Source: Hegger, et al., 2008

2.3.1 Physical factors

Physical factors are considered the most important factors in human thermal comfort, and are the most studied in the field. These factors can be categorized into three groups;

Human body thermal balance parameters, clothing parameters and environment parameters

2.3.1.1 Human body thermal balance parameters

The human body produces energy by metabolizing food but only 20% of this energy is utilized, the remaining 80% is 'surplus' heat and must be dissipated to the environment (Koenigsberger, 1974). Therefore, to maintain its thermal balance the human body loses heat to its environment in three ways: convection, radiation and evaporation.

2.3.1.2 Clothing insulation

Clothing is considered as a second skin for the human body that offers thermal protection from the environment. It is a thermal resistance layer that controls the level of heat-loss from the body to the surrounding atmosphere (Evans, 1980). The thermal insulation value is expressed in terms of *clo* units, where one *clo* is the amount of thermal resistance which "is necessary to maintain thermal comfort for a sitting – resting subject in a normally ventilated room (air movement 0.1m/sec) at a temperature of 21.1oC and RH< 50%" (1 *clo* = 0.155m2K/W). International standards have set one *clo* equal to the value of a standard Western business suit.

2.3.2 Environmental factors

There are four main environmental parameters that effect thermal comfort condition, the air temperature, mean radiant temperature, air movement and relative humidity.

2.3.2.1 Air Temperature.

Without the influence of other environmental factors (radiation, air movement, and relative humidity), the temperature is an important factor in determining thermal comfort, as 2/5 of the heat loss from the body is by convection within the room (Parsons, 2010). It is most often measured using a dry bulb thermometer; hence it is also called the dry bulb temperature (DBT). Griffith's points out that having the 'right temperature' was one of the things people considered most important in a building. Thus, in order to maintain the temperature in the thermal comfort zone, it must normally be between 16˚C to 30˚C for daytime rooms and lower for sleeping rooms. The temperature experienced by a person in a building also includes the effect of radiation from the surrounding walls and possible direct radiation from the openings. However, if the temperature is above or below this level, thermal comfort can only be achieved through increasing or decreasing the level of activity, the thermal resistance of clothing, or the amount of air movement.

2.3.2.2 Mean Radiant Temperature (MRT).

Mean Radiant Temperature is the temperature of a uniform black enclosure in which a solid body or inhabitant will exchange the same amount or radiant heat as in the existing non-uniform environment, (Lewis., et al 1992,). With respect to the human body the ISO standard defines the MRT thus: "the mean radiant temperature is the uniform temperature of an

imaginary enclosure in which radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure" (Parsons, 2010). MRT influences heat loss in two ways: the first is by conduction (when the occupant makes contact with the surface). The second is by radiant heat loss. Therefore, discomfort will be experienced when the MRT is above or below the air temperature by a few degrees (approximately 5˚C); in addition, an MRT value of 2-3 degrees above air temperature can enhance comfort. Moreover, discomfort can result from the effect of intense incoming solar radiation on the other side of the surface, causing a high level of outgoing radiation. Using an appropriate thickness of a suitable insulation for the external walls of the room will reduce the MRT to close to the room temperature.

2.3.2.3 Air movement (Air velocity)

Air movement affects heat loss from the body through convection. The association of air movement, and air temperature is important. For example in a hot climate, an increase in air movement will increase the amount of heat loss from the body, as well as increasing the evaporative cooling from the skin. This could provide thermal comfort; it is indicated by (Lewis *et al.,* 1992,) that within buildings the air speed is generally less than 0.2m/s. which is generally unnoticed, as under everyday conditions the average subjective reactions to various velocities are shown in the following table 2.1

Table 2-1 Air velocity

Air velocity m/s	**the average subjective reactions**
< 0.25	Unnoticed
0.25-0.50	Pleasant
0.50-1.00	Awareness of air movement
1.00-1.50	Draughty
> 1.50	Annoyingly draughty

Source; Anderson 2006

2.3.2.4 Relative Humidity

The relative humidity comfort value ranges from 20% to 80%. So, if it is below 20% a distinct discomfort will be experienced because of the dryness, or if it is above 80% it will create a feeling of dampness (ideally the level should not drop below 40% and not exceed 70%). It is known that human tolerance toward humidity is much greater than towards temperature, but at a high level of RH comfort starts to be rapidly affected. At such high levels it is necessary to decrease temperature in order to maintain comfort. For instance, the increase of the relative humidity from 20% to 60% will need a decrease in the temperature of 1oK (Markus and Morris, 1980) to maintain comfort.

2.3.2.5 Operative Temperature

Operative temperature (t!") Is used in most of the standards such as ASHREA 55 and

CEN EN 15251 in the adaptive section to predict comfort temperature. Nicol states that the operative temperature is a sufficient thermal index to define the neutral temperature when the air movement is slight and humidity is not excessive (Nicol, 2012).

The operative temperature is a theoretical and not an empirical measure, it is measured as the result of combining the air temperature (dry bulb temperature (t!") and the mean radiant temperature (t!),in effect it is the weighted average of the two temperatures, the weights depending on the heat transfer coefficient by convection (h!) and by radiation (h!) at the clothed surface of the occupant (Nicol *et al.*, 2012,). The operative temperature can be calculated as follows:

It can be calculated from the air velocity and air temperature and mean radiant temperature as:

$$\boldsymbol{top} = \boldsymbol{A}.\ \boldsymbol{ta} + \mathbf{1} - \boldsymbol{A}\ .\ \boldsymbol{tr}.$$

Where t!" is the operative temperature ℃, (t!) is the air temperature ℃. t! is the mean radiant temperature ℃, A is a factor according to the relative air velocity (A = 0.5 for v!"# = 0.2m, A = 0.6, for v!"# = 0.2 − 0.6 , A = 0.7for v!"# = 0.6 − 1.0), (Engineers, 2009). Therefore, approximately, at indoor air speeds below (0.1 m), the operative temperature can be calculated as:

$$\boldsymbol{top} \approx \boldsymbol{ta} + \boldsymbol{tr}\ \mathbf{2}$$

However because it is not an empirical measure, in practice it approximates very closely to the 40 mm globe temperature.

2.3.2 Thermal Comfort Calculation

It is possible to measure the environmental variables at a suitable number of points in the occupied zone in a given space, but these measurements should be interpreted in order to predict the comfort level in that zone. Due to the number of interacting factors affecting human comfort, including personal preferences, the prediction of thermal comfort is not an easy task.

Throughout the last few decades, researchers have been exploring the thermal, physiological and psychological response of people in their environment and developed several models to predict comfort. Of this range of models, just two are selected to be discussed here which are the predicted

Mean Vote (PMV) model and the Adaptive principle, that because these two models are widely known for predicting steady-state thermal comfort. The first model is based on the heat balance of the human body while the second is an approach that assumes, to a certain degree, an adaptation to the thermal environment.

2.3.3.1 The predicted Mean Vote (PMV)

PMV (Fanger, 1970) describes the conditions for climatic comfort, and methods and principles for evaluating and analysing different environments from a climate point of view, with the indices of predicted mean vote (PMV) and predicted percentage dissatisfied (PPD). The concept defines conditions that must be fulfilled in order for a person to be in “whole body” climate comfort. An additional condition is the absence of any local climate discomfort. The intention was to develop a comfort equation where the six factors are needed

in order to calculate in which thermal state “a normal” person is found. These calculation and estimation methods are used over the world and known as an international standard (ISO7730, 2006) And so the PMV equation is given as below:

PMV= [0,303. exp (-0.036.M +0,028]. {(M - W) - 0, 00305 [5733 - 6, 99. (M - W}-Pa] - 0, 42. [M-W-58,15] (1,7.10-5).M.(5867-Pa) - 0,0014 .M. (34-ta) - (3,96.10-8)/∫C1.[(Tc1+ 273)4 - (tr + 273)4] - [∫C1 .(hc .(tc1 - ta)]}

Where,

M: metabolic rate, (W/m2)

W: effective mechanical power, (W/m2)

∫c1: clothing surface area factor

ta: air temperature, (°C)

tr : mean radiant temperature, (°C)

pa: water vapour partial pressure, (pa)

hc: convective heat transfer coefficient, W/m2.K t

c1: clothing surface temperature, (°C)

PMV is "scaled" to predict thermal sensation votes on a seven point scale (hot

3, warm 2, slightly warm 1, neutral 0, slightly cool -1, cool -2, cold -3.

Negative values indicate an uncomfortable feeling due to a cold sensation. Positive values indicate an uncomfortable feeling due to a hot sensation where. Zero is the neutral point, representing the comfort state. The major limitation of the PMV model is the explicit

constraint of skin temperature and evaporative heat loss to values for comfort and 'neutral' sensation at a given activity level.

2.3.3.2 The Adaptive Principle

The adaptive principle suggests that people will adapt to certain climatic conditions. For instant, in warmer climate, when environmental thermal comfort parameters point at a higher PMV, people will become adaptive to the higher temperatures and still feel comfortable. As an analogy, a corresponding "PMV principle" could be written as: No change should occur that produces discomfort. In a properly designed environment, will people maintain their comfort? (Raja Nicol; Humphreys, 2001). The adaptive principle is supported by field studies in many different environments, and from these global field studies of thermal comfort rating and temperatures, (Humphreys, 2012) found that comfort temperature differed between groups of people. This means that comfort conditions calculated with the heat balance models did not fully agree with the comfort conditions that found in the field. By linking the comfort temperature to the climatic situations in which individuals find them. Comfort temperature is a result of the interaction between the subjects and thermal environment. Humphreys (2012) has analysed many of the completed questionnaire studies of comfort, and found the face value of comfort zones ranged from 17°C in England to 30°C in Iraq and India.(Nicol and Humphreys, 2012) also conclude that people with more opportunities to adapt themselves to the environment will be less likely to suffer discomfort. The main input of the adaptive models is the monthly mean outdoor temperatures T and then comfort temperatures Tc or ranges of T could be determined. Since adaptive models are based mainly on human behaviour and outside weather conditions, they are usually based on extensive surveys of

thermal comfort in a wide range of buildings, climates, and cultures. According to adaptive models, the comfort temperature Tc could be determined by the following equations (ASHRAE,2009);

Tc =75.6 + 0.43(t out - 71.6)exp – [t out – 71.6 / 61.1] 2

For climates and buildings where cooling and central heating are not required, the operative comfort temperature t is determined by the equation:

Toc = 66 + 0.142 (t out - 32)

In general, the adaptive model is essentially a regression equation that relates the desired temperature indoors to the monthly average temperature outdoors. The only input variable used is the average outdoor temperature, which has an indirect impact upon the human heat balance. Consequently, the adaptive model does not include the six classical thermal parameters that have an impact upon the human heat balance and, therefore, upon thermal sensation.

2.3.3 Comfort Zone

According to Çakir (2006), the comfort zone may be defined as "a thermal condition in which little or no effort is required by occupants to adjust their bodies to surrounding environmental conditions". The greater the effort that is required, the less comfortable the climate is felt to be. However, it is the aim of the designer to build houses that provide an indoor climate close to an optimum, within a certain range in which thermal comfort is still experienced. This range is called the comfort zone. It differs somewhat with individuals. It depends also on the

clothing worn, the physical activity, age and health condition. Although ethnic differences are not of importance, the geographical location plays a role because of habit and of the acclimatization capacity of individuals. Four main factors, beside of many other psychological and physiological factors, determine the comfort zone:

i. air temperature
ii. temperature of the surrounding surfaces (radiant heat)
iii. relative humidity
iv. air velocity

).

A number of scales were developed for comfort zone, some of them are shown in Table (2.2).

Table 2-2: Thermal sensation scales_

	ASHRAE	Fanger	Rohles & Nevins	Gagge's DISC	SET* (°C)
Painful			+5	+5	
Very hot			+4	+4	37.5-
Hot	7	+3	+3	+3	34.5 – 37.5
Warm	6	+2	+2	+2	30.0 – 34.5
Slightly warm	5	+1	+1	+1	25.6 – 30.0
Neutral	4	0	0	0.5	22.2 – 25.6
Slightly cool	3	-1	-1	-1	17.5 – 22.2
Cool	2	-2	-2	-2	14.5 – 17.5
Cold	1	-3	-3	-3	10.0 – 14.5
Very cold			-4	-4	

*SET: Standard Effective Temperature **Source: Rosenlund (2000)**

Another scale of comfort zone is ASHRAE which has defined a comfort zone for winter (cold) and summer (hot) seasons. This definition is only depends on relative humidity and temperature (Evans (1980). Evans shows that there are different comfort zones defined in five successive ASHRAE standards. They also show difficulty of defining a desirable comfort zone, with significant variations proposed over a period of thirty years. Basically, the possibilities of comfortable clothing limit the acceptable thermal swing to 8 degrees, a lower swing than originally proposed.

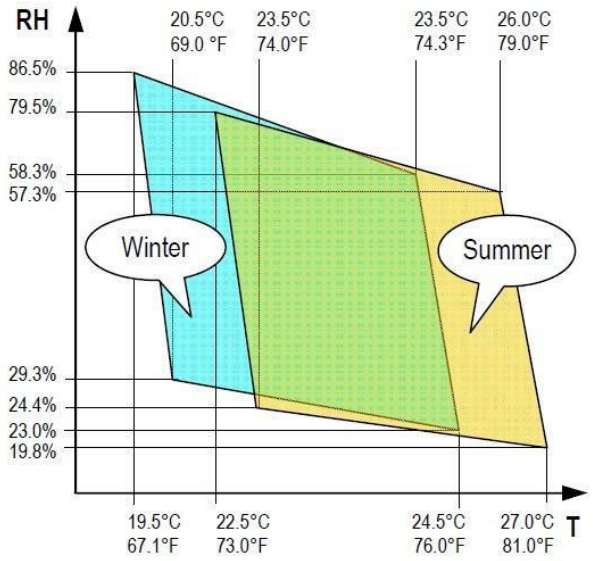


Figure 2.2: Relative humidity (RH) / temperature (T) diagram based on comfort zone According to ASHRAE 55-1992

2.3.4 Bioclimatic Charts

The most commonly used bioclimatic charts are Olgyay and Givoni's Bioclimatic Chart. Olgyay (1969), expresses the comfort zone in graphic form taking into consideration two climatic variables which are the dry bulb temperature DBT on the vertical axis and the relative humidity RH on the horizontal. The comfort zone is laying in the aerofoil shaped zone at the centre of this graph. The higher lines above this comfort zone indicate the effect of air movement on extending the upper boundary of the comfort zone. The lower lines below the comfort zone indicate various levels of radiation that would compensate for the lower than comfortable temperatures. The desirable comfort zone indicated lies between 30% and 65% relative humidity (Olgyay, 1992). It is worth to mention that comfort zone here is directly applicable to inhabitants of the temperate zone of approximately 40° latitude.

Figure (2.3) illustrates Olgyay's Bioclimatic chart.

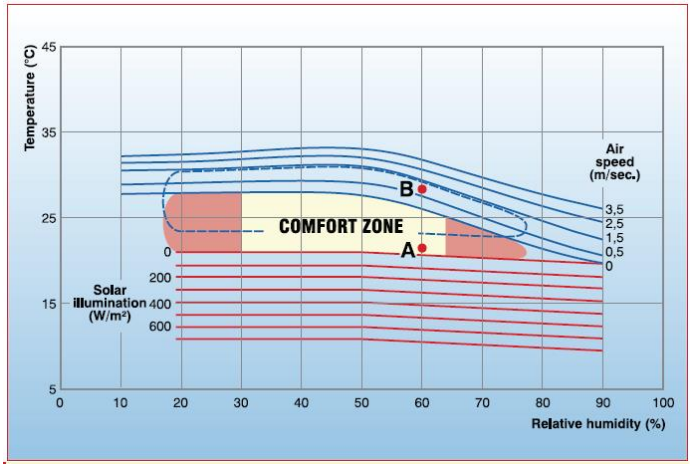


Figure 2.3: Bioclimatic Chart showing comfort zone (Source: Somfy Group, 2009)

2.3.5.1 Psychrometric Chart

Szokolay, (2008) stated that the Standard Effective Temperature SET is the latest comfort index now generally accepted. The SET combines the effect of temperature and humidity and is defined as *"the equivalent air temperature of an isothermal environment at 50% RH in which a subject, wearing clothing standardized for the activity concerned, has the same heat stress (skin temperature Tsk) and thermoregulatory strain (skin wettedness* w) *as in the actual environment"* (ASHRAE, 2009). The comfort zone for any location and for different month can be plotted on the Psychrometric chart (Figure 2.4) as follows; (Szokolay, 2008)

1. Establish the average temperature of warmest and coldest months (Tav)

2. Find the neutrality temperature for both and the limits of comfort

Neutral temperature Tn =17.6+ 0.31* Tav ……eq

Lower limit: TL= Tn- 2.5 Upper limit: TU = Tn + 2.5

3. For the side boundaries, either by following the slope of SET lines on the Psychrometric chart or constructing the corresponding sloping SET lines by determining the X-axis intercept from:

+ 0.023*(TL – 14) * AH50……eq.

T = TU + 0.023 * (TU -14) * AH50 ……..…….eq.

(Where AH50 is the absolute humidity (g/kg) at the RH 50% level at the TL and TU)

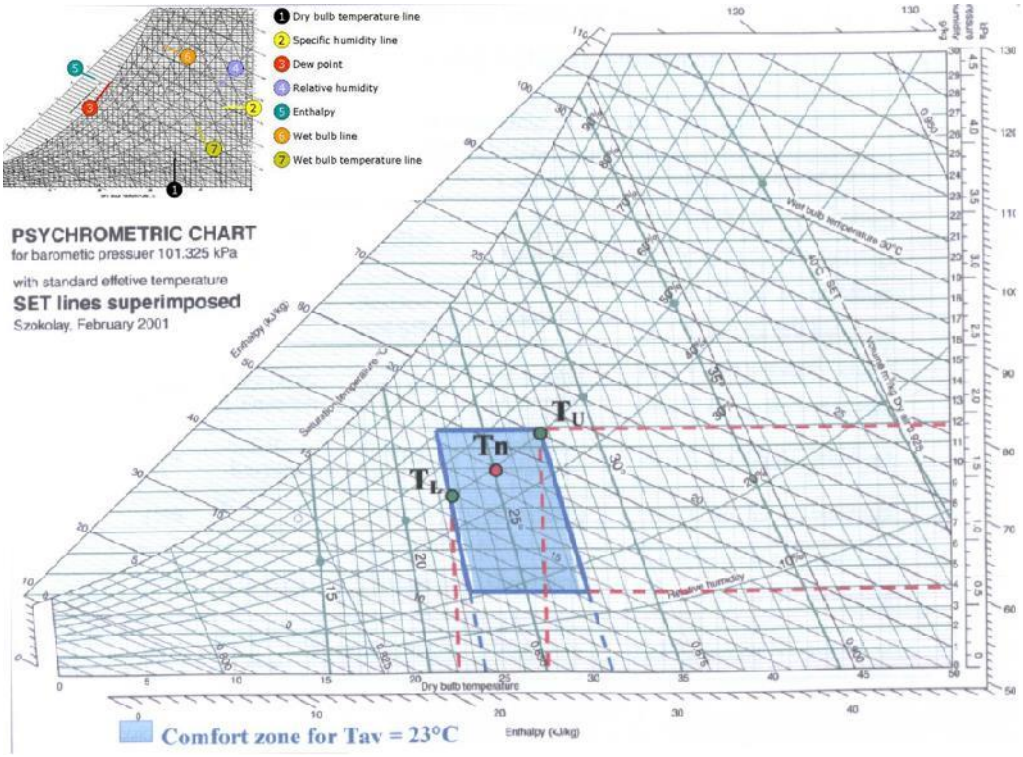


Figure 2.4: Psychrometric chart. Source: Szokolay, 2008

2.3.5 Thermal Comfort Scales

Thermal sensation and thermal comfort are different but closely associated in the study on thermal comfort. Thermal sensation depends on skin temperature (cold through hot) while thermal comfort depends on the desired physiological state, uncomfortable through comfortable (Nicol et al, 2012). The scales used to measure these processes are briefly illustrated below;

The ISO 7730 provides a method of assessing moderate thermal environments using the PMV/PPD index, but also includes some criteria for local comfort. PMV is calculated using temperature, mean radiant temperature, humidity and air velocity of the environment as its

basis, the thermal scale of -3 to 3 range that deviates from 0 (neutral) in either direction, developed by Fanger (1970) and later used as an ISO standard.

