EFFECT OF SOLAR SHADING ON THE THERMAL COMFORT OF DESIGN STUDIOS: A CASE STUDY OF DESIGN STUDIO DEPARTMENT OF ARCHITECTURE, AHMADU BELLO UNIVERSITY, ZARIA.

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Abstract

There has been a drastic increase in the use of active cooling systems in buildings all around the world especially in hot humid climate regions. The last two decades has witnessed a severe energy crisis in developing countries especially during dry season primarily due to cooling load requirements of buildings. Solar shading is the term used to identify a number of systems to control the amount of heat and light from the sun admitted into the building and are a key factor in mitigating the impact of energy consumption in the environment. This study is aimed at evaluating the effect of solar shading on the thermal comfort of design studio and this will answer the question to what extend does passive cooling affects thermal comfort? The methodology employed for this research is that of case study and quasi-experiment (using Autodesk ECOTECT Analysis), a baseline model was design and analysed with and without solar shading features and the difference was deducted. Findings from this study indicates that the indoor temperature with and without solar shading features are 31.23^0 and 42.15^0 respectively. Therefore, the indoor temperature difference is 10.92^0. In conclusion, when designing buildings, adequate emphasizes should be given to solar shading in order to enhance the thermal comfort of occupant and reduce the quantity of energy consumption in buildings. However, this paper focuses more on solar shading, it is recommended that research on the effect of other passive cooling techniques measure should be carried out.

Keywords: Building, Design Studio, Energy Consumption, Thermal Comfort, Solar Shading.

INTRODUCTION

Buildings are the major economic sector in the world and the quality of buildings shapes the life of citizens (Santanmouris, 2005). With people spending about 80 to 90 percent of their lives indoors (ASHRAE, 2015), to many the risk to health may be greater due to exposure to indoor air pollution than outdoor air pollution, there is no place where we spend more time in our life. Designing a comfortable place requires ingenuity; a place where the thermal comfort will be at optimal, a place where the energy consumed will be minimized, providing people a place to achieve their most ambitious goals, to give people a place where they can always feel safe and secure, a place to carry out daily activities, to give them a place where they can live the life they want.

Thermal problems are very common in buildings, to cope with this problems Architects/Engineers use different systems, which can either be the active and/or passive cooling techniques. Active cooling (also called Artificial cooling system) refers to the cooling technologies that must introduce energy with the help of an external device to enhance heat transfer, example air condition, heat extractor or an electric fan. Passive cooling (also known as Natural cooling system) uses free, renewable sources of energy such as the sun and wind to provide cooling, ventilation and lighting needs for a building (Santanmouris, 2005).

Spaces/buildings can be classified into different categories depending on the function allocated to it. Design Studios in the context of this research can be defined as large spaces with drawing equipment for conceiving, designing, developing and actualizing new ideas design. The indoor quality of the studio determines to a large extent the comfort and performance of users (students) which calls for adequate consideration because it can help student brings out the best in them because of the comfortable environment and at the same time increases students' performance. Since architecture Students spend a long part of their day in studio, the thermal environment needs to be properly addressed and taken care of in order to design a comfortable space for them.

Designers have endeavoured to create indoor environments in which they can feel comfortable but achieving optimal thermal comfort has continually been a challenge especially using passive techniques. This has led to the creation of several mechanical means of cooling building (which in themselves causes more harm than good). However, the extent to which passive techniques in studio design contributes to thermal comfort is an area that has not been adequately research in.

Although there has been research on passive cooling techniques in residential building, very little consideration has been given to that of institutional buildings especially design studio, thus the need to underscore its effect on thermal comfort of design studios. The rate of designing uncomfortable building has become very alarming and worrisome. Many building occupants have developed sick building syndrome (SBS), become unproductive/inefficient in their activities (Kolleeny, 2012; Zagreus, Huizenga, Arens and Lehrer, 2004). All of these is now prevalent because architects no longer design with ingenuity but become carried away by either the aesthetics or the money of the building.

Many institutional buildings, especially large halls like design studios are very hot inside, some others lack proper cross ventilation, some inadequate building material selection/specification, and others bad orientation which has left users with no option then to remain uncomfortable and complain through out there stay in that environment. Because of these reasons, the research chooses to take a deep study into the effects of passive cooling techniques on thermal comfort in design studios in other to create a conductive environment for students to carry out their normal day to day activities.