Also, the standard specifies ‘classes’ or ‘categories’ of buildings according to the range of PMV that occurs within them: so Class A buildings maintain their indoor environment within ± 0.2 PMV (PPD≦ 6%), Class B ±0.5 PMV

(PPD≦10%), and Class C ± 0.7 PMV (PPD≦ 15%)

European Standard EN15251 was developed by Comité Européen de Normalisation (CEN) in response to calls from the European Union for standard to back up the Energy Performance of Buildings Directive (EPBD). The standard includes consideration of other aspects of the environment such as indoor air quality, lighting and acoustics as they impinge on the energy use of a building (Nicol, 2012). The standard follows the general lines of ASHRAE standard, although, EN15251 uses categories for buildings they are defined by the nature of the building rather than referring directly to the quality of their indoor environment (Table 3.6). These current comfort standards, (ISO 7730 ISO, 2005) determine design values for operative temperatures in school classrooms, based on the heat balance and the adaptive thermal comfort model respectively. However, there is no assurance that results from comfort studies performed in climate-control chambers, such as offices or university classrooms which reflect the thermal sensation and preference of school children.

Table 2-3: Suggested applicability of the categories and their associated acceptable temperature range –

Category	Explanation	Suggested acceptable range
I	High level of expectation only used for spaces occupied by very sensitive and fragile persons	±2K
II	Normal expectation (for new buildings and renovations)	±3K
III	Moderate expectation (used for existing buildings)	±4K
IV	Values outside the criteria for the above categories	(only acceptable for a limited periods)

Source: British Standards (BSI, 2007)

ASHRAE, the American Society of Heating Refrigeration and Air Conditioning Engineers controls and sponsors ASHRAE standard 55. This standard was the first international standard to include an adaptive component. Following the extensive work of (De and Brager, 2002) and using data collected in ASHRAE project RP884 (De, 1994) an adaptive standard was developed that applies to natural conditioned buildings in which the principle means of control of indoor temperature is the use of windows. See Figure 3. 10 which describes the acceptable temperature ranges. The standard utilizes the relationship between the indoor comfort temperature and outdoor thermal temperature. These standard defines zones within

which 80% or 90% of building users might expect to find the conditions acceptable. The zones are based on the comfort equation for naturally conditioned buildings derived from the RP884 ASHRAE database;

T comf = 0.31 To + 17.8 ..... eq.

T comf is the optimal temperature for comfort and To is the mean outdoor temperature for RP884 ASHRAE survey.

T accept = 0.31 To + 17.8 _+ T lim……..... eq.

Where T accept gives the limits of the acceptable zones and T lim is the range of acceptable temperatures; for 80% = 3.5 K and 90% = 2.5K.

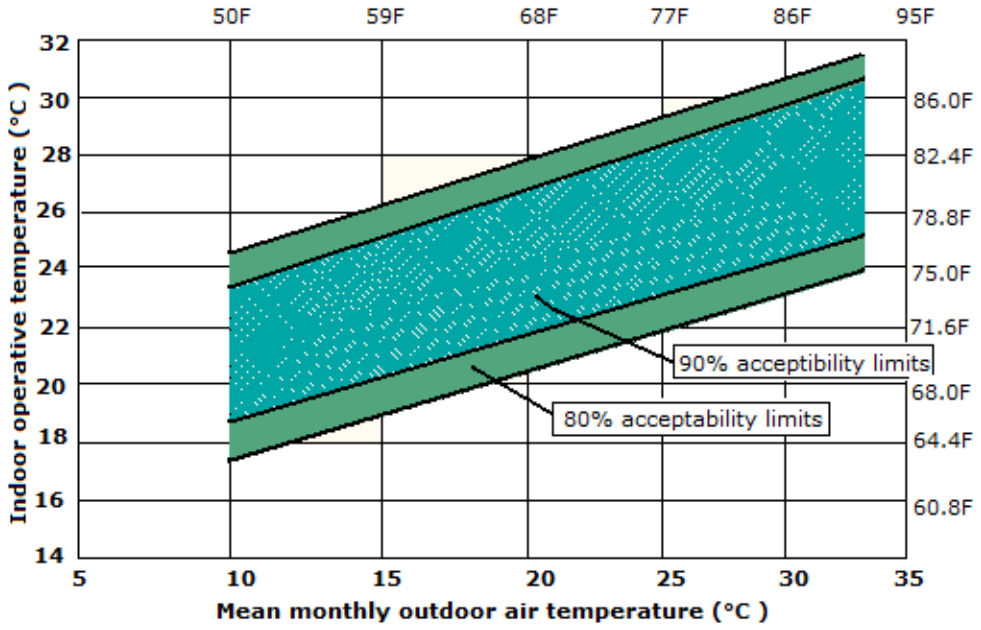


Figure 2.5: Acceptable operative temperature ranges for naturally conditioned buildings_ source: ASHRAE Standard 55, (2004)

The **Bedford scale** was criticised on the ground that it consists of semantic relationship between warmth and comfort which may not be necessarily constant, whereas the ASHRAE scale contains no explicit reference either to comfort or pleasantness (Humphreys, 1976). However, it was later reported that the two scales in practice behave in a very similar way, and the results obtained by them may be compared directly with each other. Givoni used another method to scale the thermal sensation; he also used seven levels in his scale, which is showing in the Table 2.4

Table 2-4: Categories of Votes for Thermal Sensation.

ASHRAE	**Scale**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Description		**Very cold**	**Cold**	**Slightly cold**	**Neutral**	**Slightly Un cold**	**Un Cold**	**Very Un cold**
Fanger	**Scale**	**+3**	**+2**	**+ 1**	**0**	**_ 1**	**_ 2**	**_ 3**
Description		**Hot**	**Warm**	**Slightly warm**	**Neutral**	**Slightly cool**	**Cool**	**Cold**
TS-Givoni method	**scale**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Description		**Very cold**	**Quite cold**	**Cold**	**Comfort**	**Hot**	**Quite hot**	**Very hot**

Source: British Standards (BSI, 2007)

The main difference between the Bedford scale and the ASHRAE scale is the inclusion of comfort in the Bedford scale (Nicol, Hunphreys, & Roaf, 2012). Bedford (Bedford, 1936) combines thermal sensation and comfort using a 7-point scale: much too warm, too warm, comfortably warm, comfortable, comfortably cool, too cool, much too cool, whereas in

ASHRAE 55 (ASHRAE 55, 2010) thermal sensation is defined with seven categories: cold, cool, slightly cool, neutral, slightly warm, warm, and hot without indication of pleasantness or comfort (ASHRAE 55, 2010). Due to different interpretations of the words in a descriptive scale in cold and warm climates, a “preference vote” is suggested to be added to the “comfort vote” (Nicol, Hunphreys, & Roaf, 2012). Brager et al, (2002) note that a combination of scales has been used in both field and laboratory studies. In addition to the commonly used 7-point

ASHRAE thermal sensation scale, the 3-point McIntyre preference scale (McIntyre, 1978) has been used to explore acceptability of the thermal environment by asking the direct question, with possible responses of "warmer", "no change", "cooler". Thermal acceptability can be measured indirectly through voting within the three central categories of the seven-point thermal sensation scale (slightly cool, neutral and slightly warm) — but this is not necessarily equal to a direct measure of acceptability, since neutral temperature in cold climates is lower than the optimum or preferred temperature and vice versa in warm climates (McIntyre, 1978).

Therefore to conclude, it has been found that among these four scales considered above, are both ASHRAE and Bedford scales, considering that the researcher used ASHRAE scale in this study to measure the thermal comfort in the case study buildings and subsequently in case study city.

2.4 Passive Cooling of buildings

Cooling is the transfer of energy from a space or from the air, to a space, in order to achieve a lower temperature than that of the natural surroundings. In recent years, air conditioning systems are used to control the temperature, moisture content, circulation and purity of the air within a space, in order to achieve the desired effects for the occupants. The shortage of conventional energy sources and escalating energy costs have caused the re-examination of the general design practices and applications of air conditioning systems and the development of new technologies and processes for achieving comfort conditions in buildings by natural means.

In recent years, the rapid economic growth in some of the thickly populated nations has stimulated the utilization of sustainable energy sources and energy conservation methodologies considering environmental protection. Globally, buildings are responsible for approximately 40% of the entire world's annual energy consumption (Omer, 2009). Most of this energy is for the provision of lighting, heating, cooling and air-conditioning. The increasing level of damage to the environment has created greater awareness at the international level, which resulted in the concept of green energy building in the infrastructural sector. Hence, the major focus of researchers, policy makers, environmentalists and building architects has the conservation of energy and its utilization in buildings. It is further established that alternative energy sources, techniques and systems can be used to satisfy a major portion of the cooling needs in buildings.

This topic, natural and passive cooling, covers all natural processes and techniques for cooling buildings. It is cooling without any form of energy input, other than renewable

energy sources. Passive cooling techniques are also closely linked to the thermal comfort of the occupants. It is also possible to increase the effectiveness of passive cooling with mechanically assisted heat transfer techniques, which enhance the natural cooling processes discussed by (Santamouris, Balaras, Dascalaki, Argiriou, & Gaglia, 1996). Such applications are called “hybrid “cooling systems. Energy consumption is maintained at very low levels, but the efficiency of the systems and their applicability is greatly improved.

The passive cooling of buildings is broadly categorized under three sections

i. Heat prevention/reduction, (Reduce heat gains)
ii. Thermal moderation (Modify heat gains) and
iii. Heat Dissipation (Remove internal heat).

The various methods adopted for each of these, are further classified and given in Fig. 2.6

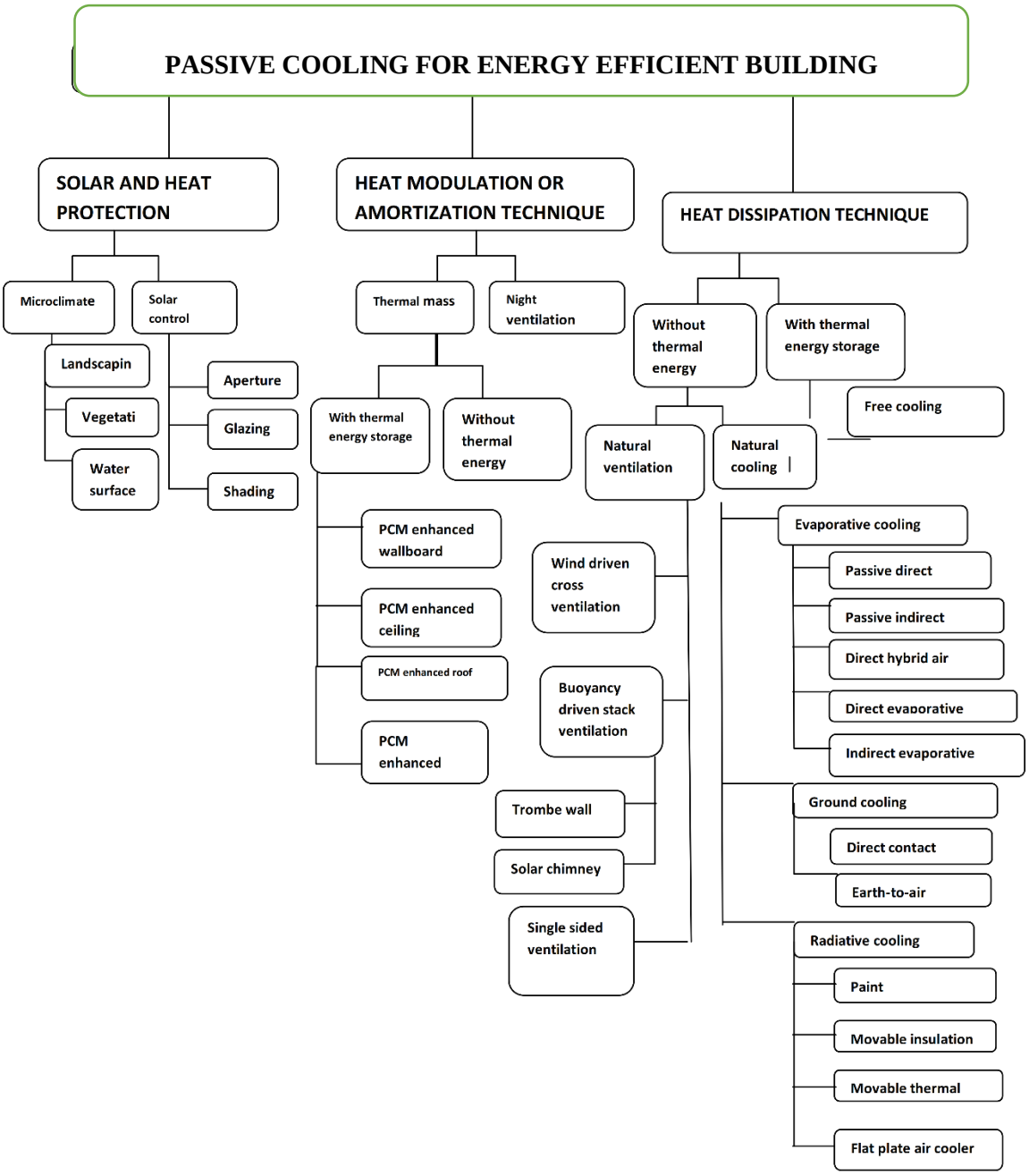


Figure 2.6: Classification of passive cooling methods in energy efficient building

Source: (Geetha & Velraj, 2012)

2.4.2 Solar and heat protection techniques

A building must be adapted to the climate of the region and its microclimate (Asimakopoulos, 2013). It is very important to minimize the internal gains of a building in order to improve the effectiveness of passive cooling techniques. The site design is influenced by economic considerations, zoning regulations and adjacent developments, all of which can interfere with the design of a building, with regard to the incident solar radiation and the available wind. Vegetation can not only result in pleasant outdoor spaces, but can also improve the microclimate around a building and reduce the cooling load. Solar control is the primary design measure for heat gain protection.

2.4.2.1 Microclimate

Climate is the average of the atmospheric conditions over an extended time over a large region. Small-scale patterns of climate, resulting from the influence of topography, soil structure, ground and urban forms, are known as microclimates. The principal parameters characterizing climate are air temperature, humidity, precipitation and wind.

The climate of cities differs from the climate of the surrounding rural areas, due mainly to the structure of cities and the heat released by vehicles. In general, the climate in cities is characterized by ambient temperatures, reduced relative humidity, reduced wind speed and reduced received direct solar radiation.

The microclimate of an urban area can be modified by appropriate landscaping techniques, with the use of vegetation and water surfaces, and can be applied to public places, such as parks, play-grounds and streets (Givoni, 1991)

The first stage in managing higher future internal temperatures in buildings is to attempt to make the external air as cool as possible. Within the built environment this involves enhancing the green and blue infrastructure of parks, trees, open spaces, open water and water features. There is a growing interest in the use of rooftop gardens, green walls and green roofs for their cooling effect (Liu & Baskaran, 2003)Parks and other open green spaces can be beneficial through their cooling effects in summer, through shading and transpiration (Gill, Handley, Ennos, & Pauleit, 2007) and improved access for natural wind-driven ventilation. In addition, the presence of water, plants and trees contributes to microclimate cooling, and is an important source of moisture within the mostly arid urban environment (Robitu, Musy, Inard & Groleau, 2006) urban surfaces should be cool or reflective to limit solar gain. Pavements, car parks and roads can be constructed with lighter finishes and have more porous structures. Limor, David & Evyatar (2009), studied the climatic analysis of landscape strategies for outdoor cooling in a hot-arid region, considering the efficiency of water use. Six landscape strategies were studied, using different combinations of trees, lawn, and an overhead shade mesh.

2.4.2.2 Vegetation

Vegetation modifies the microclimate and the energy use of buildings by lowering the air and surface temperatures and increasing the relative humidity of the air. Furthermore, plants can control air pollution, filter the dust and reduce the level of nuisance from noise sources. Indoor simulations still tend to be isolated from an important element affecting urban microclimate, such as urban trees. The main advantage of urban trees, as a bioclimatic responsive design element is to produce shade, whereas its main disadvantage is blocking the

wind (Yoshida et al, 2006). In addition the effects of specific urban tree types - for example, the different leaf area densities and evapotranspiration rates of urban trees influence solar access and heat exchanges if planted around buildings (Radhi, 2009) as shown in plate I.



PLATE I: Image showing vegetation

Source: (Dave Pinkney, 2010)

2.4.2.3 Water surfaces

Water surfaces modify the microclimate of the surrounding area, reducing the ambient air temperature, either by evaporation, or by the contact of the hot air with the cooler water surface as shown in plate II. Fountains, ponds, streams, waterfalls or mist sprays may be used as cooling sources, for lowering the temperature of the outdoor air and of the air entering the building.



PLATE II: Image showing Water body

Source: Legislative Assembly of the Northern Territory (2017)

The asphalt and concrete used in urban environments is typically too dense to allow water permeability, and therefore, drastically limits the latent heat exchange. The water and air passage allows latent heat exchange, and therefore decreases the temperature of the pavement. This, in turn, assists trees and other landscape root systems to better access air and nutrients, providing cooler root zones which result in larger and denser shading landscape materials (Goldn, 2007).

2.4.2.4 Solar control

Solar radiation reaches the external surfaces of a building in direct, diffuse and reflected forms and penetrates to the interior through transparent elements. In general, incident radiation varies with geographic latitude, the altitude above sea level, the general atmospheric conditions, the day of the year, and the time of the day. For a given surface, incident radiation varies with the orientation and the surface's angle to the horizontal plane.

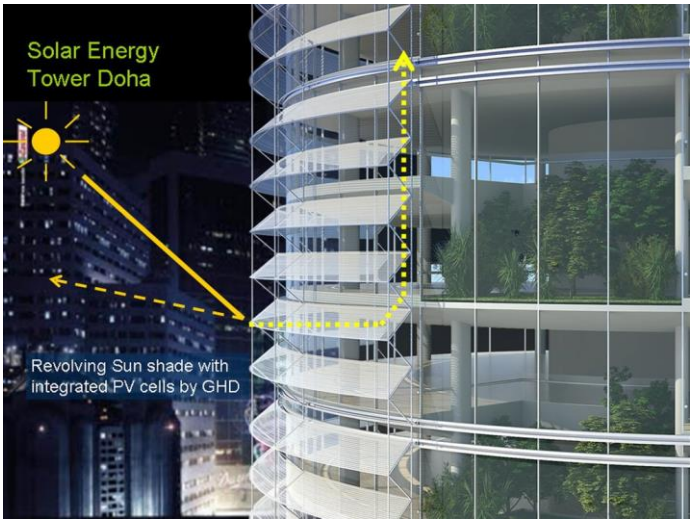


PLATE III: Image showing Shading device for solar protection

Source: (Open building, 2012)

The admission of solar radiation into an interior space may cause problems, such as high indoor temperatures, thermal and visual discomfort to the occupants, damage to sensitive objects and furnishings. Thus, it is of vital importance that solar radiation should be controlled. Solar control denotes the complete or partial, permanent or temporary exclusion of solar radiation from building surfaces or interior or surrounding spaces. Solar control may be achieved through the following techniques.

2.4.2.5 Aperture

The appropriate combination of the orientation, size and tilt of the various openings on the building's envelope is of vital importance. This is because these parameters affect the surface's view of the sun and sky over the daily and monthly cycles. Mazria (1979), defines the best orientation for the solar apertures of a building as one which receives the maximum amount of solar radiation in winter and the minimum amount in summer. Designing the building form from the perspective of energy efficiency means considering the floor area, perimeter, building height and aspect ratio.

2.4.2.6 Glazing

The thermal properties of the glazed surfaces of a building affect the penetration of solar radiation to the interior. The influences of channel width and the dimensions of the inlet and outlet openings affect the convection process, and hence, affect the overall heating performance.

Using double glazing could increase the flow rate by 11-17%. On the other hand, insulating the interior surface of the storage wall for summer cooling can avoid excessive overheating due to south facing glazing (Guohui, 1998).

Transparent selective films represent an interesting option for the control of solar heat gain, to be used to treat windows or façades, especially in existing buildings, to improve the performance of windows and transparent façades. Transparent selective coatings and films are being manufactured nowadays by all major glass and glazing companies all over the

world. They represent quite an advanced technology and are being increasingly used in double and even triple glazing systems to improve window performance.

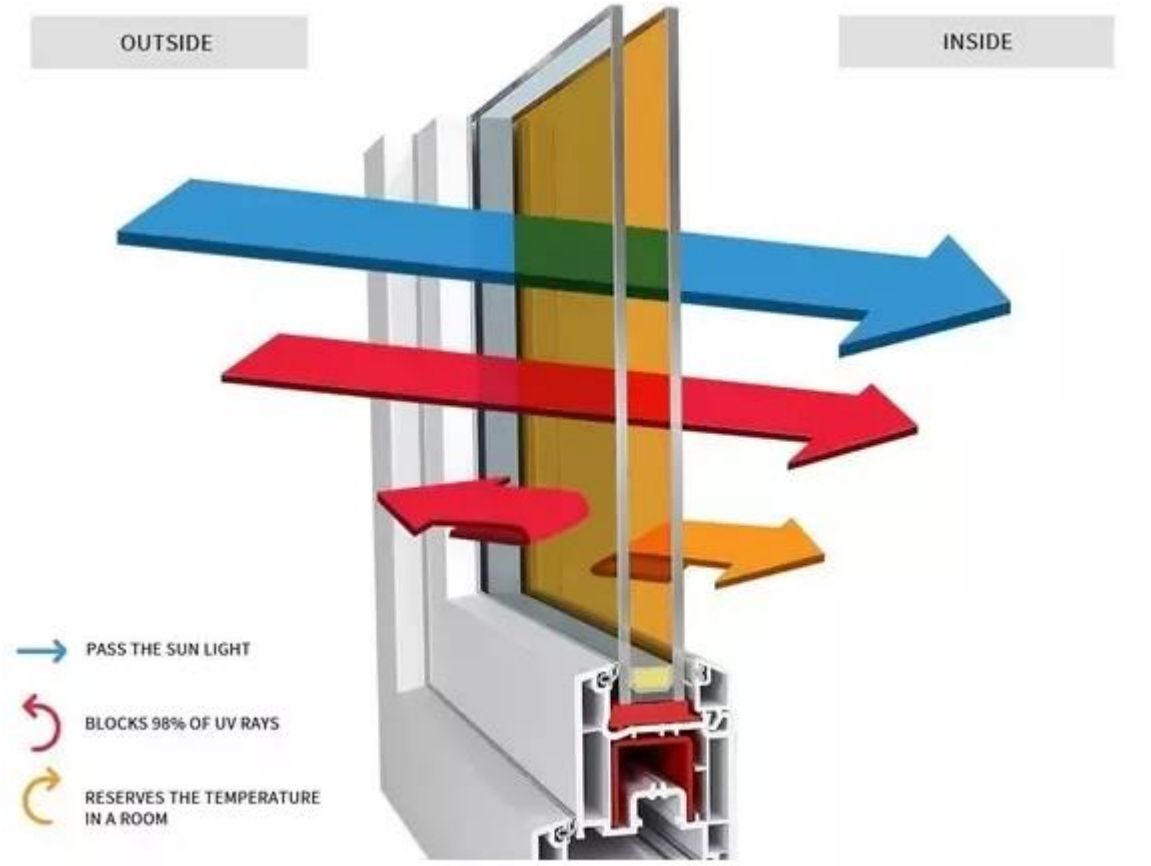


Figure 2.7: showing glazing properties reflecting UV rays

Source: (Buster Smith, 2016)

Many researchers have investigated the optical properties of selective coatings and films for window applications. Roos et al. (2001) investigated the effect of the angle of incidence of solar radiation on the optical properties of solar control windows. Nostell, (2000) presented the results of a wide experimental campaign on various coatings, while Durrani et al. (2004)

measured the optical properties of three-layer systems on glass substrates. The modelling of complex fenestration systems (CFS), including multi-layer glass panes, solar control films, translucent materials and shading devices, has been done by various researchers.

2.4.2.7 Shading

Shading denotes the partial or complete obstruction of the sunbeam directed toward a surface by an intervening object or surface. The shadow varies in position and size depending upon the geometric relationship between the sun and the surface concerned.

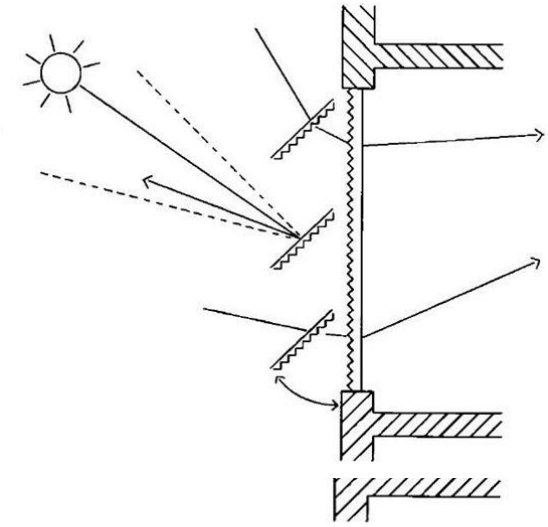


Figure 2.8: Image showing an example of a moveable exterior shading device

Source: (what-when-how ‘’WWH’’ , 1999)

Shading devices are essentially a second link between day lighting and the thermal performance of perimeter spaces. Thus, an integrated analysis should be carried out in order to take into account the interactions between the different parameters and to attain optimal results. However, with a few exceptions, an integrated façade analysis is not applied at the early design stage, when critical decisions with small economic impact could lead to

significant energy savings during the lifetime of the building, and a simultaneous improvement in interior conditions (Clarke 2001).

2.4.3 sHeat modulation or amortization technique (*Modify heat gains)*

The thermal management of a building could be achieved by two methods. In the first method the thermal mass of a building (typically contained in walls, floors, partitions - constructed of materials with high heat capacity) absorbs heat during the day and regulates the magnitude of indoor temperature swings, reduces peak cooling load and transfers a part of the absorbed heat to the ambient in the night hours. The remaining cooling load can then be covered by passive cooling techniques. In the second method the unoccupied building is pre-cooled during the night by night ventilation, and this stored coolness is transferred into the early morning hours of the following day, thus reducing energy consumption for cooling by close to 20% (Brown, 1990).

2.4.4 Heat dissipation technique (*Remove internal heat)*

In many cases, the avoidance and modulation of heat gains cannot maintain indoor temperatures at a control level. A more advanced cooling strategy includes heat rejection to heat sinks, such as the upper atmosphere and the ambient sky, by the natural processes of heat transfer. The design of a building is a very important factor which influences the cooling potential of a natural cooling technique. Natural cooling refers to the use of natural heat sinks for excess heat dissipation from interior spaces, including: natural ventilation, evaporative cooling, ground cooling and radiative cooling, and also the use of a PCM based system for free cooling.

2.4.4.1 Natural ventilation

Natural ventilation is the most important passive cooling technique. In general, the ventilation of indoor environments is also necessary to maintain the required levels of oxygen and air quality in a space. Traditionally, ventilation requirements were achieved by natural means. In the majority of older buildings, infiltration levels were such as to provide considerable amounts of outdoor air, while additional requirements were satisfied by simply opening the windows.

Modern architecture and the energy-conscious design of buildings have reduced air infiltration to a minimum, in an attempt to reduce its impact on the cooling or heating load. Better construction has resulted in buildings being sealed from the outdoor environment. In particular, the construction of large glass office-buildings, which do not allow the opening of windows, has further eliminated the possibility of using natural ventilation for supplying fresh air to indoor spaces. The successful design of a naturally ventilated building requires a good understanding of the air flow patterns around it and the effect of the neighbouring buildings. The objective is to ventilate the largest possible part of the indoor space. The fulfilment of this objective depends on the window location, interior design and wind characteristics.

2.4.4.2 Wind-driven cross ventilation

Wind-driven cross ventilation occurs via ventilation openings on opposite sides of an enclosed space. Figure 2.9 shows a schematic of cross ventilation serving a multi-room building. The building floor span depth in the direction of the ventilation flow must be limited

to effectively remove the heat and pollutants from the space by typical driving forces. A significant difference in wind pressure between the inlet and outlet openings and a minimal internal resistance to flow are needed to ensure sufficient ventilation flow.

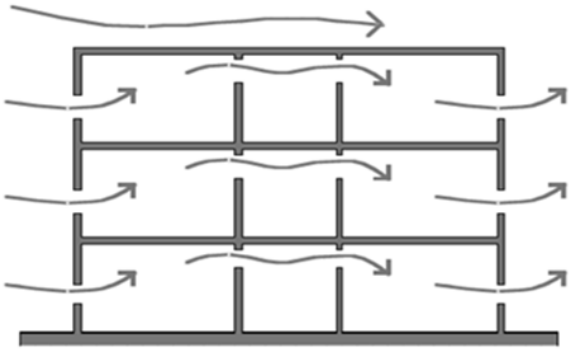


Figure 2.9: Concept of wind driven cross ventilation system

Source: (Geetha & Velraj, 2012)

Awbi (1996) investigated the air movement and the distribution of CO in a naturally ventilated office room and an atrium, using computational fluid dynamics. The results showed that natural ventilation is capable of achieving acceptable CO2 levels. Raja, Nicol and McCartney, 1998 have carried out a field study of the thermal comfort in naturally ventilated office buildings in Oxford and Aberdeen, UK. Their studies are focused to find the effect of controls in modifying the indoor thermal conditions. They have concluded that cross ventilation with control settings plays a significant role in lowering the indoor temperature.

The model is verified by comparing the results of steady two dimensional flows around a long square cylinder immersed in the atmospheric boundary layer with the experimental

values. These analyses have been taken as a reference to model the computational domain for the atmospheric air flow around the model room.

2.4.4.3 Buoyancy-driven stack ventilation

Buoyancy-driven stack ventilation or displacement ventilation (DV) relies on density differences to draw cool, outdoor air in at low ventilation openings and exhausts. Figure 2.10 shows the schematic of stack ventilation for a multi-storied building. A chimney or atrium is frequently used to generate sufficient buoyancy forces to achieve the needed flow. However, even the smallest wind will induce pressure distributions on the building envelope that will also act to drive the airflow (Geetha & Velraj, 2012).

Seppänen, Fisk, Eto & Grimsrud (1989) compared the displacement and conventional mixing ventilation systems in commercial buildings in the United States, by using the DOE-2.1C building simulation program. The study analyzed the north, south, and core zones of the buildings in four representative US climates. The results showed that displacement systems generally yielded superior air quality and thermal comfort, compared to conventional mixing systems operated with recirculation.

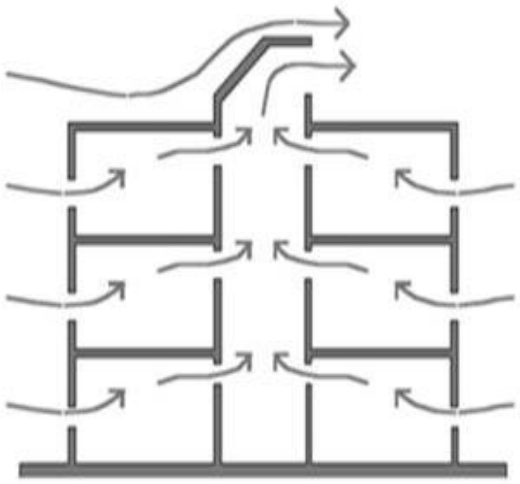


Figure 2.10: Concept of buoyancy driven stack ventilation system.

Source: (Geetha & Velraj, 2012)

2.4.4.4 Single-sided ventilation

Single-sided ventilation typically serves single rooms, and thus, provides a local ventilation solution. Fig.2.11 shows a schematic of single-sided ventilation in a multi-room building. The ventilation airflow in this case is driven by room-scale buoyancy effects, small differences in envelope wind pressures. Consequently, the driving forces for single-sided ventilation tend to be relatively small and highly variable (Geetha & Velraj, 2012).

Jiang and Chen (2001) compared several CFD models and found that for single sided ventilation, it is important to obtain instantaneous flow information, in order to correctly predict the ventilation rate and air change effectiveness. Reynolds Averaged Navier Stokes (RANS) modelling could not correctly calculate the ventilation

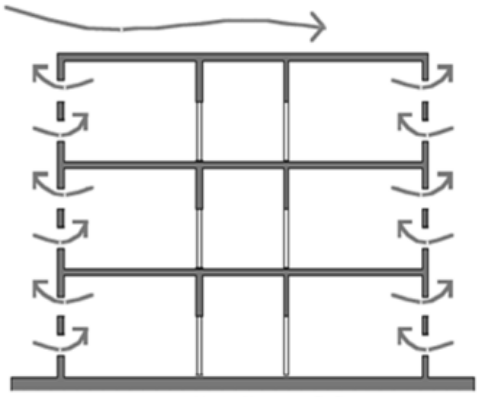


Figure 2.11: Concept of single-sided ventilation system.

Source: (Geetha & Velraj, 2012)

2.4.5 Natural cooling; Evaporative Cooling

Evaporative cooling is a process that uses the effect of evaporation as a natural heat sink. Sensible heat from the air is absorbed to be used as latent heat necessary to evaporate water. The amount of sensible heat absorbed depends on the amount of water that can be evaporated. Evaporative cooling is a very old process, having its origin some thousand years ago, in ancient Egypt and Persia. Modern evaporative coolers are based on the prototypes built in the early 1900s in the United States. Amer (2006) has found that among some passive cooling systems, evaporative cooling gave the best cooling effect, followed by the solar chimney, which reduced inside air temperature by 9.6°C and 8.5°C, respectively.

Passive direct systems include the use of vegetation for evaporation, the use of fountains, sprays, pools and ponds as well as the use of porous material saturated with water. Trees

and other plants transpire moisture in order to reject their sensible heat. The theoretical analysis of the role of plant evapotranspiration has shown, that the evapotranspiration from one tree can save 250 to 650 kWh of electricity used for air-conditioning per year (Orosa & Oliveria, 2012). One acre of grass can transfer more than 50 GJ on a sunny day, while evapotranspiration from wet grass can reduce the ground surface temperature by 6-8°C below the average surface temperature of the bare soil.

3.0 RESEARCH METHODOLOGY

3.1 Introduction

Having identified the scope and objectives of the study, it is necessary to follow an appropriate research methodology which refers to a set of methods. In this study, various research methods have been chosen to suit the different aspects of the research.

This chapter provides information on how the research was conducted in order to achieve the research aim and objectives. It covers the sampling selection, research strategy, design and method adopted for this thesis thereby contextualizing the methodology and justifying their use as compared to alternative ones

3.2 Research Design.

This research involves the use of both qualitative and quantitative research,why purposive sampling method is adopted, and this involved the purposive selection of the case that falls within the hot-dry climate region of Nigeria.

Case study is a useful strategy for converting tacit knowledge into explicit knowledge so practitioners can learn more about the performance of their study systems. It is also particularly appropriate for individual researchers; it gives the opportunity for one aspect of a problem to be studied in depth within a limited time scale (Bell, 1999). Yin (1994) appears to operate from realist ontology when he defends case method against attacks, especially in relation to the 3 forms of validity: construct validity, internal validity, and external validity. A key suggestion for dealing with construct validity is to use multiple sources of evidence; for internal validity Yin (1994) stresses the importance of building

cases over time in order to eliminate alternative explanation; for external validity he points out that case studies rely on analytic rather than statistical generalizations. Sekaran (2003) stated that: "case studies involve in depth, contextual analysis of similar situations in other organisations, where the nature and definition of the problem happens to him the same as experienced in the current situation. Remenyi, *et al*. (1998) define it as "a detailed investigation of the context and processes that affect a phenomenon within organisations".

Yin (1994) also defines the case study as "an empirical investigation into contemporary Phenomenon operating in a real-life context". He states that the case study is the preferred strategy when "how" or "why" questions are being posed. This allows the researcher to determine not only what happened but also why it happened. The case study is excellent as a recorder of decisions, reasons, motivations and structural relationships (Leavy, 1994). It is used if the researcher wishes to gain a rich understanding of the context, and it is a worthwhile way of exploring existing theory Yin (1994) classified case studies into 3 types for research purposes:

i. Exploratory case studies: sometimes considered as a prelude to social research;
ii. Explanatory case studies: may be used for doing causal investigations;
iii. Descriptive case studies: require a descriptive theory to be developed before starting the project.
iv. Evaluative case study**:** The evaluative case study is used in testing the effectiveness of policies or programs in order to suggest modifications and alternatives. Here, purposive sampling is used which may be typical or representative of diversity and best and worst cases.

Case study is chosen so as to assess the effectiveness of passive cooling strategies adopted to enhance thermal comfort so as to suggest relevant modifications and alternatives. (Chafe,*et al.*,2016).

3.3 Population of Study

Population of study comprises the totality of all subjects that have a set of specifications and characteristics that are of interest to the researcher and to whom the research results can be generalised (Polit and Hungler, 1999). The research population for this study involved hot-dry climate region of Nigeria. All case studies, with same climatic characteristic. (Chafe,*et al.*,2016).

3.4 Sampling

Sampling involves a subset of the research population selected to represent the research population (LoBiondo-Wood and Haber, 2006). For the purpose of this research, a non-probability sampling was used and the selection was purposive where three Schools of Environmental Studies were selected after careful consideration and due to particular interest of the study. These three Schools of Environmental Studies selected are located in Katsina, Zaria And Talata Mafara. This is because they have the same effect of climatic charcteristics within the region.

3.5 Instrument of Data Collection

Case study for theoretical research in architecture may require the use of general methods for data collection (Oluigbo, 2010). For case studies approach, it is important to use as many instrument of data collection. The tools or instrument of data collection used are;

i. Measured drawings
ii. Participant observation
iii. Questionnaire
iv. Checklist

3.5.1.1 Checklist

Checklist was in form of field forms outlining the variables of passive cooling strategies. It contained the list of variables which were observed and noted during the survey.

Photographs were taken to support the notes taken during the visit and for record. The photographs also provided a significant source of visual data about the case to outside observers. The photographs of relevant areas were taken in order to show the features of passive cooling strategies, the cases possessed as well as the extent to which they were applied.

3.5.1.3 Sketches

Sketches showing the selected case studies were made during the field survey. These sketches were considered vital to form an opinion on the physical setting and spatial organisation of the case studies in order to explain the research.