This study is aimed at determining the effects of solar shading in design studios'; Case study of Department of Architecture, Ahmadu Bello University, Zaria.

REVIEW OF RELATED LITERATURES

Solar Shading as a means of Enhancing Thermal Comfort

Among all other solar passive cooling techniques solar shading is relevant to thermal cooling of buildings especially in a developing country owing to their cost effectiveness and easy to implement.

Shading with tree reduces ambient temperature near outer wall by 2°C to 2.5°C. On an average a depression of six degrees centigrade in room temperature has been observed when solar shading techniques are adopted (Batty, Hinai, Probert, 1991). Kumar, Garg and Kaushik (2015) evaluated the performance of solar passive cooling techniques such as solar shading, insulation of building components and air exchange rate. In their study they found that a decrease in the indoor temperature by about 2.5°C to 4.5°C is noticed for solar shading. Results modified with insulation and controlled air exchange rate showed a further decrease of 4.4°C to 6.8°C in room temperature. The analysis suggested that solar shading is quite useful to development of passive cooling system to maintain indoor room air temperature lower than the conventional building without shade (ibid).

Shading by overhangs, louvers and awnings.

Well-designed sun control and shading devices, either as parts of a building or separately placed from a building facade, can dramatically reduce building peak heat gain and cooling requirements and improve the natural lighting quality of building interiors. The design of effective shading devices will depend on the solar orientation of a particular building façade as shown in figure 1. For example, simple fixed overhangs are very effective at shading south-facing windows in the summer when sun angles are high.

However, the same horizontal device is ineffective at blocking low afternoon sun from entering west facing windows during peak heat gain periods in the summer.

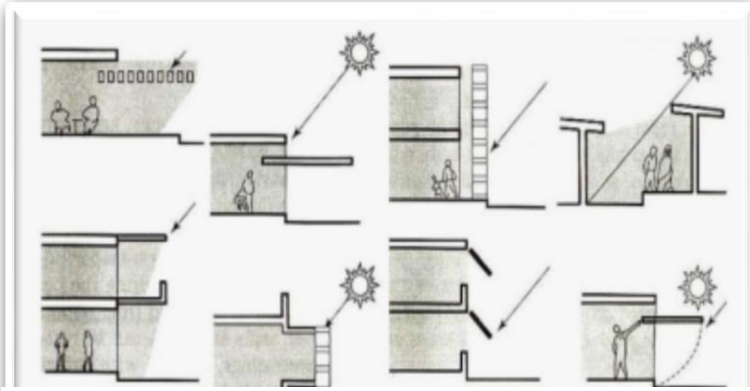

Figure 1: Shading by overhangs, louvers and awnings
Source: Kamal 2012

Shading of Roof

Shading the roof is a very important method of reducing heat gain. Roofs can be shaded by providing roof cover of concrete or plants or canvas or earthen pots. Shading provided by external means should not interfere with night-time cooling. A cover over the roof, made of concrete or galvanized iron sheets, provides protection from direct radiation. Disadvantage of this system is that it does not permit escaping of heat to the sky at night-time (Figure 2).

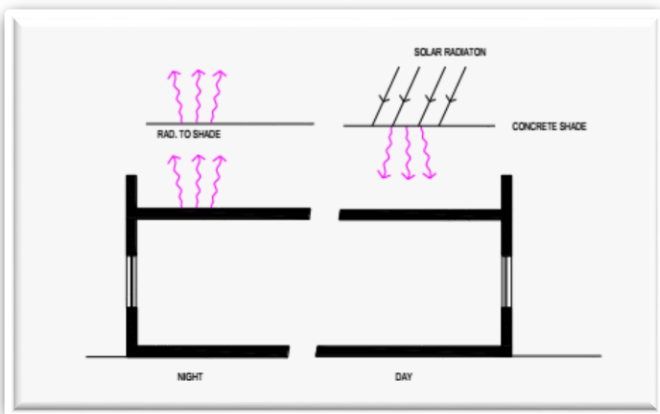

Figure 2: Roof shading by solid cover
Source: Kamal 2012

Shading by trees and vegetation

Proper Landscaping can be one of the important factors for energy conservation in buildings. Vegetation and trees in particular, very effectively shade and reduce heat gain. Trees can be used with advantage to shade roof, walls and windows. Shading and evapotranspiration (the process by which a plant actively release water vapor) from trees can reduce surrounding air temperatures as much as 5°C. Different types of plants (trees, shrubs, vines) can be selected on the basis of their growth habit (tall, low, dense, light permeable) to provide the desired degree of shading for various window orientations and situations. The following points should be considered for summer shading (ibid);

1. Deciduous trees and shrubs provide summer shade yet allow winter access. The best locations for deciduous trees are on the south and southwest side of the building. When these trees drop their leaves in the winter, sunlight can reach inside to heat the interiors.
2. Trees with heavy foliage are very effective in obstructing the sun's rays and casting a dense shadow. Dense shade is cooler than filtered sunlight. High branching canopy trees can be used to shade the roof, walls and windows.
3. Evergreen trees on the south and west sides afford the best protection from the setting summer sun and cold winter winds.
4. Vertical shading is best for east and west walls and windows in summer, to protect from intense sun at low angles, e.g. screening by dense shrubs, trees, deciduous vines supported on a frame, shrubs used in combination with trees.
5. Shading and insulation for walls can be provided by plants that adhere to the wall, such as English ivy, or by plants supported by the wall, such as jasmine.
6. Horizontal shading is best for south-facing windows, e.g. deciduous vines (which lose foliage in the winter) such as ornamental grape or wisteria can be grown over a pergola for summer shading.

Shading by textured surfaces

Surface shading can be provided as an integral part of the building element also. Highly textured walls have a portion of their surface in shade as shown in Figure 3. The increased surface area of such a wall results in an increased outer surface coefficient, which permits the sunlit surface to stay cooler as well as to cool down faster at night.

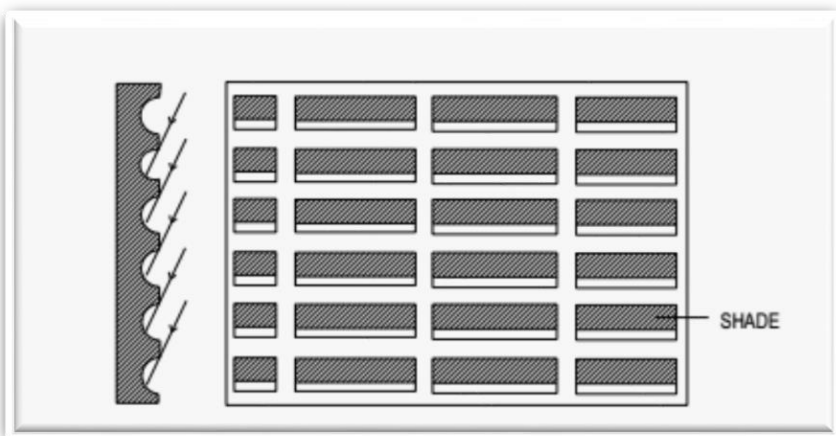

Figure 3: Shading due to surface texture
Source: (Kamal, 2012)

Thermal Comfort

By looking at comfort, "The American Society of Heating Refrigeration and Air Conditioning

Engineers" ANSI/ASHRAE Standard 55 (2010) defined it as a "condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation". The main criteria for thermal comfort for the human body as a whole can be divided into environmental variables: air temperature, mean radiant temperature, humidity, air velocity and personal variables: clothing and metabolic rate (activity). In addition, there are other environmental parameters that can cause local thermal discomfort such as draught, a high vertical temperature difference between head and feet, radiant temperature asymmetry and warm or cold floors.

To know about the thermal climate, we need to know about the heat exchange between human and their environment. The human body continuously generates heat with an output varying from about 100W for a sedentary person to 1000W for a person exercising actively. To avoid discomfort, the body temperature must be within a narrow range, and within a wider range to avoid danger from heat or cold stress (ASHRAE Handbook, 2009).

RESEARCH METHODOLOGY

The research was carried out in two main phases, that is, through an extensive research in literature review and also through case study by identifying the present passive cooling techniques used in the department and a quantitative analysis using simulation through ECOTECT Software.

Case Study

The selected case study for the research is the 400level Design Studio in Department of Architecture, Faculty of Environmental Design, Ahmadu Bello University, Zaria. This studio is located on latitude 11.1512^{0}N and Longitude 7.6546^{0}E on the second floor of the faculty multi-story building, below the building is the CAAD Lab and the faculty administrative offices and above is the roof top comprising a lecture hall and restaurant.