3.5.1.4 Notes

This instrument of data collection was adopted to back-up information discussed during the interview and what was observed during the field survey. Comprehensive notes were prepared as an ongoing record of what was happening as the research progressed.

3.6 Procedure for Data Collection

The data was collected through multiple instrument of data collection. All the selected case studies were visited by the researcher for field survey, photographs were taken, notes and sketches were formed.

The field survey involved visual survey of both architectural features and bioclimatic principles. According to Adler and Adler (1994) observation is unobtrusive and does not require direct interaction with participants. The researcher in this case observed the principles of passive cooling strategies qualitatively using checklist. List of variables in the checklist were checked and assessed sequentially. Thorough assessment of the cases'

physical state, architectural features and passive cooling strategies was conducted using the prepared checklist. During the visual survey, careful and direct observation was carried out to obtain data which was not obtainable from other methods. First, spatial organisation and site planning of each case were assessed. Sketches were made, photographs and notes were taken. The nature of the building structure, materials used, building aesthetics and the application of bioclimatic principles were documented by the researcher.

However, in cases where were no documentation available for the architectural drawings, the buildings were surveyed and the drawings were prepared by the researcher through sketches, photographs and notes. All photographs were taken either by the author or with help of other persons. Photographs of relevant areas of the case studies were taken in order to highlight the observed features of passive cooling strategies. Sketches showed the spatial organization of some of the study cases while notes explained the observed passive cooling techniques in each of the selected cases.

3.6.1 Simulation of the case

(Pollock, et al., 2007) indicated that simulation of a case is an appropriate approach for the evaluation of an office building in other to assist in the delivery of a sustainable green office and with high rating of energy performance.

This tool is used because:

i. It will help in determining the thermal comfort level of the building
ii. It will help to optimize the building design in order to improve its overall performance.
iii. It will generate possible data for analysis

3.6.2 Variables of Study

A number of key variables were kept constant throughout the study. The variables were selected on the basis of their relevance to the objectives of the research and were used to measure and describe the theoretical problem of the research. The selected variables for this research include:

i. Building form, shape and orientation
ii. Natural ventilation
iii. Thermal protection through shading
iv. Opening techniques adopted, Size and Materials
v. Trees planted,
vi. Water bodies around such a ponds, and fountains
vii. Courtyard

3.7 Data Analysis

The theoretical idea of what was studied provided the basis to describe the method to be used for analysing the content. For this research, the analysis was first focused on the individual interviews, then the field survey carried out. The data was then analysed and compared the results to identify the application of passive cooling strategies principles in each selected cases.

The data obtained during the field survey was presented through sketches, notes and photograph translating the study into more and more essential meaning. The field survey addressed the meaning of each observed variable. The checklist was analysed and the data was presented in a simple and tabular form. The checklist of the variables analysed was developed so that the studied data can easily be acknowledged. The data analysed during the survey was tabulated with each variable presented in column.

4.0 FINDINGS

4.1 Introduction

4.2 Case Study One: Nuhu Bamalli Polytechnic School of Environmental Studies, Zaria

Background

The School of Environmental Studies Nuhu Bamalli Polytechnic Zaria is located in the main campus of the school along Zaria Kaduna Express Road. Zaria local government area of Kaduna state, Nigeria. The school consists of six departments which are; Architecture, Building, Urban and Regional Planning, Quantity Surveying, land Survey and Estate Management Department. The School is a single building housing classes, studios, workshops and staff offices built in 2012. Plate VI below shows approach façade of the school



PLATE IV: Façade of the School of Environmental Studies Nuhu Bamalli Polytechnic (Source: Author's field work, 2016.)

4.2.1 Site Planning and Landscaping

The School has four building blocks attached by a central building block and it is a double storey building with classes, studios and staff offices. Figure 4.1 below shows the site plan of the school. However, as there is no presence of any green landscaping on site, this became a demerit of the survey although this alone cannot dent the research.

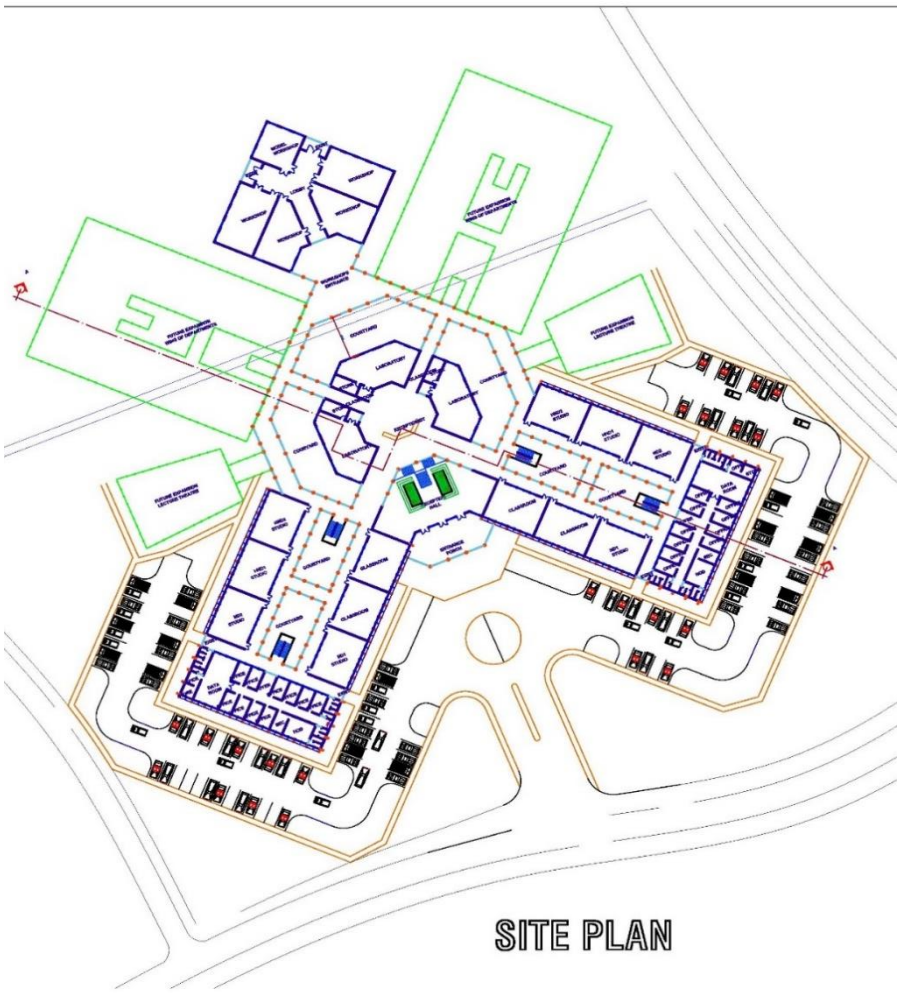


Figure 4-1: Site plan of School of Environmental Studies Nuhu Bamalli Polytechnic, Zaria.
(Source: Author's field work, 2016.)

4.2.2 Structure and Materials

The form is simple with a grid framework construction. The building has a structural grid framework of columns and beams, using hollow blocks to demarcate spaces. Also, courtyards are integrated within the building.



PLATE V: Concrete structure with integrated courtyard
(Source: Author's field work, 2016.)

4.2.3 Application of Passive Cooling Strategies

4.2.3.1 Building form, shape and orientation

According to study carried out by the researcher, the school of environmental studies Nuhu Bamalli polytechnic was designed and planned to make the best use of the sun, the prevailing winds and other environmental condition to achieve comfort in the internal environment without necessarily over dependence on artificial methods.

The longer side of the school is oriented towards the sun with longer axis running in east-west direction for the building to adapt to the climate of the region. Also, the shape is rectangular with a central court yards and the building composition and form different

wings plate VI and VII which is a great advantage to the indoor environment and a good consideration for thermal comfort in hot-dry climate.



PLATE VI: School of Environmental Studies Nuhu Bamalli Polytechnic building form and Shape
(Source: Author's field work, 2016.)



PLATE VII: School of Environmental Studies Nuhu Bamalli Polytechnic planting in the courtyard
(Source: Author's field work, 2016.)

4.2.3.2 Natural Ventilation

The building form was designed to make the best use of the prevailing winds for indoor environment comfort. A central courtyard (plate IX) was introduced to promote ventilation and all the classes were designed with a projected walkway for shading. The large green areas and trees around the school also aid ventilation.

Clear glass large windows were used for ventilation and lighting (plate VIII).



PLATE VIII: Types of windows used for ventilation.
(Source: Author's field work, 2016.)



PLATE IX: School of Environmental Studies Nuhu Bamalli Polytechnic planting in the courtyard
(Source: Author's field work, 2016.)

4.2.3.3 Passive Cooling Techniques

The open spaces around the building and the various courtyards (plate X) serve as heat sink during the day and radiate the heat during the night. The large areas without trees and plantation and large paved areas around the building are seen as principles used to increase the temperature around the site because of the heat and increase of re-radiation of the areas. Indoor plants which help in evaporative cooling and in absorption of solar radiation were planted only in few courtyards.



PLATE X: courtyards as a passive cooling technique
(Source: Author's field work, 2016.)

4.2.3.4 Thermal protection through shading

Thermal protection was considered according to the survey carried out, the building façade straight flat and no recesses, concrete walkway on the first floor used as shading elements to protect the indoor environment from the glaring sun and to provide a buffer between the living spaces and he outdoor environment as shown in plate XI. All external walls are not shaded and all the windows are exposed to glaring sun and thus increasing heat gain and as well higher indoor temperature. However, despite only few shading

techniques introduced in the design, NO trees can be located (plate XI) near the building which is a demerit to the school because large tress can provide shading against the elements of weather.



PLATE XI: Showing side view of School of Environmental Study Nuhu Bamalli Polytechnic Zaria.
(Source: Author's field work, 2016.)

4.2.4 Summary case

The summary presents the researcher's assessment of the application of Passive cooling strategies Principles and the results obtained during the researcher's field survey at the School of Environmental Studies Nuhu Bamalli Polytechnic Zaria, are presented in table 4-1.

Table 4-1: Assessment of Passive cooling strategies Principles study variables

Passive cooling strategies Principles Scale Factor: Excellent=5, Very Good=4, Good=3, Fair=2, Poor=1				
Variables	**Features**	**Method Adopted**	**Scale Factor**	**Remarks**
Building form, orientation and shape	rectangular X shape plan, Proper positioning of buildings on site	NO SPECIFIC orientation of the longer axis of the building along the east-west direction, massive building form and rectangular building shape	2	**Fair**
Natural Ventilation	Use of projection windows and a court yard	Open able windows	4	**Very Good**
Thermal protection through shading	All the windows are exposed to glaring sun and thus increasing heat gain and as well higher indoor temperature.	Only outside covered walkways around the building	2	**Fair**
Opening techniques adopted, Size and Materials	Courtyard, and unpaved areas around the site	courtyard and glass sliding and casement windows	3	**Good**
Trees planted,	**NO** Trees around the buildings	Absence of hedges, large trees and the green areas has demerit on improving the site microclimate and passive cooling	1	**Poor**
Courtyard	Courtyard, and unpaved areas around the site	Open courtyard	4	**Very Good**

(Source: Author, 2016.)

4.3 CASE STUDY TWO: SCHOOL OF ENVIRONMENTAL STUDIES HASSAN USMAN POLYTECHNIC KATSINA

4.3.1 Background

The School of Environmental Studies Hassan Usman Polytechnic Katsina is located in Katsina Local Government area of Katsina State Nigeria. The School consist of three Departments which are; Architecture, Building, and Quantity Surveying Department. The school has different building blocks for classes, studios and staff offices. Plate XII below shows view of staff offices of the school, as well as an early attempt at greasing the area with trees and shrubs



PLATE XII: School of Environmental Studies Hassan Usman Polytechnic Katsina.
(Source: Author's field work, 2016.)

4.3.2 Site Planning and Landscaping

From the field survey carried out, the small building units were well positioned and zoned on the site. The building units were distributed on the site with the longer axis of the rectangular form running along the east-west direction except the multipurpose hall whose orientation is otherwise (longer side facing the east and west). The school has a

large number of unpaved unmarked parking spaces with no elements of shading around the offices and most classes. (Plate XIII).



PLATE XIII: Approach façade of a typical staff offices of the school.
(Source: Author's field work, 2016.)

4.3.3 Structure and Materials

From the study carried out, the school design is modern and conventional. The walls were made up from concrete/masonry block finished with emulsion paint, the roof is conventional hip roof covered with aluminium roofing sheet.

4.3.4 Application of Passive cooling Strategies

4.3.4.1 Building form, shape and orientation

According to investigations carried out by the researcher, School of environmental studies Hassan Usman Polytechnic Katsina was planned with units of small buildings spread on the large site. All the buildings units observed were L shape with most of the buildings' longer sides elongated along the east-west direction, that is, with the longer sides facing the north and south in order to make the best use of the sun. The orientation which the L

shape cannot provide appropriate side to face the sun direction has made the buildings to be planned haphazardly (Plate XIV).



PLATE XIV: School of Environmental Studies Hassan Usman Polytechnic Katsina.
(Source: Author's field work, 2016.)

4.3.4.2 Natural Ventilation

The field survey shown that the building form was simple which promotes ventilation within the indoor environment. The mode of natural ventilation was through the sliding windows provided in all the interior areas and large windows (plate XV) in the studios.



PLATE XV: Windows for natural lighting.
(Source: Author's field work, 2016.)

4.3.4.3 Passive Cooling Techniques

The vast green areas by the north side of Quantity Surveying Department (plate XVI), large unpaved areas and presence of large number of trees around the building were seen as passive principles adopted to improve the site microclimate because of the absorption of heat and minimisation of re-radiation of the areas. While on the offices area absence of trees and shading contribute much to the heat. Presence of high level windows contribute and enhance cooling through stack effect (plate XVI).



PLATE XVI: Green areas and large trees.

(Source: Author's field work, 2016.)

4.3.4.4 Thermal protection through shading

The large trees provided shade to the small building units and the minimisation of windows number and sizes also protect the indoor environment from the glaring sun (plate XVI). On the other hand, absence of trees and shading contribute much to the heat around the offices area (Plate XVII).



PLATE XVII: Absence of trees and shading devices and presence of high level windows. (Source: Author's field work, 2016.)

4.3.5 Summary case

The summary presents the researcher's assessment of the application of Passive cooling strategies Principles and the results obtained during the researcher's field survey at the School of Environmental Studies Hassan Usman Polytechnic Katsina, refer to the table 4.2.

Table 4-2: **Assessment of Passive cooling strategies Principles study variables.**

Passive cooling strategies Principles **Scale Factor: Excellent=5, Very Good=4, Good=3, Fair=2, Poor=1**				
Variables	**Features**	**Method Adopted**	**Scale Factor**	**Remarks**
Building form, orientation and shape	Small building units, simple forms and rectangular shape	Orientation of the longer axis of the building along the east-west direction and did not consider orientation	3	**Good**
Natural Ventilation	Sliding and projection windows	Use of sliding windows in offices and projection windows in the classes	2	**Fair**
Thermal protection through shading	Trees around classes areas	Shading is largely from the large trees around the building	3	**Good**
Opening techniques adopted, Size and Materials	Courtyard, vast green and unpaved areas around the site	Use of sliding windows in offices and projection windows in the classes	2	**Fair**
Trees planted,	Large green areas and trees around the classes area	The hedges, large trees and the green areas improves the site microclimate and passive cooling	2	**Fair**
Courtyard	Courtyard, and unpaved areas around the site	Open courtyard	4	**Very Good**

(Source: Author's field work, 2016.)

4.4 CASE STUDY THREE: SCHOOL OF ENVIRONMENTAL STUDIES ABDU GUSAU POLYTECHNIC TALATA MAFARA

4.4.1 Background

The School of Environmental Studies Abdu Gusau Polytechnic Talata Mafara is located in Talata Mafara Local Government area of Zamfara state Nigeria. The School consist of Six Departments which are; Architecture, Building, Quantity Surveying, Estate Management, Land Survey and Urban and Regional Planning Department. Moreover, School of Environmental studies AbduGusau Polytechnic at present occupies one of the buildings in School of Engineering, in view of this, there is need for school of Environmental to have a Building of its own. As mentioned above these are some of the reasons for the study. The School has four Building blocks attached by a longest building block on the west side of the building and it is a double storey building with classes, studios and staff offices. Plate XVIII below shows view of staff offices of the school



PLATE XVIII: School of Environmental Studies Abdu Gusau Polytechnic Talata Mafara
(Source: Author's field work, 2016.)

4.4.2 Site Planning and Landscaping

The School has four building blocks attached by a longest building block on the west side of the building and it is a double storey building with classes, studios and staff offices. Plate XIX below shows view of staff offices of the school (Figure 4.2). However, there was no presence of any green landscaping on site. Therefore, this could be a demerit of the survey but this alone cannot dent the research.

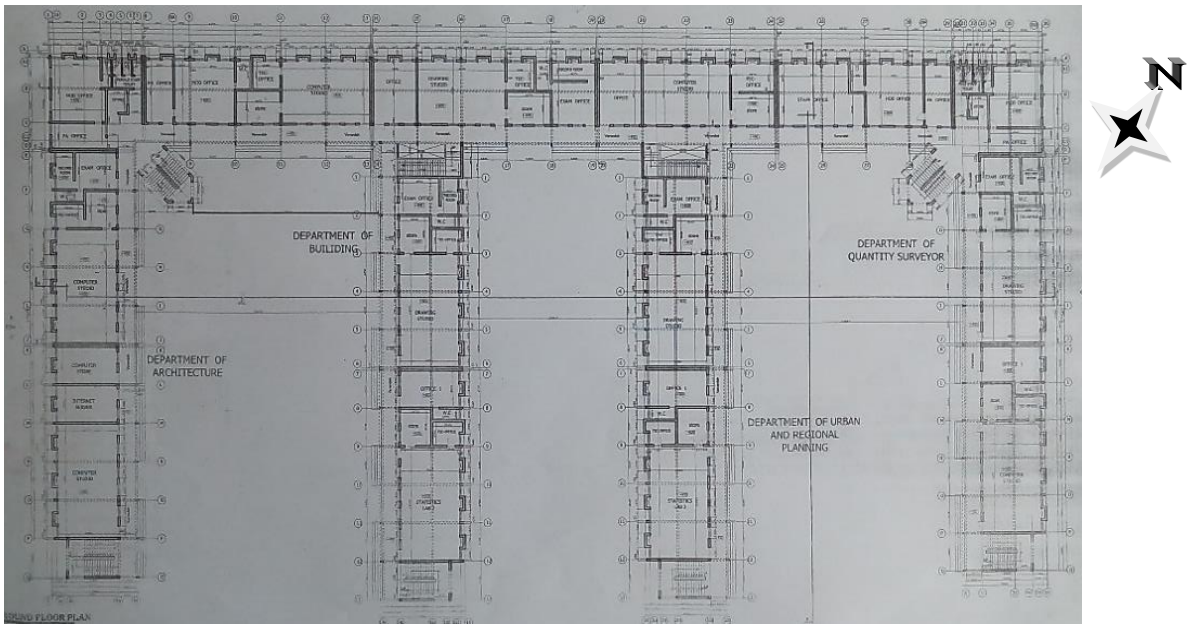


Figure 4-2: Floor plan of School of Environmental Studies Abdu Gusau Polytechnic Talata Mafara.

(Source: Author's field work, 2016.)

4.4.3 Application of Passive cooling strategies

4.4.3.1 Building form, shape and orientation

The newly constructed school has a compact and massive design layout with open courtyards as shown in fig. 4.2. The cluster plan and the composition allows minimal exposure to the sun which can improve the thermal condition of the internal environment.



PLATE XIX: School of Environmental Studies Abdu Gusau Polytechnic Talata Mafara.

(Source: Author's field work, 2016.)

4.4.3.2 Natural Ventilation

Sliding windows for ventilation of the interior spaces were embedded in the block walls system. The courtyards also promote ventilation in the classes, office areas and other spaces. However, there is no other means of ventilation other than the sliding windows and thus providing in sufficient ventilation.



PLATE XX: Sliding windows for ventilation.

(Source: Author's field work, 2016.)

4.4.3.3 Passive Cooling Techniques

According to the field survey carried out, the courtyards (see plate XXI) and the large open spaces around the school are the only passive cooling techniques observed. The courtyard serve as heat sink during the day and radiate the heat during the night. The unpaved surfaces in the courtyards can aid passive cooling of the School but due to absence of trees less or no passive cooling can be achieved in the day time (see plate XXII).



PLATE XXI: Open Court yard for passive cooling. :
Source: Author's field work, 2016.)



PLATE XXII: Absence of trees around the school.
(Source: Author's field work, 2016.)

4.4.3.4 Thermal protection through shading

Thermal protection was considered according to the survey carried out, the building façade deep recesses, concrete shading elements and balconies designed to protect the indoor environment from the glaring sun on the ground floor however no any aspect of shading was applied on the building this is also a demerit to the building passive cooling (plate XXIII).



PLATE XXIII: Recesses on ground floor to provide shading.

(Source: Author's field work, 2016.)

4.4.4 Summary case

The summary presents the researcher's assessment of the Passive cooling strategies Principles and the results obtained during the researcher's field survey at the School of Environmental Science Abdu Gusau Polytechnic Talata Mafara

sTable 4-3: **Assessment of Passive cooling strategies Principles variables**

Passive cooling strategies Principles **Scale Factor: Excellent=5, Very Good=4, Good=3, Fair=2, Poor=1**				
Variables	**Features**	**Method Adopted**	**Scale Factor**	**Remarks**
Building form, orientation and shape	Four building blocks attached by a longest building block on the west side of the building and it is a double storey building.	Orientation of the longer axis of the building along the east-west direction	4	**Very Good**
Natural Ventilation	Sliding windows	Use of sliding windows and no other means	2	**Fair**
Thermal protection through shading	**Recesses** on ground floor to provide shading.	300mm deep recess provide less shading	2	**Fair**
Opening techniques adopted, Size and Materials	Courtyard, and unpaved areas around the site	Open courtyard and glass sliding windows	4	**Very Good**
Trees planted,	**NO** Trees around the buildings	Absence of hedges, large trees and the green areas has demerit on improving the site microclimate and passive cooling	1	**Poor**
Courtyard	Courtyard, and unpaved areas around the site	Open courtyard	5	**Excellent**

(Source: Author, 2016.)

4.5 COMPARATIVE ANALYSIS OF RESULTS/FINDINGS

Table 4.4 summarises and compares the results obtained from the three selected cases. Among all the three cases, school of environmental studies Nuhu Bamalli polytechnic Zaria was found out to be the case with highest consideration of Passive cooling strategies principles, therefore, it offers the most suitable indoor environment for learning passively. However, School of Environmental Study Abdu Gusau Polytechnic Talata Mafara was good and the absence of large trees on site no doubt affect the micro climate.

Meanwhile, all the selected cases failed in the application of Passive cooling strategies effectively. Because one case will have a better feature and will lack a feature which another case has and this is why there is need for a proposal of a better building that has the best application of all passive cooling design strategies studied in this research. Table 4-4 show results.

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Table 4-4: **Comparative Analysis of the Cases**

Variables	Nuhu Bamalli polytechnic Zaria	Hassan Usman Polytechnic Katsina	AbduGusau Polytechnic
Building form, orientation and shape	rectangular X shape plan, Proper positioning of buildings on site	Small building units, simple forms and rectangular shape	Four building blocks attached by a longest building block on the west side of the building and it is a double storey building.
Natural Ventilation	Use of projection windows and a court yard	Sliding and projection windows	Sliding windows
Thermal protection through shading	All the windows are exposed to glaring sun and thus increasing heat gain and as well higher indoor temperature.	Trees around classes areas	Recesses on ground floor to provide shading.
Opening techniques adopted, Size and Materials	Courtyard, and unpaved areas around the site	Courtyard, vast green and unpaved areas around the site	Courtyard, and unpaved areas around the site
Trees planted,	**NO** Trees around the buildings	Large green areas and trees around the classes area	**NO** Trees around the buildings
Courtyard	Open Courtyard.	Open Courtyard.	Open Courtyard.

(Source: Author, 2016.)

5.0 SIMULATION AND FINDINGS

5.1 SIMULATION OF A CASE STUDY

In order to identify the level of thermal comfort one case study was selected to simulate indoor temperature the case study selected is the school of environmental studies Nuhu Bamalli polytechnic Zaria. Figure 5.1 shows the site plan of the school.

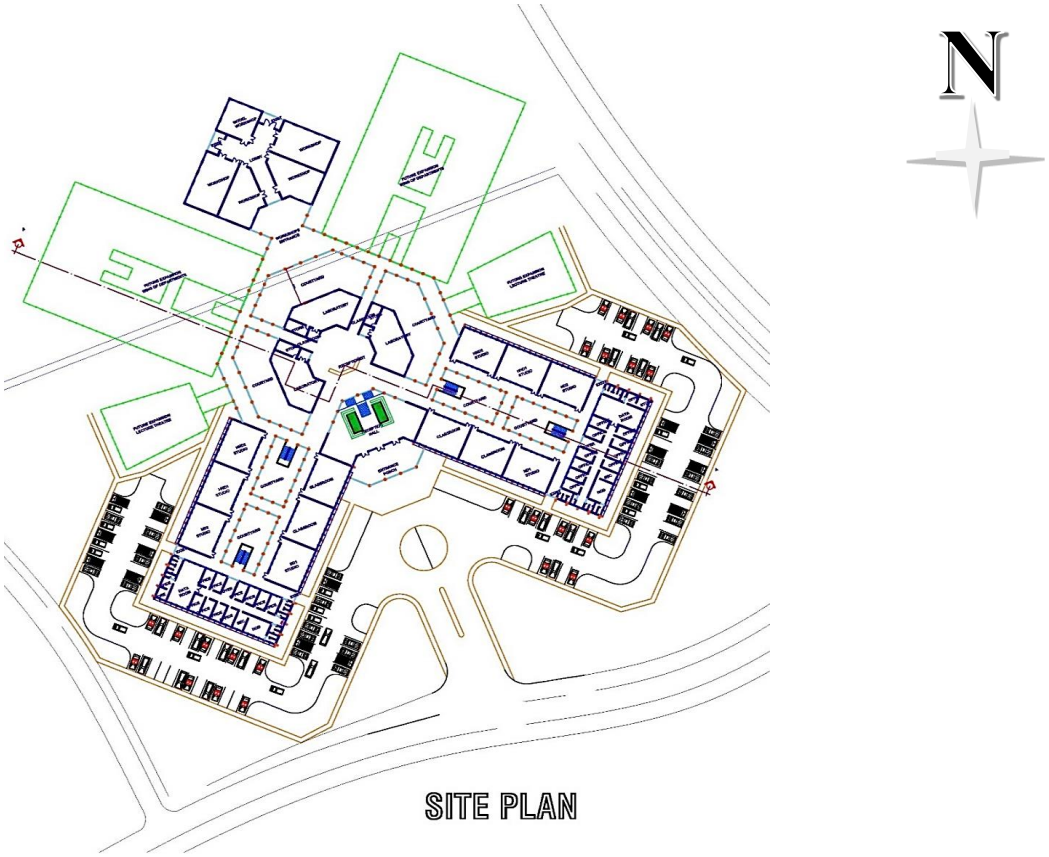


Figure 5.1: Site Plan School of Environmental Studies Nuhu Bamalli Polytechnic. (Source: Author's field work, 2016.)

5.2 SIMULATION SOFTWARE

Autodesk's ECOTECT is building analysis software that allows user to easily design and work in 3D. ECOTECT offers a wide range of analysis options from acoustics to energy efficiency tools. ECOTECT's tool related to energy efficiency can be found under thermal analysis in interface of the ECOTECT as shown in Figure 5.2. For this tool to be used properly it requires the adherence to some specific principles when constructing the model that will be analysed. Since this dissertation deals with ways to improve energy efficiency and passive control strategies in buildings, results from this tool will be described in this chapter.

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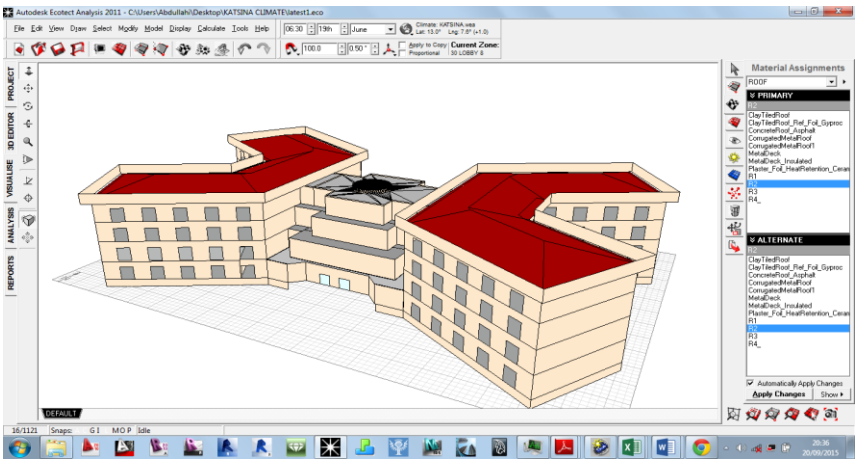


Figure 5.2: Interface of Autodesk ECOTECT.

(Source: Author, 2016.)

5.3 ROOM TEMPERATURE OF DIFFERENT AREAS WITHIN THE BUILDING

Room temperature is quite high during hot season on top floor and the average shows values that exceed the comfort level (above 30°C) in almost all rooms. The case on ground floor is just at the high limit of the comfort level which is above 30°C but lower than

upper floor temperature and it is clear that the level of comfort is far better at ground floors then top floors.(Figure 5.3).

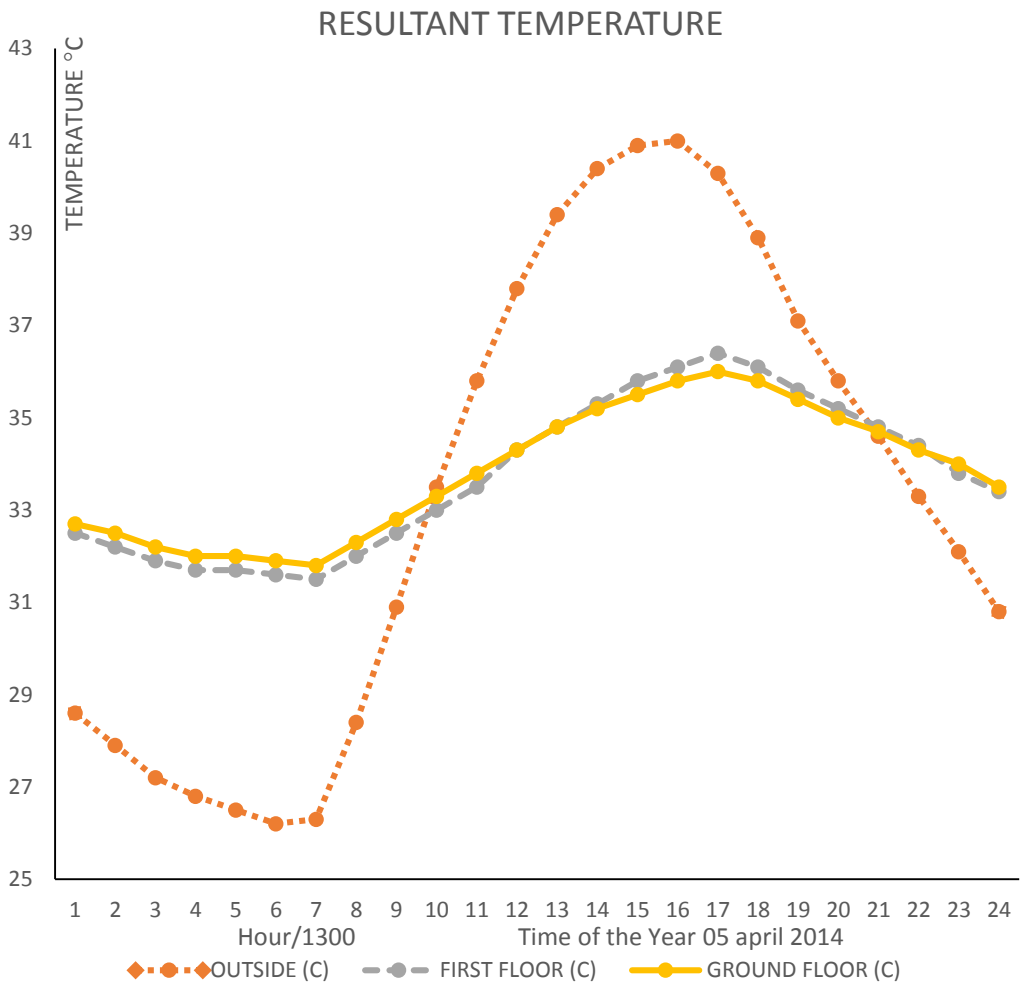


Figure 5.3: Interior temperature of ground floor first floor and outside (Entrance bay).

(Source: Author, 2016.)

5.3.1 Solar Heat Protection

The solar heat penetration is depending on the following building design aspects: glazing fraction / fenestration, shading devices, orientation, shading from external surrounding, specific heat storage capacity of the building and geometry of the room; and can be minimized if the surface is shielded from the direct rays of the sun or glazing fraction

sun-shading on the outside of the facade but if this is not possible, painting the surface a light colour and adding insulation should be considered because heat from the sun must be considered when identifying the total interior temperature.

5.3.2 Internal Zone Temperature

Simulations have carried out to measure the existing comfortable temperature during hot season months at ground middle, ground corner and first floor corner. The corner rooms which are HND2 studios are expose by to the solar radiation more than the middle room which is a class Figure 5.3 shows the number of resultant temperature that recorded on ground corner studios in order to find number of hours situated within comfort range. A similar situation expose in first floor studio with temperature above 32 °C in the daytime and this is perhaps as a result of three sides are expose to solar radiation without any element of shading. These zones are shown as uncomfortable places to be and only the class which is at the middle and on ground floor shows a close level to comfort even though the temperature is above the comfort zone. It might be due to it is located on middle and has only two sides expose to thermal comfort

To conclude, here is a comparing between the three floors and it can be seen that the earth cover significantly improves the internal temperatures on ground floors, although these temperatures do not meet recommendation of comfortable temperatures design for habitable rooms but still the lowest one between the other spaces where the temperature rise to unacceptable level.

Figure 5.3 demonstrate that the differences between temperature on different floors and different directions. It is realizable that the ground floor has the lowest temperature from the first floor as a result of that; floor structure is in contact with the ground and lose heat

by conduction into the ground itself in addition to the ground type of Zaria city which is within the hot dry climate.

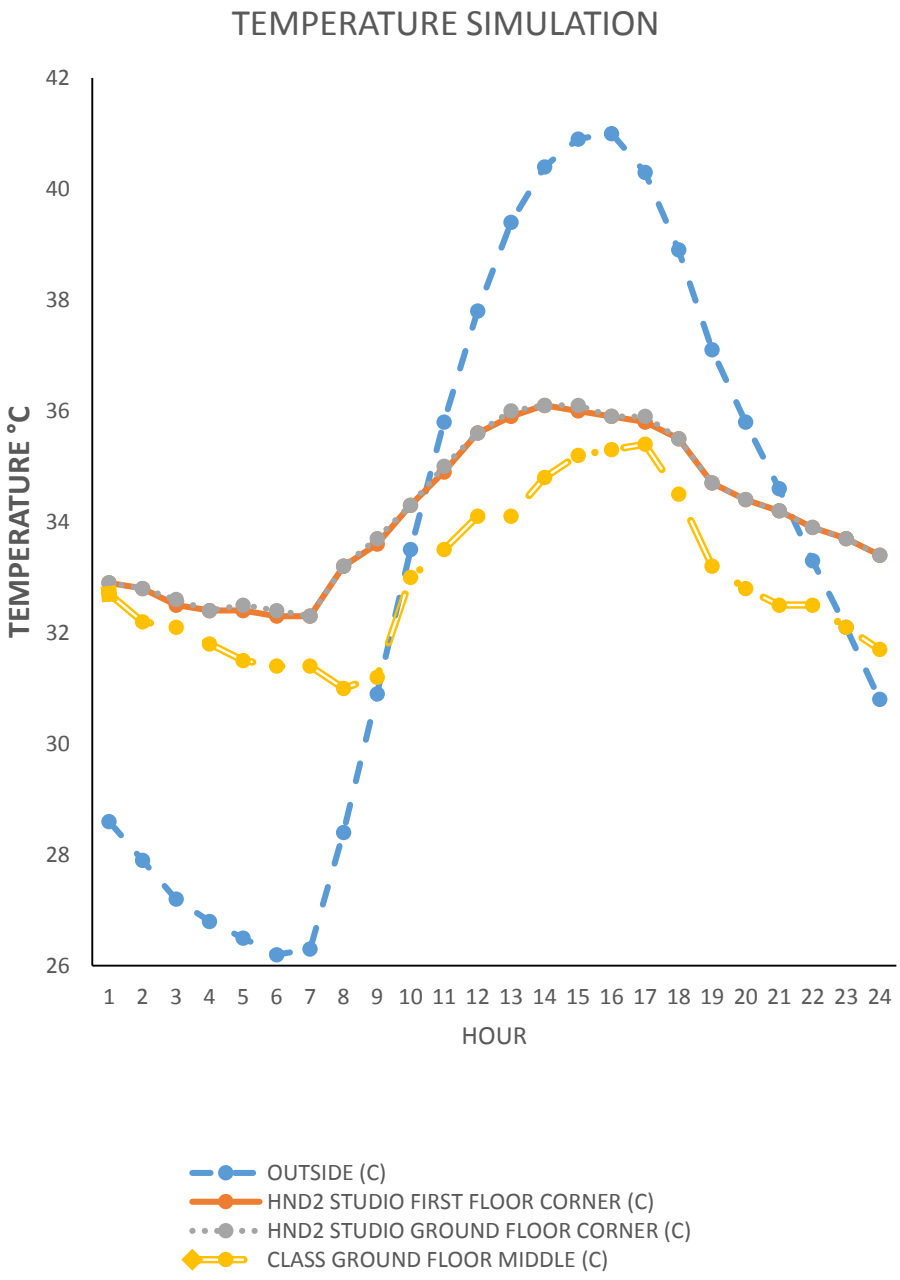


Figure 5.4: differences between temperature on different floors and different directions (Architecture Department).

(Source: Author, 2016.)

5.4 FINDINGS FROM CASE STUDIES AND SIMULATION

The results presented in this chapter aimed to investigate the observation data and analysis that were obtained from fieldwork and simulate one case study building. Some of the obtained results are presented here in points as following;

1) None of the case take 100% consideration of solar radiation while orienting the building
2) There is no any identifiable structure constructed purposely because of shading
3) All three case studies utilize courtyard and this can help in providing adequate ventilation
4) Buildings' orientation play a significant role on heat gain during hot season, rooms exposed to high solar radiation show a high room temperature than those located on within the adjacent walls. Upper floor's rooms that located on a big courtyard are shown a better performance than those located on small courtyard.
5) In respect to indoor temperature, upper rooms are the worse where the temperature reach up to 39°C on peak day hours beside the temperature drop to uncomfortable level during night, the situation is different on ground flat when simulation indicated better performance on ground floor even though the recorded temperature still above the comfort level but not as high as those recorded on top floor.
6) Results of ECOTECT simulation show that temperature at peak hour (between13:00 and 17:00 O'clock) up to 40°C which is almost 12°C above comfort range. This means that it is impossible to achieve comfort temperature with passive cooling.