Figure 4: Site location of Design Studio, Department of Architecture, A.B.U., Zaria.
Source: Google Earth, 2015, Retrieved on October, 2017

This Architectural design studio strategically located was designed to comfortably accommodate and cater for the student needs. Since it was design for student daily and regular activities, several passive design techniques were used in order to achieve thermal comfort even in the absent of electricity. The building was shaded with a glass partition by 2.4m on three different sides (South, west and east), this is a significant passive design strategy among others that were used as shown in Figure 5 and 6. The presence of Landscaping elements around the building also serve as passive cooling techniques.

Figure 5: Showing solar shading device of Studio Work Space.
Source: Author's Field work

Figure 6: Showing solar shading device of Studio Work Space.
Source: Author's Field work

Simulation

Simulation according to New Oxford advanced English dictionary (2010) means to produce a computer model of something or the imitation of the operation of real-world process or system over time, which grow in popularity each year, were selected using computerized program such as ECOTECT and ENERGY PLUS which provide reasonable results. The heating and cooling loads will be calculated for each model. The results will be evaluated in order to optimize the thermal temperature of the models. ECOTECT software is a comprehensive, concept-to-detail sustainable design analysis tool, providing a wide range of simulation and building energy analysis functionality that can improve performance of existing buildings and new building designs.

ECOTECT Analysis

"ECOTECT is a conceptual design analysis tool designed by Dr Andrew Marsh of Square One research that features overshadowing, shading design, lighting, acoustic and wind analysis functions as well as thermal. It uses CIBSE Admittance Method to calculate heating and cooling loads for any number of zones within a model. These load factors are direct and indirect solar gains, internal gains, inter-zonal gains, inter-zonal heat flow and pull-down loads due to intermittent usage". ECOTECT gives thermal analysis of hourly internal temperatures and load breakdowns as well as annual temperature distributions and the effects of thermal mass.

According to the software authors, the strength of ECOTECT lies in allowing the user to "play" with design ideas at the conceptual stages, providing essential analysis feedback from even the simplest sketch model. ECOTECT progressively guides the user as more detailed design information becomes available. Again, according to the software authors, weaknesses of the software are as follows: As the program can perform many different types of analysis, the user needs to be aware of the different modelling and data requirements before diving in and modelling /importing geometry. For example; for thermal analysis, weather data and modelled geometry in an appropriate manner is important; and appropriate/comprehensive material data is required for almost all other types of analysis.

In this study Ecotect 2011 is used to run simulations and to specify alternative materials to the models. By this method, the alternative graphs of hourly temperatures, discomfort period and monthly heating and cooling loads of the houses in respect to thermal neutrality comfort band were obtained and the effects of different materials on thermal comfort in the same houses were observed. The results produced by simulation and collected in real life differed so that calibration was modelled to handle the difference. The materials and its effects on thermal comfort were assessed.

4.0 RESULTS, FINDINGS AND DISCUSSION

4.1 Result and Findings

This section presents in detail how the collected data were analysed. A baseline model was designed with an Autodesk software of Revit Architecture 2017 as shown in Figure 7. The second stage involve exporting it to ECOTECT 2011 software were the model will be analysed with and without passive cooling techniques and the results were observed and recorded as shown in Figure 8. The third stage involves interpretation and presentation of results in various tables and charts.

The results of the thermal comfort analysis presented here are without the mechanical cooling set (that is active cooling techniques). The indoor temperature is therefore maintained about an average of 24˚C. The dependent variable used to examine the thermal performance of the variables is annual and monthly energy consumption.