6.0 THE SITE

6.1 Introduction

One of the main conditions for optimal service in educational facilities, is the location of the building in terms of distance as well as environmental condition; these are often ignored factors, usually causing many problems for students. A certain characteristics of each site will suit the project well while others will differ. This set of characteristics used in the analysis is what is termed as “Site Selection Criteria”. However, since this is a building the polytechnic site selection is restricted as it will be given by the school authority obtained from the planning section of the polytechnic.

6.1.1 General Climatic Data

Zamfara State has total rainfall figures ranging from 600-700mm annually. Generally, climate varies considerably according to months and seasons. A cool dry (harmattan) season from December to February; a hot dry season from March to May; a warm wet season from June to September; a less marked season after rains during the months of October to November, characterised by decreasing rainfall and a gradual lowering of temperature .According to the Köppen Climate Classification system, Zamfara has a Semi-arid climate, abbreviated "Bsh" on climate maps

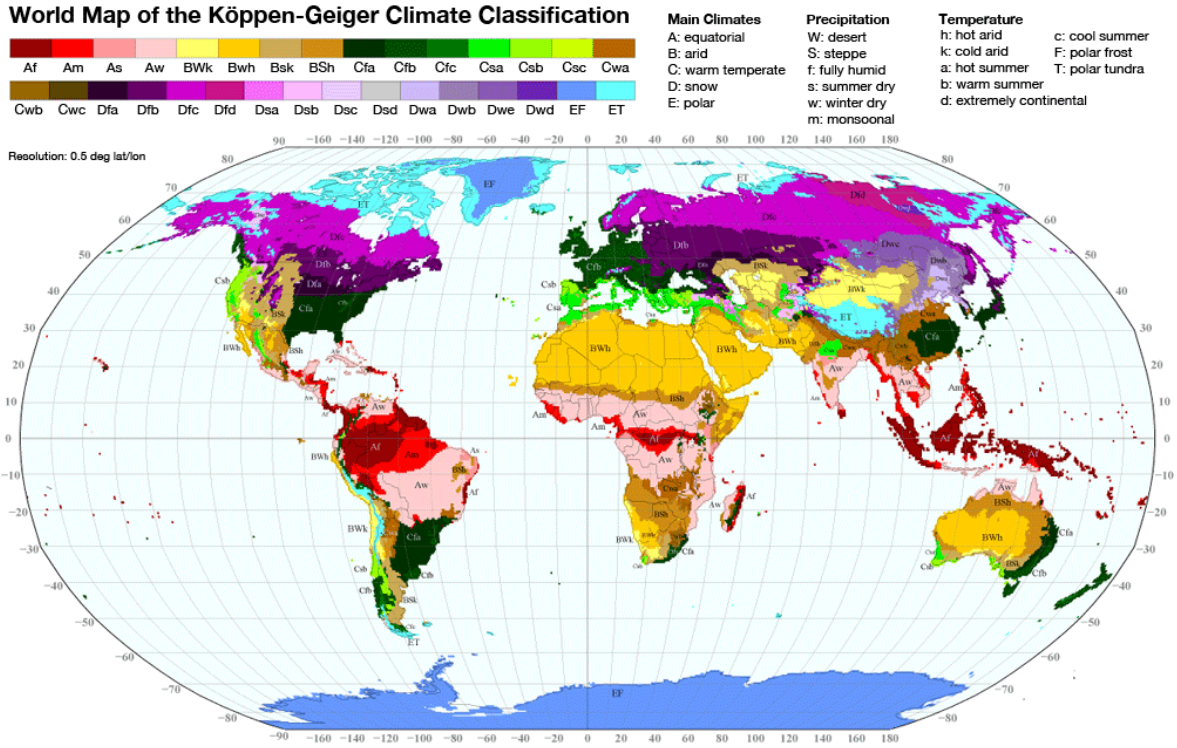


Figure 6-1: Köppen Climate Classification system

Source: (weatherbase, 2015)

The figures above indicate that July has the highest solar radiation (8.45 kWh/m² a day), and therefore observation also shows that July is the month with clearest sky in the year, even so a general look to the table indicated that Zamfara has a relative clear sky even in winter months and sun almost present when there is only partial cloud cover. April is the warmest month of the year. The temperature in April averages 30.8 °C. In January, the average temperature is 21.2 °C. It is the lowest average temperature of the whole year. Wind speed is given in the Table above as well, generally, this wind are pleasant as the dominant winds blow from the north and northwest in all seasons. However, in July and August this zone is affected for many days by wind from the south.

6.1.2 Precipitation

The chart below plots the average monthly precipitation amount.

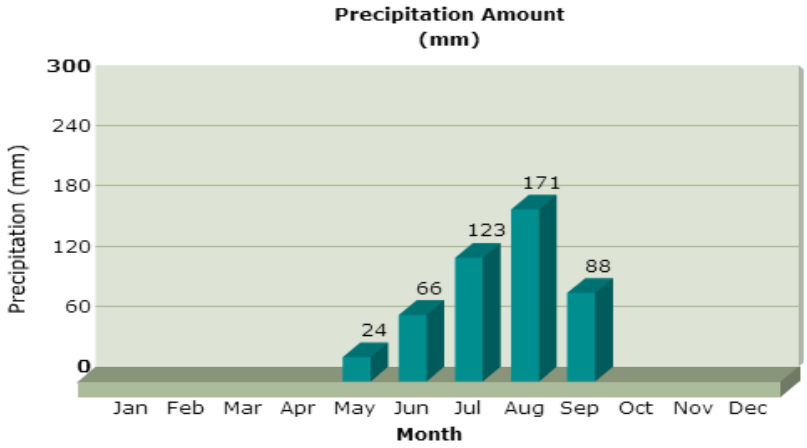


Figure 6-2 : Monthly precipitation amount

Source: (myweather2, 2015)

6-2Temperatures

The chart below plots the average high and low temperature for each month of the year.

It also shows the maximum and minimum recorded temperatures.

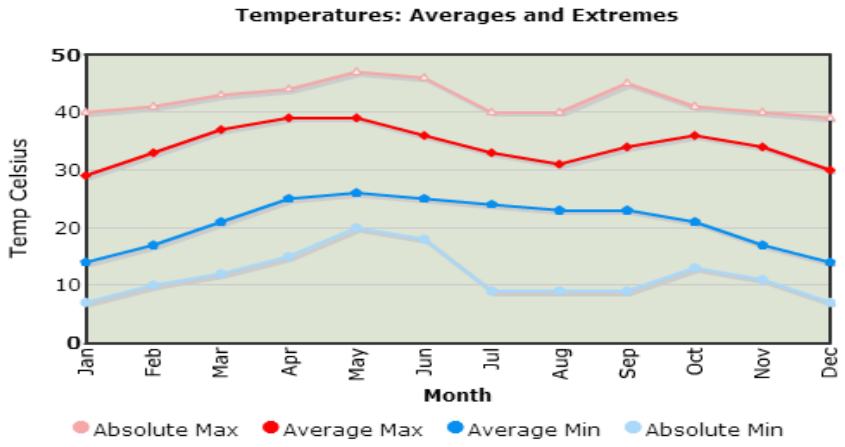


Figure 6-3 High and low temperature for each month of the year

Source: (myweather2, 2015)

6.1.3 Wind speed

The chart below plots the average daily wind speed you can expect for any month. It also shows the maximum recorded sustained wind speed for each month

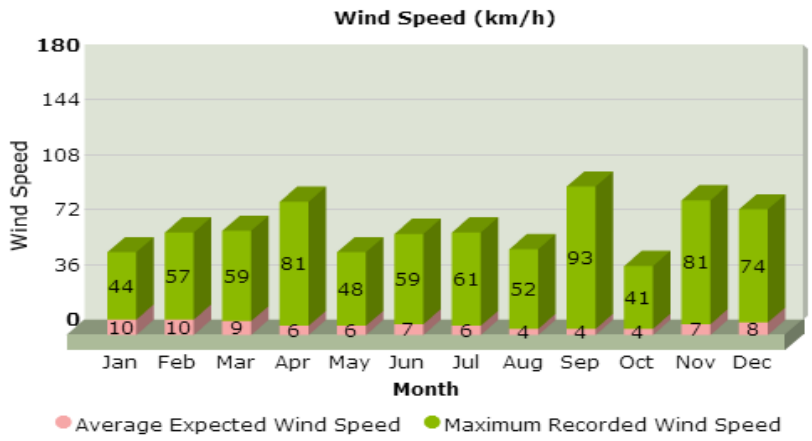


Figure 6-4: Average daily wind speed

Source: (myweather2, 2015)

6.2 Study Area (Profile)

The study area Talata Mafara in Zamfara is located at the extreme margin of northern Nigeria that lies on geographic coordinates of 11008'N and 13022'N and longitudes 6052'E and 9020'E. Zamfara urban area covers a total land area of about 3,370km2 (Rumah and Sheikh, 2010). Talata Mafara is one of the oldest urban centres of Nigeria believed to have been established in 1600AD as citadel and political capital in the pre and post Danfodio's Jihad, of the 19th century. It has its roots stretching back considerably before the advent of British colonizers and has served as entre port to the Saharan and trans-Saharan trade (Isah, 2011).

6.3 Site Selection Criteria and Features

Many criteria have been developed in selecting a suitable site for a School of Environmental Design. While some are ranked as most important of what a School of Environmental Design's site must possess, some are there to make a sites choice easier when there is a tie or an equal evaluation standards. But, since this is a Building the Polytechnic site selection is restricted as it will be given by the School authority obtained from the planning section of the Polytechnic.

6.4 Site Location

The proposed School of Environmental Design is located at Talata Mafara, Zamfara state of Nigeria as shown in figure 6.5. The city is lying between $12^0$15'N of the equator and $7^0$30'E of the Greenwich Meridian and it is characterised with hot-dry climate. The site for the School of Environmental Studies is located within the School in Talata Mafara Zamfara state. The territory is north of the confluence of the Niger and Benue rivers.

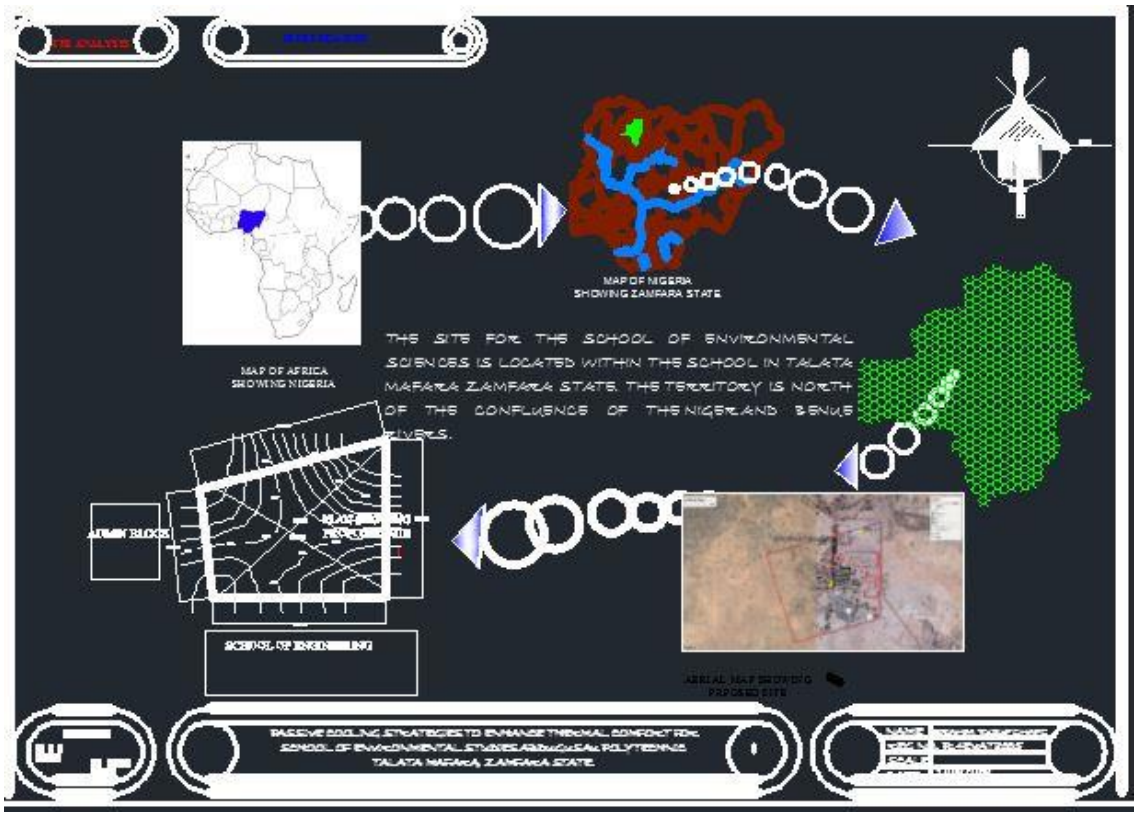


Figure 6-5: Site Location.

6.5 Site Analysis

The physical, climatic, and general features of the site were analysed in order to identify the possible opportunities that will be utilised for a better design and also to take note of the threats and to take possible measures that will reduce their effect to the building. The following are features that were noted during analysis of the site.

6.5.2 Topography

The topography of the site is relatively flat and has a Low lying strip of land with 0.5% gradient sloping towards the north-west end of the site. Site drainage would take this direction in order to use the concept of natural gravity. While the water supply should come from south-eastern direction in order to also use the principle of natural gravity.

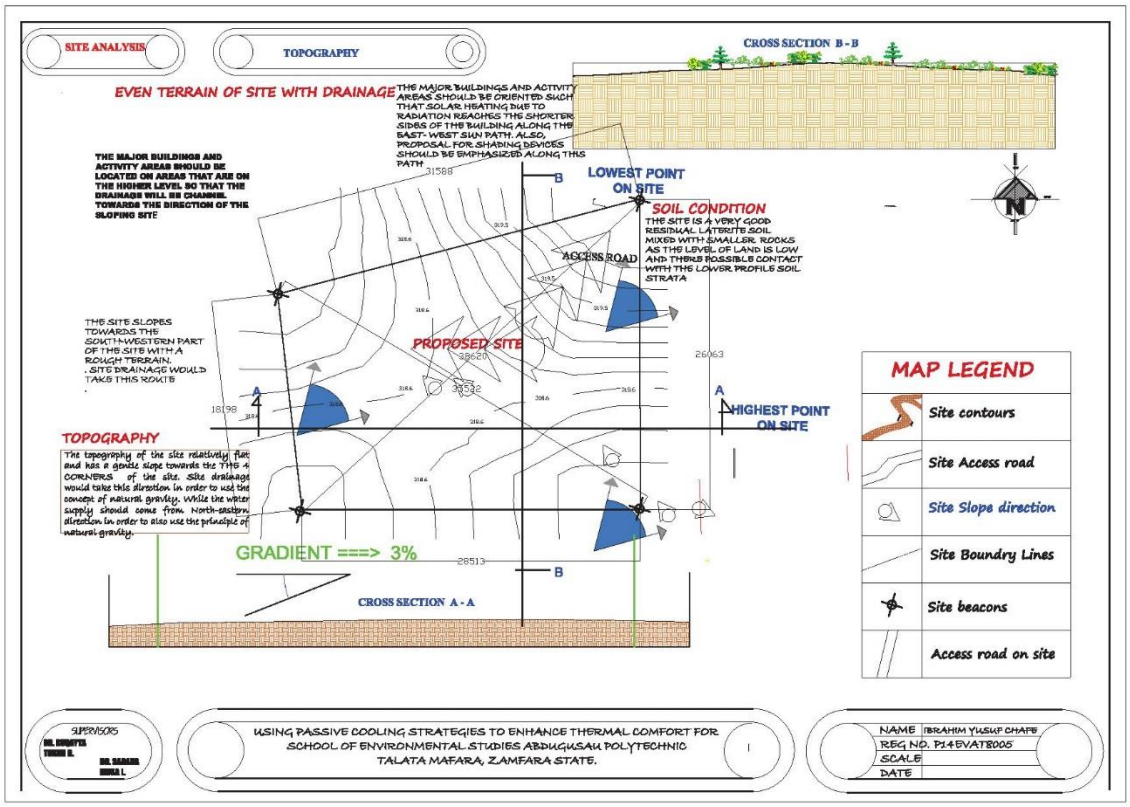


Figure 6-6: Topographical analysis of the site

6.5.3 Vegetation

Vegetation of the site is typically that of the Sudan Savannah, characterized by isolated neem and locust bean trees and shrubs. However, the original vegetation has been greatly altered by human activities such as clearance for cultivation and firewood. More than half of the land is bared with little or no grasses during the dry season but dominated with grasses during the rainy season. However, the western, part of the site is densely populated with mango trees. Outdoor garden will be best located toward this side.

6.5.4 Services

Services like electricity power lines, water supply lines, telephone services, well-constructed tarred roads and pedestrian paths, well designed drainages are all available

on site figure 6.7. The site is accessed from the main road leading to the admin block of the school

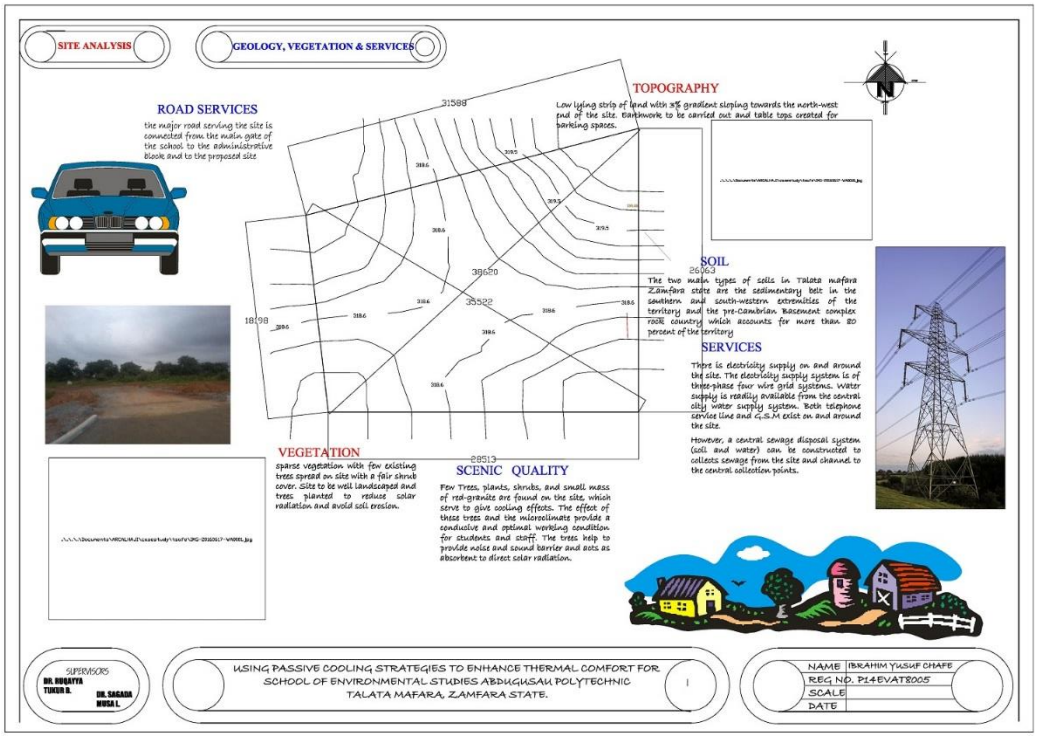


Figure 6-7 Site vegetation services and geology

6.5.5 Climate

The climate of Zamfara varies considerably with months and seasons for instance during the month of December to February a cold and dusty harmattan season is witnessed and hot dry season from the month of April with temperatures ranging from 32^0c to 40^0c as shown in figure 6.8 below. The hot dry season is followed by a raining season from June to September.

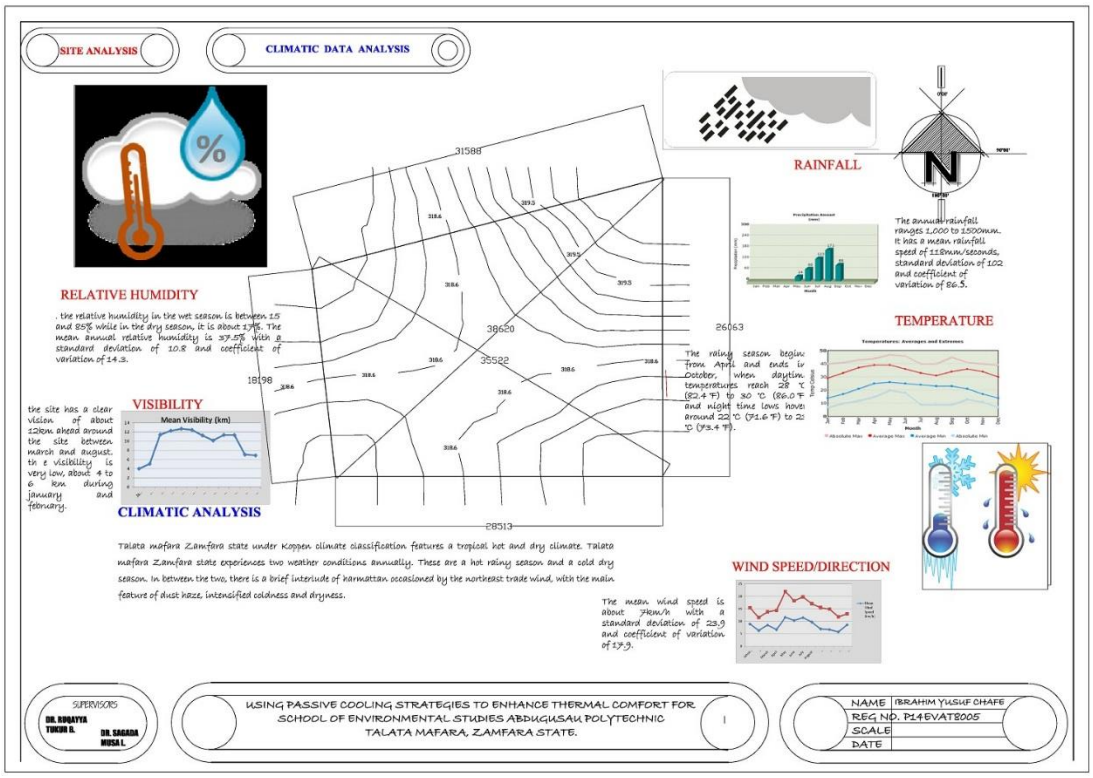


Figure 6-8: Climatic data analysis

7.0 DESIGN REPORT

7.1 Design Brief

A school of environmental studies sponsored by TET FUND of the Federal Government of Nigeria for Abdu Gusau Polytechnic Talata Mafara Zamfara state is a major building and represents a major capital commitment when it is constructed, followed by an ongoing commitment to maintain and operate. The floor area should be assessed to ensure that every square metre is justified for the services which the school will require.

Buildings and adequate space will continue to be vitally important for each departments. Each department should have adequate facilities of teaching learning and practice which will be designed to meet the requirement of international standard. The building should be able to accommodate stated number of students in each department. The departments are;

a. Architecture

b. Building

c. Urban and Regional planning

d. Quantity surveying

e. Land survey (Geomatics)

f. Estate management

7.2 Concept Development

Design concept is the manner in which ideas are arranged to achieve a form, order or format. Concept reflects the function of a building to an observer. However, the concept for the proposed School of Environmental Design Zamfara is divided into Architectural concept which is concept of the spatial organization of spaces in the building, and Façade concept which shows how the form and façade is achieved.

7.2.1 Architectural Concept

The School of Environmental Design Building is an H-shape building form with a central facade depicting the drawing instruments; T square, set square, compass and protractor, thus presenting the School of Environmental Design as a new Architectural image within the Polytechnic. The Concept is that: from the entrance gate there's a walkway leading to the main building which depicts a path to knowledge. The steps in front of the main building depicts the challenges one encounter on seeking knowledge. After the buildings main entrance is the security and circulation which is a bit darker depicting that ignorance is darkness the courtyard is brighter depicting knowledge is light. The courtyard sky view depicting sky is the limit of learned people.

7.2.2 Facade Concept

The key element of the façade was developed specially for the building. The four appendages of the buildings depict arrangement of drawing instruments. The centre of building is a structure mimicking the semi-circle shape protractor. This sequence of drawing instruments creates a uniform and prestigious overall Architectural appearance with characteristic styling.

7.3 Floor Plans

This design considers the basic design characteristics of the hot and dry climate by focusing on the climatic suitability parameters so as to achieve thermal comfort and minimise interior temperature in order to achieve some basic standards.

7.3.1 Site plan

The site plan aimed at incorporating strategies that will minimise SHGC by creating various planting on the site. Also water bodies such as fountain and cascades were built in order to improve evaporative cooling. The trees around the building and within the site will provide adequate shading to the environment. This will create a micro climate that is favourable for learning and cooler than the outside building. The following figure 7.1 shows a sketch of site plan

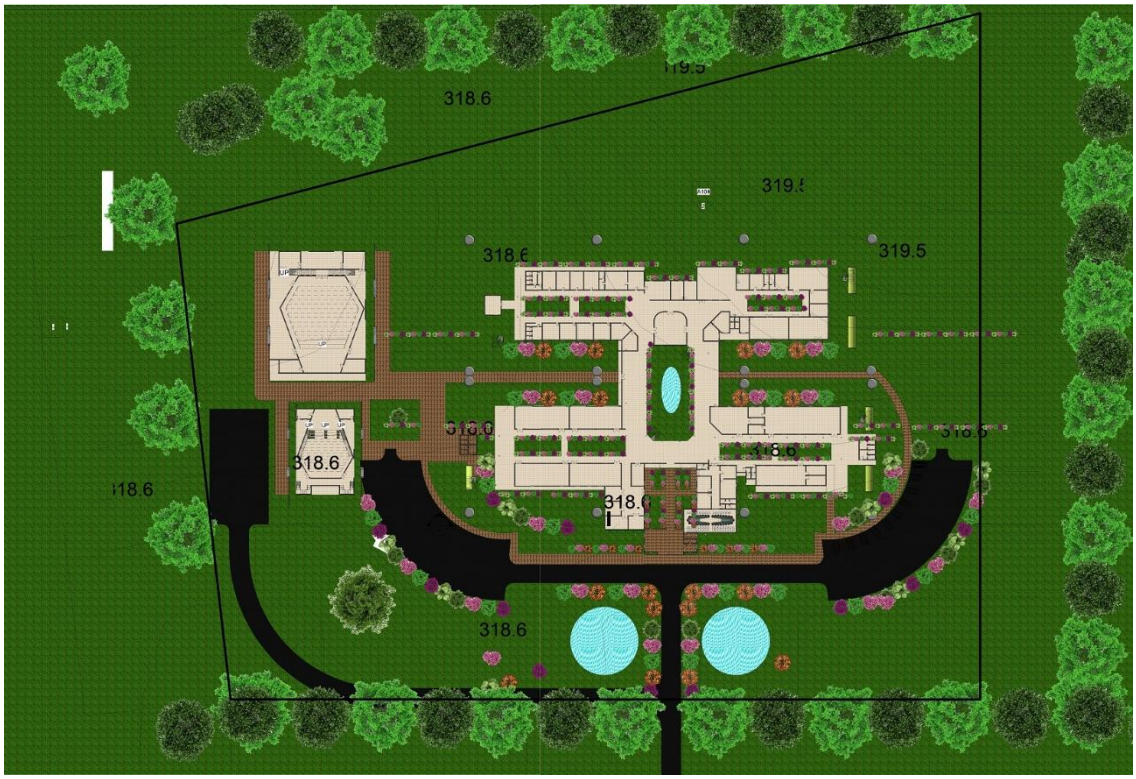


Figure 7-1: Site plan

7.3.2 Ground floor plan

The ground floor as shown in figure 7.2 is categorized for general use, general studios, data room computer lab are placed here for general use by students of the school. The facilities in this zone are more of general oriented activities and are placed here for easy accessibility. The first floor can be accessed by staircase located around the courtyard. Director's office Conference room for the school are also located on ground floor.



Figure 7-2: Ground Floor plan of main School of environmental design building

7.3.3 First floor plan

The first floor house administrative section of building quantity survey and estate management departments with their classes close to each department. Also classes for architecture department are located on this floor. There is departmental data room and conference room for each department.

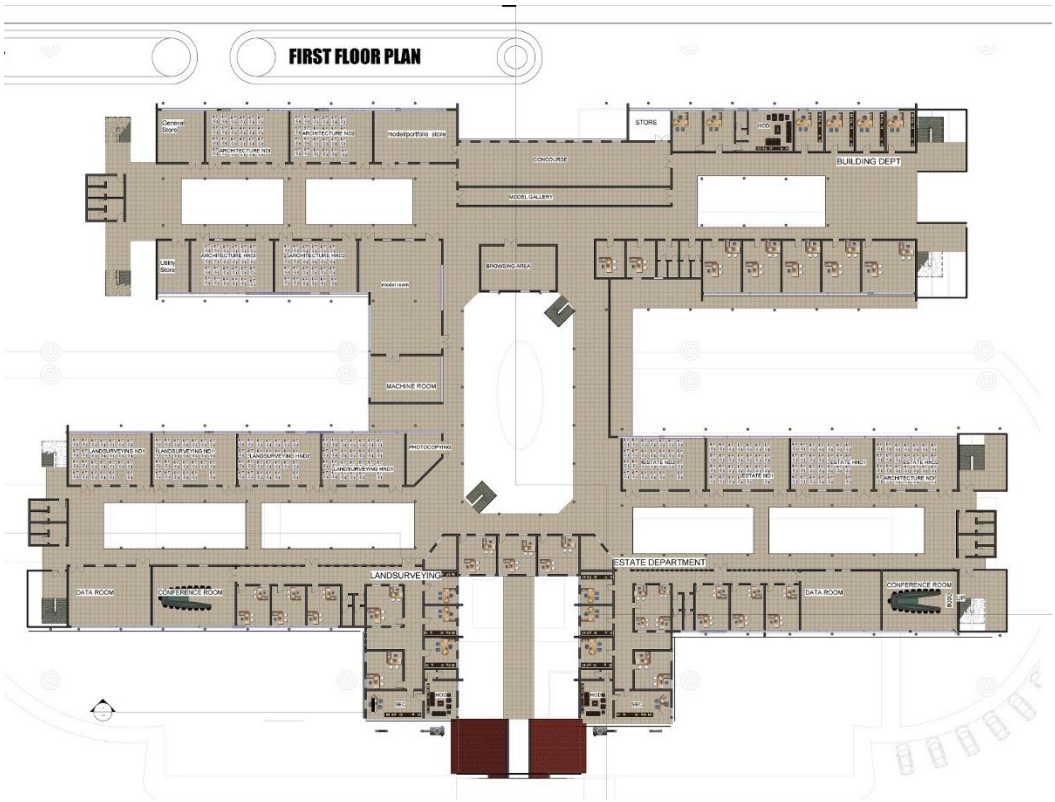


Figure 7-3: First floor plan

7.3.4 Second floor plan

The second floor house administrative section of building land survey and Urban and Regional Planning departments with their classes close to each department. Also studios for architecture department are located on this floor. There is departmental data room and conference room for each department.

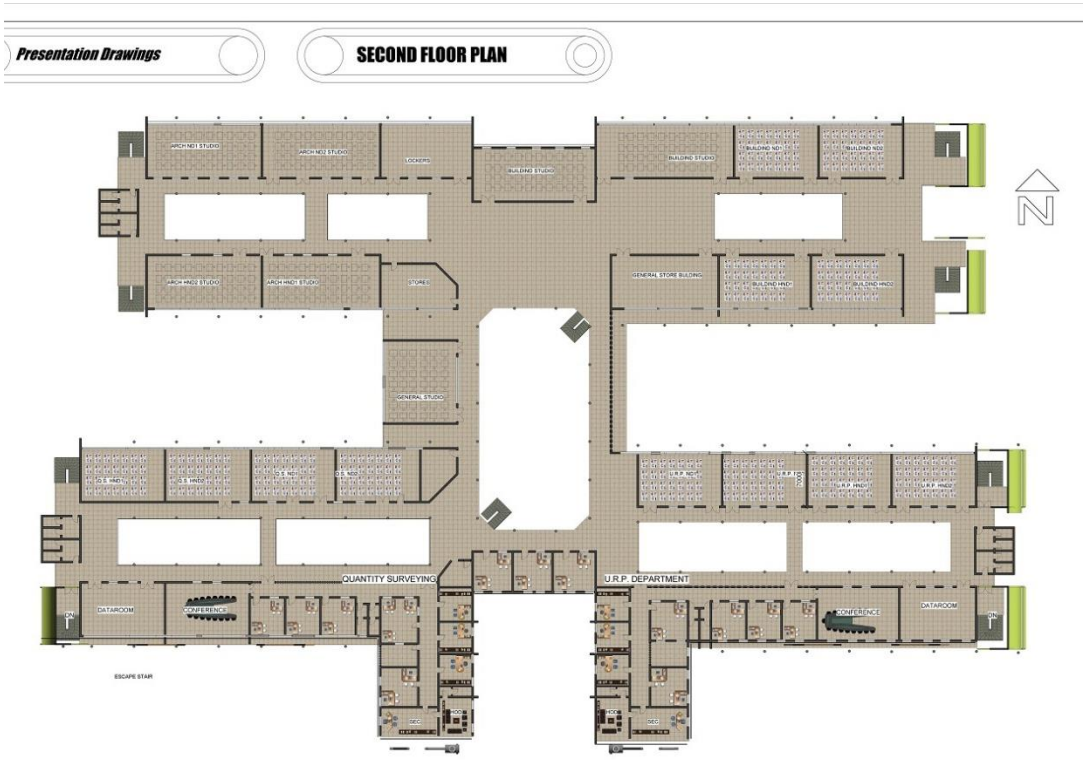


Figure 7-4: Second floor plan

7.4 Schedule of Accommodation

The resulting schedule of accommodation, outlined below and expanded into data sheets for each part of the School of environmental design, shows the space required to meet the department needs. During that time there will be many changes which cannot be foreseen, and the design must ensure that the building will be flexible and able to adapt readily to changing circumstances.

Table 7-1: Schedule of accommodation for the School of Environmental Design

Department	FUNCTIONs	No. of people	Area M^2	Unit	Total area M^2
Architecture	**Lecturers Office**	**2**	**18**	**14**	**252**
	Class room	**40**	**77**	**4**	**308**
	studio	**40**	**112**	**4**	**448**
	Model room	**10**	**65**	**1**	**65**
	Portfolio store	**20**	**60**	**1**	**60**
	Lockers	**20**	**40**	**1**	**40**
	Concourse	**50**	**90**	**1**	**90**
	Model gallery		**18**	**1**	**18**
	E studio	**40**	**95**	**2**	**190**
	W/c	**1**	**4.5**	**8**	**36**
Building	**Lecturers Office**	**2**	**18**	**14**	**252**
	Class room	**40**	**77**	**4**	**308**
	studio	**40**	**96**	**3**	**288**
	workshop	**20**	**85**	**3**	**255**
	W/c	**1**	**4.5**	**8**	**36**
Quantity survey	**Lecturers Offices**	**2**	**18**	**56**	**1008**
Land survey	**Class room**	**40**	**77**	**16**	**1232**
Estate	**Data room**	**40**	**95**	**4**	**380**
U.R.P.	**Conference**	**30**	**78**	**4**	**312**
	W/c	**1**	**4.5**	**24**	**108**
	General Studio	**60**	**120**	**4**	**480**
Directorate	**General Data room**	**80**	**138**	**1**	**138**
	Computer Room	**120**	**235**	**1**	**235**
	Director	**1**	**25**	**1**	**25**
	Deputy director	**1**	**20**	**1**	**20**
	Exam officer	**1**	**20**	**1**	**20**
	Secretary	**1**	**18**	**1**	**18**
	Conference	**60**	**135**	**1**	**135**

7.5 Passive Cooling Strategies Applied in the Proposed Design of School of environmental design

The following strategies were applied in the design of the School of environmental design to create a conducive, comfortable and suitable environment for learning process

i. Building form

The building form used in the design was in such a way that the surface area to volume ratio is very large as required in hot dry climate.

ii. Building Orientation

The building orientation is such that the longer sides of the building face north and south. This will reduce the amount of surface exposed to the solar radiation. However, this is against the suggestion by ECOTECT software of 12.5˚ off north, this expose the building during cold season but the problem is that, cold discomfort rarely occur in Zamfara and even if it happens its usually during the night hours when the School of Environmental Design is closed.

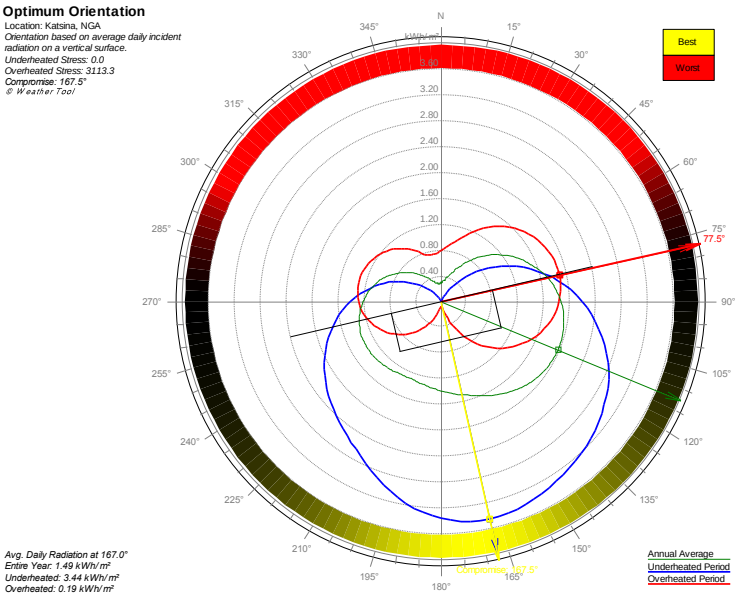


Figure 7-5: ECOTECT best Orientation for Zamfara

iii. Landscaping

Hard and soft Landscape was judiciously used to provide conducive learning environment.

External wall

Walls on the external sides of the building were fortified with shading device above to prevent conduction of heat from solar radiation..

iv. Roof

Roofing system used in the building is insulated with 50mm polyurethane material and adequate roof ventilation was provided as show in figure below.