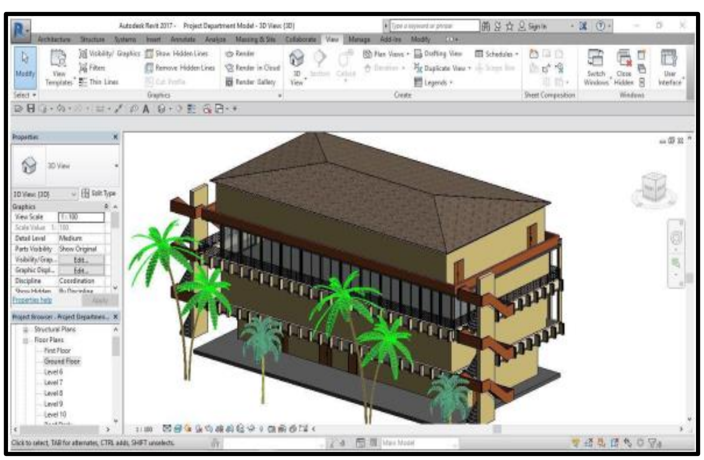

Figure 7: 3D View of the Baseline Model from Revit
Source: Author's field work

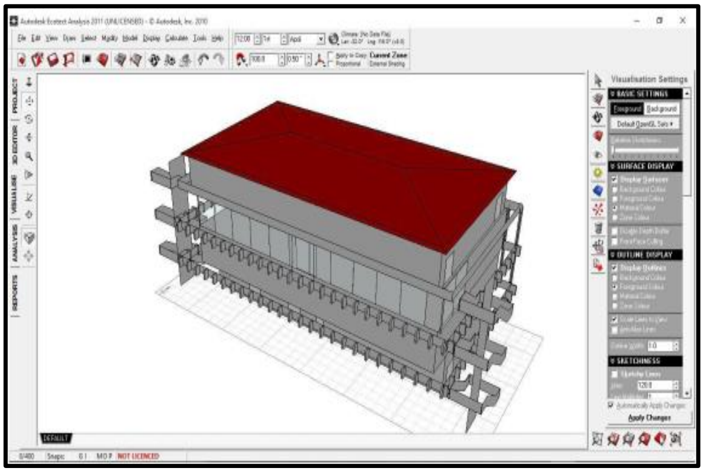

Figure 8: Interface of Autodesk ECOTECT
Source: Author’s field work

ECOTECT was used to compare the lighting, ventilation, temperature, acoustics and humidity as the factors that affect thermal comfort in the design model with and without the presence of the various solar shading elements available in the design studio. Several materials were appointed to the corresponding building components afterwards an ECOTECT simulation was ran to observe how these factors of thermal comfort behaved all together in regards to passive design.

4.2 Model with Solar Shading Elements

Simulation for the 12th of October by 9:00am for Zaria Weather

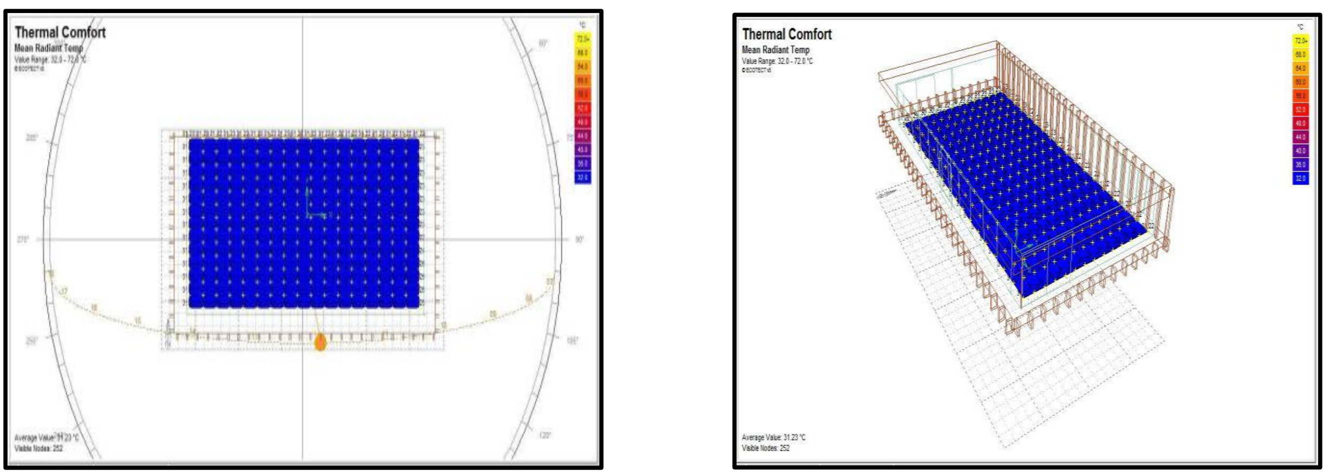

Figure 9a: Simulation result of the plane area of Design Studio at 9am on the 12th October
9b: Model of the perspective view of the simulated project of the design Studio.

As shown in Figure 9 (a and b), the colour ranges from blue to yellow that is from a cool and comfortable zone to a harsh and uncomfortable zone. Blue has the dominant colour and the analysis has an average value of 31.23^{0}C mean radiant temperature.

Table 1: Mean Radiant Temperature available on the simulated working plane area

Mean Radiant Temperature (⁰)	Percentage (%)
32-36	91.67
36-40	0
40-44	0
44-48	0
48-52	0
52-56	0
56-60	1.59
60-64	5.95
64-68	0
68-72	0

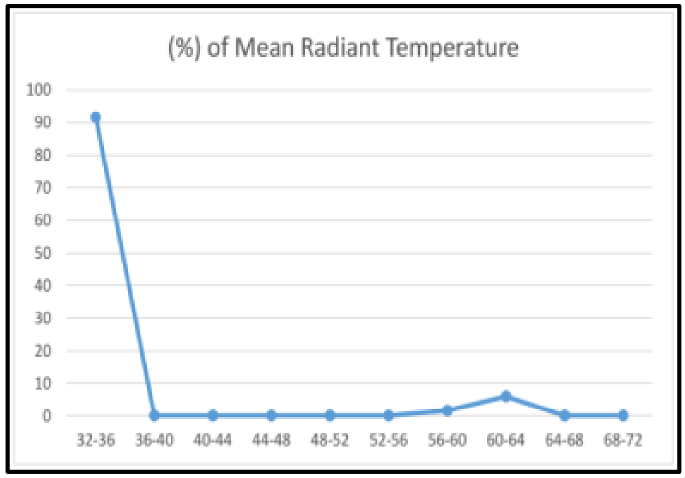

Figure 10: Percentage area graphical representation of the simulated working plane area of Design Studio

From the simulation conducted for 400level Design Studio, department of Architecture A.B.U., Zaria as shown in Figure 10 at 9am on the 12th of October it was deduced that the average Mean Radiant Temperature is 31.23^{0}C of which signifies a comfortable/adequate indoor environment for the student. The area that falls above the Normal mean radiant temperature is 7.33% and 91.67% falls within the acceptable indoor environment temperature.

4.3 Model Without Solar Shading Elements

Simulation for the 12th of October by 9:00am for Zaria Weather

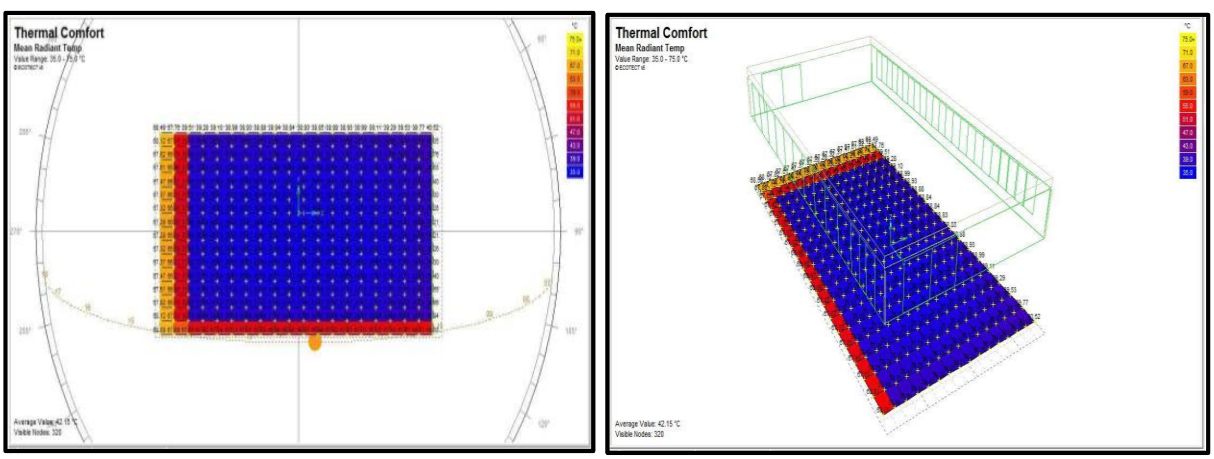

Figure 11a: Simulation result of the plane area of Design Studio at 9am on the 12th October
11b: Model of the perspective view of the simulated project of the design Studio.