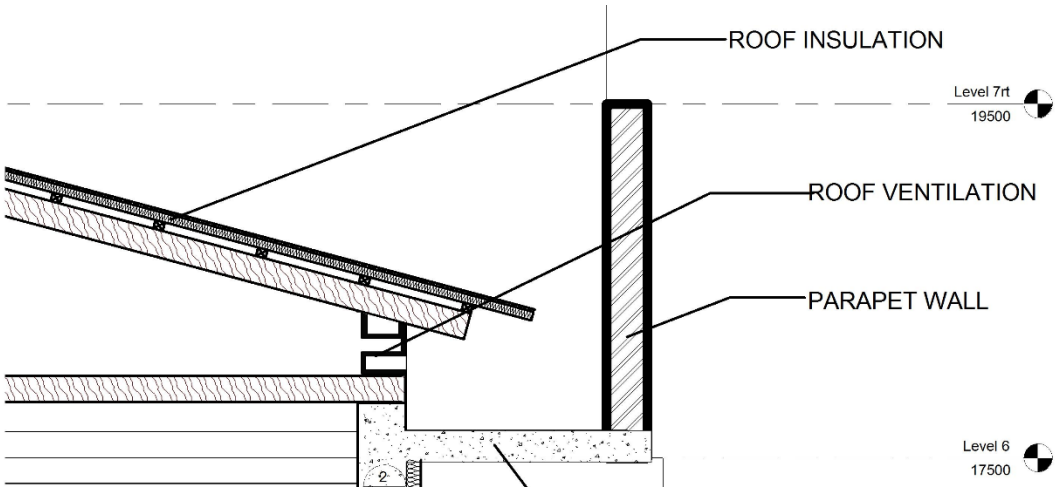


Figure 7-6: Roof details

v. Shading Device

Different shading device were incorporated in the design of the School of Environmental Design. At the front sides of the building concrete shading was used while at the centre metallic shading was used to improve penetration of day-lighting. As can be seen in the following figure.

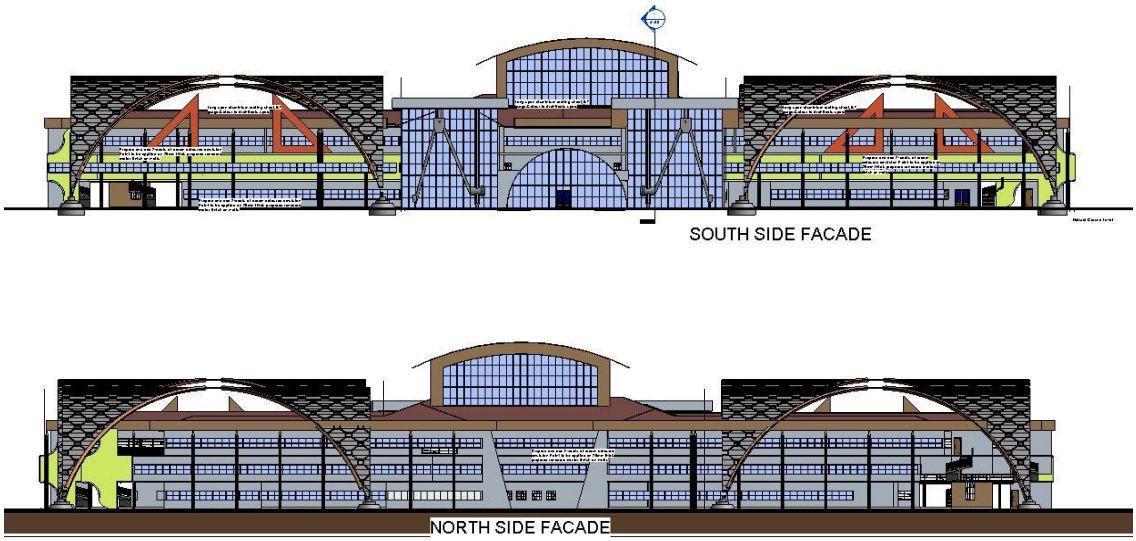


Figure 7-7: Front and rear shading device

vi. Passive Cooling Design Features

Various Passive cooling design features were adopted in order to achieve energy efficient building the following figure shows all the strategies used for the design.

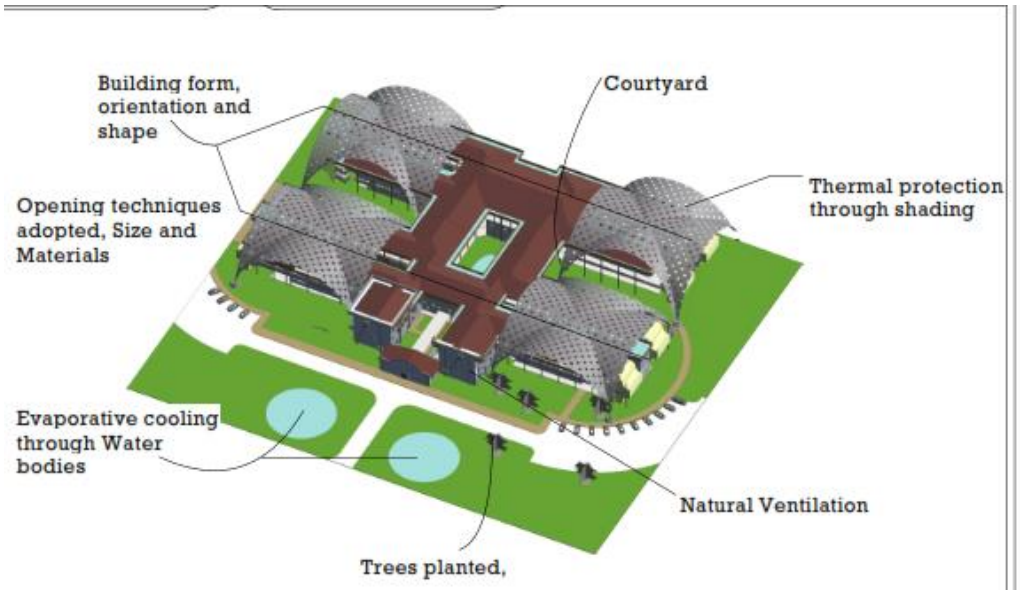


Figure 7.8: Research Variables.

Simulation of the Proposed School

In order to identify the level of interior temperature some selected rooms were simulated. The rooms selected are; studio on the second floor, class room on the first floor and lecturer's office on the ground floor. The procedure is the same as the simulated case study.

7.6 Internal Zone Temperature

Simulations have carried out to measure the existing comfortable temperature during hot season months at ground middle, ground corner and first floor corner. Here is a comparison between the three floors and it can be seen that the earth cover significantly

improves the internal temperatures on ground floors, although these temperatures do not meet recommendation of comfortable temperatures design for habitable rooms but still the lowest one between the other spaces where the temperature rise to unacceptable level.

Figures 7.9 demonstrate that the differences between temperature on different floors and different directions. It is realizable that all the three floors have nearly the same temperature unlike the existing case study where the ground floor has the lowest temperature from the first floor. This may be due to overhead shading device applied in this design and it can also be seen that there is improvement in the temperature reduction of up to 1.2ºC.

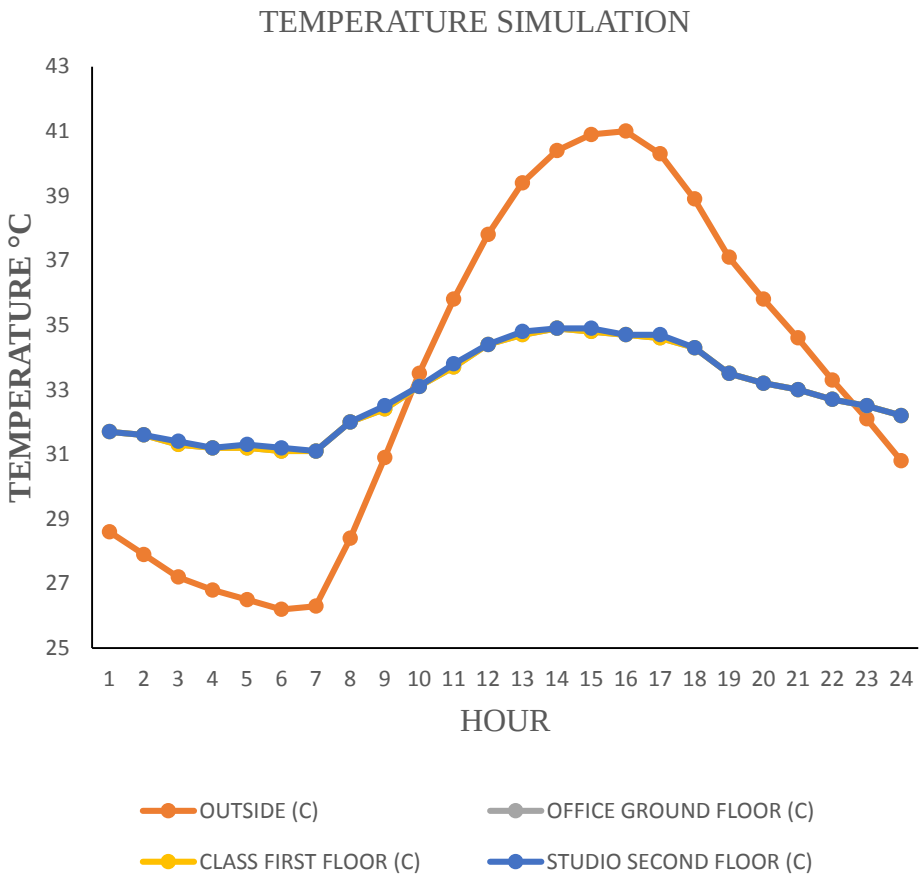


Figure 7-9: differences between temperature on different floors and different directions.

8.0 CONCLUSION AND RECOMMENDATIONS

8.1 Conclusion

The effective application of passive cooling strategies should be considered right from design stage, in order to achieve optimal thermal comfort in indoor spaces, operational stage of the building should be taken into consideration during design to avoid destroying these natural passive environmental factors like trees, water bodies, etc that can also be used on the same site.

From the results established, the application of these passive cooling strategies result to improved thermal comfort between slightly warm and slightly cool with 15% improvement on comfort hours

Therefore, with the application of these passive cooling principles, buildings can maintain satisfactory thermal comfort with reduced need for mechanical cooling systems.

8.2 Contribution to Knowledge

1 Overhead shading device reduce temperature and improved comfort hours to 15% as compared to building without shading device

2 buildings' orientation play a significant role on heat gain during hot season, rooms exposed to high solar radiation show a high room temperature than those located on within the adjacent walls. Upper floor's rooms that located on a big courtyard are shown a better performance than those located on small courtyard.

3 In respect to indoor temperature, upper rooms are the worse where the temperature reach up to 39°C on peak day hours beside the temperature drop to uncomfortable

level during night, the situation is different on ground flat when simulation indicated better performance on ground floor even though the recorded temperature still above the comfort level but not as high as those recorded on top floor.

4 Results of ECOTECT simulation show that temperature at peak hour (between13:00 and 17:00 O'clock) up to 40°C which is almost 12°C above comfort range. This means that it is impossible to achieve comfort temperature with passive cooling however passive cooling improve significantly temperature within the building.

8.3 Recommendations

I. With the current climate challenge of global warming and the growing depletion of the ozone layer; this study recommend application of passive design principles, which will go a long way in reducing the embodied energy of materials used in buildings and the overall carbon foot print as more natural means is been utilized.

II. This study also recommends the use of courtyards design system and high plant coverage to reduce temperature level of buildings, therefore, increasing thermal comfort.

8.4 Areas of Further Research

The challenge for this dissertation has been to design a School of Environmental Studies building that will be thermally comfortable and respond to the micro-climate of Zamfara. So further research can be;

I. This study as stated earlier is only restricted the micro-climate of Zamfara so further research can be done in other cities within the hot-dry climate of Nigeria.

II. There is need to replicate this research on another building typology to confirm the effect of the used energy efficiency strategies in such building.

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APPENDICES



Figure 1: Exterior 3D of Proposed School of Environmental Studies AbduGusau Polytechnic Talata Mafara, Zamfara State.



Figure 2: Exterior 3D of Proposed School of Environmental Studies AbduGusau Polytechnic Talata Mafara, Zamfara State.

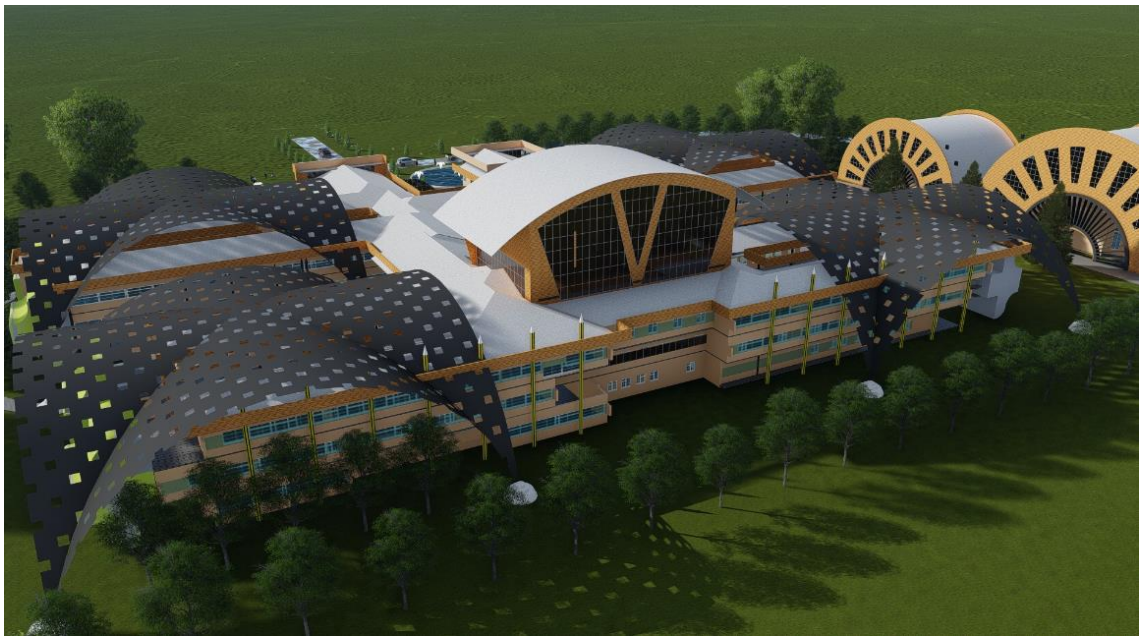


Figure 3: Exterior 3D of Proposed School of Environmental Studies AbduGusau Polytechnic Talata Mafara, Zamfara State.



Figure 4: Exterior 3D of Proposed School of Environmental Studies AbduGusau Polytechnic Talata Mafara, Zamfara State.



Figure 5: Interior 3D of Director Office.



Figure 6: Interior 3D of School Conference Room.



Figure 7: Interior 3D of Open Courtyard.

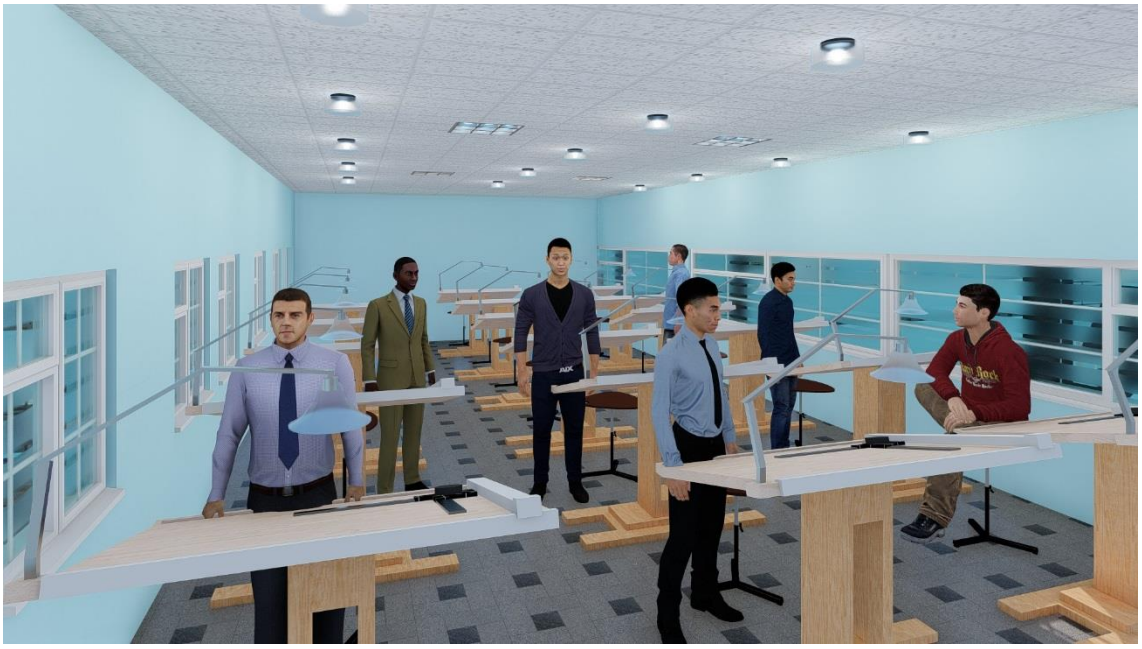


Figure 8: Interior 3D of Design Studio



Figure 9: Interior 3D of Open Courtyard.

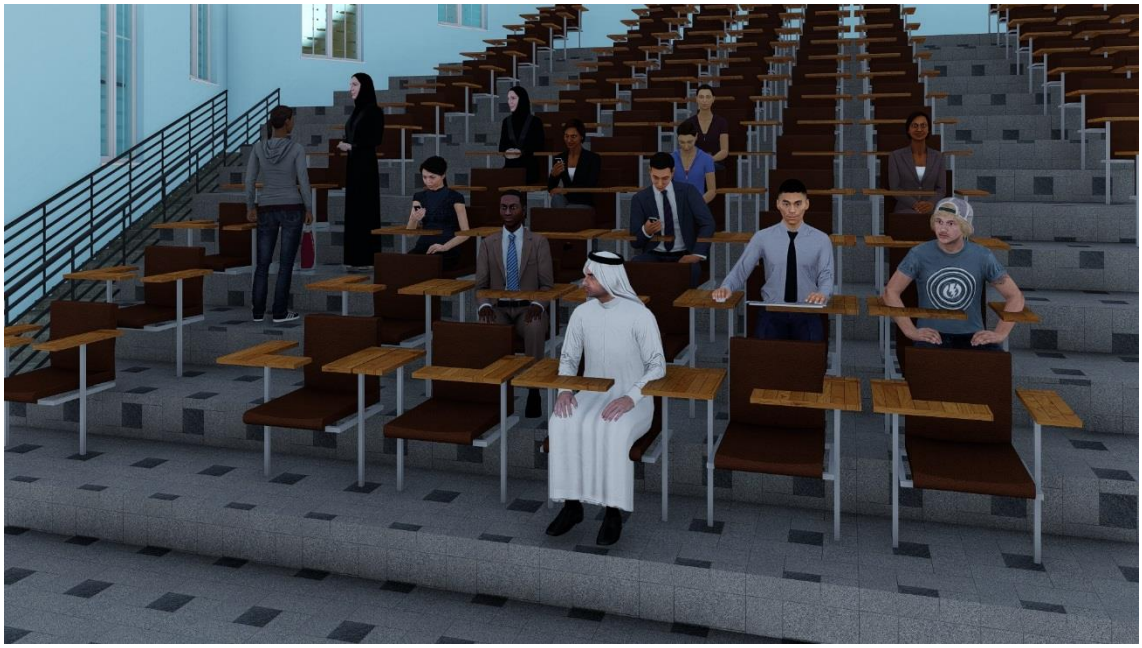


Figure 10: Interior 3D of Auditorium.