As shown in Figure 11, the colour ranges from blue to yellow that is from a cool and comfortable zone to a harsh and uncomfortable zone. Blue has the dominant colour and the analysis has an average value of 42.15^{0}C mean radiant temperature.

Table 2: Mean Radiant Temperature available on the simulated working plane area

(from-to)	(%)
35-39	76.88
39-43	7.5
43-47	0
47-51	0
51-55	0
55-59	0
59-63	0
63-67	5
67-71	10.62
71-75	0

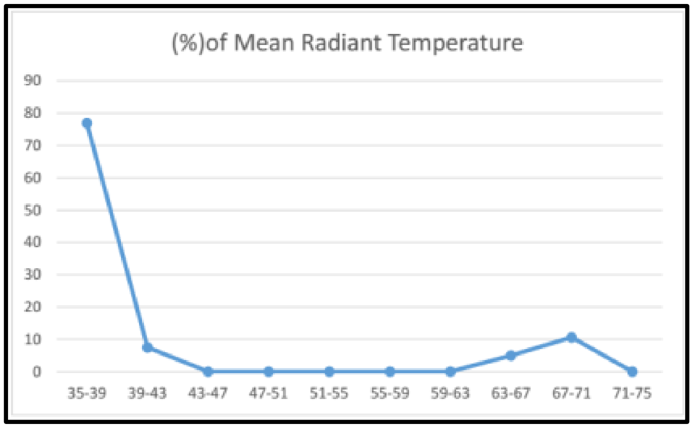

Figure 12: Percentage area graphical representation of the simulated working of the design studio

From the simulation conducted for 400level Design Studio of the model without the solar shading features as shown in Figure 12 at 9am on the 12th of October it was deduced that the average Mean Radiant Temperature is 42.15^{0}C which signifies an uncomfortable/harsh indoor environment for the student. The area that falls above the Normal mean radiant temperature is 23.12% and 76.88% falls within the acceptable indoor environment temperature.

4.4 Discussion

For the simulation carried out for both the Design Studio with and without the passive cooling techniques. It was deduced that an average value of 31.23^{0}C and 42.15^{0}C Mean Radiant Temperature which signifies a comfortable and an uncomfortable environment respectively. 91.81% of the area of the space in Design Studio with passive cooling techniques fall within the acceptable thermal comfort, but while 76.25% of the area in Design Studio without Passive Cooling Techniques falls above the Standard.

From the above deduction, we have a clear difference of average value of 10.92^{0}C Mean Radiant Temperature which is about 14.88% difference between both temperatures.

CONCLUSION AND RECOMMENDATION

Conclusion

This research carried out was fully on the effect of solar shading as a passive cooling techniques on thermal comfort of design studio with case study of department of architecture, A.B.U. Zaria in order to compare a model with and without passive design techniques on thermal comfort and find out the percentage difference between the two models with an aim of solving the problem of uncomfortable indoor environment. This research stated out the passive design techniques and ways of achieving them in design studios. Therefore, the quality of thermal comfort in institutional buildings such as design studios should be considered with a good orientation, landscape and with sufficient openings such as windows.

This research has proved that there is a difference between the thermal comfort of design studio with and without the solar shading elements. From the results conducted on 12th October at 9am in the model with solar shading elements it was noted that the average value of mean radiant temperature available in the simulated is 31.23^{0}C, while the average value of mean radiant temperature for the model without solar shading elements available in the simulated area is 42.15^{0}C. Therefore, it is deduced that there is 10.92^{0}C mean radiant temperature difference, from this, it is established that solar shading increases the mean radiant temperature of the indoor environment by 14.52%.

Recommendations

From the result obtained in this research, it is evident that solar shading helps increases the thermal comfort of design studio, so it's advisable to always shade our fenestrations in our design studios in other to enhance the indoor environment and make learning comfortable for students. Solar shading simulation in respect to thermal comfort is also recommended for Architects from the design stage in order for them to have an idea of users' comfort in the building before execution.

There are so many aspects of passive cooling techniques such as sun shading, orientation, landscaping, building form and finishes, Natural Ventilation techniques and sustainable planning, here concentration was placed on sun shading and insulation as seen in the building, further research should be carried out on other aspect of passive cooling techniques.

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