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EFFECTS OF CLIMATE ON BUILDING ELEMENTS USING ECOTECT SOFTWARE

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ABSTRACT

Comfort is a necessity for every human being and over the years the search for it has been influenced by the impact of the microclimate. As elements of climate (solar radiation, precipitation, temperature, humidity) have posed a challenge to the design and construction of buildings that could comfort the occupants. Buildings now have to moderate the outdoor climate and provide comfort conditions for its occupants without excess use of energy. This can only be done by designing buildings that respond to the microclimatic conditions of the environment. It is against this backdrop that this paper seeks to investigate the effectiveness of faculty buildings in respect to the climate. The study area selected is Federal University Birnin Kebbi in Nigeria, based on the extreme climatic conditions of intense solar radiation and temperature; hence the study area provides the opportunity to investigate the effects of harsh weather on faculty buildings in the region. Three faculty buildings were randomly selected in the study area, furthermore modelled and analysed with the existing climatic data, using Ecotect simulation software. The simulation of the buildings was based on peak period of solar radiation (February, March, April, May and June) and extreme recorded temperature of a single day (45°C of 10th April 2011). The results of the simulation illustrate a slightly better performance along the East and West functions of the faculty buildings housing major functions (at 45°C having an average differential temperature of 1 to 3 when compared with the outdoor environment in all the three selected faculty buildings) and a considerable better performance along the North and South functions of the faculty buildings housing lesser functions (at 45°C having an average differential temperature of 3 to 6). From the findings of the research it has been concluded that the designers of the faculty buildings did not take into consideration the extreme climatic conditions of the micro climate as illustrated with lack of good design orientation. The study then recommends that the Architects and Planners should adjust the subsequent buildings yet to be constructed on the master plan in order to improve the performance moderation of the microclimate.

Keywords: climate, building form, building orientation, building material, simulation.

1.0 INTRODUCTION

Comfort is a necessity for every human being and over the years the search for it has been influenced by the impact of the climate. As elements of climate (solar radiation, precipitation, temperature, humidity) have posed a challenge to the design and construction of buildings that could comfort the occupants. Buildings now have to moderate the outdoor climate and provide comfort conditions for the occupants without excess use of energy.

One of the major challenges facing designers now is the problem of climate change fuelled by greenhouse gas emissions (Olotuah, 2015). The burning of fossil fuels has caused the concentrations of heat trapping greenhouse gases to increase significantly in the atmosphere. The gases prevent heat from escaping to space and thus have precipitated global warming. This is a serious environmental effect, and it is as a result of the adoption of uniform style of architecture irrespective of the climatic conditions thus consuming high energy in buildings. Subramanian *et al* (2016) asserted, how adoption of international styles of architecture in 20th century has eradicated traditional concepts to the local climate making it difficult to achieve comfort without use of mechanical systems. This practice is causing serious environmental impact (Kabiru, 2011). Architects using these concepts of design are endangering the eco-system contributing to the effect of climate change (Arup and Design Genre, 2016). Buildings must adapt to the climate of the region and its microclimate (Geetha and Velraj, 2012). The architects should take into consideration the climatic conditions of the location in order to design efficient buildings. According to Asli (2006), understanding and control of the climatic effects at the location of the building are crucial even before design decisions are made. Furthermore, there is a growing trend towards achieving low energy building designs with the aid of simulation (Aleksandrowicz, 2015).

1.1 Sun, Temperature and Building Elements

Radiation from the sun determines the amount of heat gain or loss on the earth surface. the relationship between the sun and the site has to be taken into consideration right from the design process in order to design efficient buildings (Ateeque. 2017). Generally. the amount of solar access radiation on a building mostly depends on the position of the sun in relation to the building. The sun is dynamic and mostly moves in the direction of east to west (sunrise and sunset). the lower the angle of the sun in relation to the building the lesser the heat radiation and consequently. the higher the angle of the sun the more the heat radiation. Therefore. proper orientation of the building to the sun can control the overall heat gain or loss on the building elements (walls. roof and openings). Consequently. the decision on the choice of material type. shape and composition are determined by the effect of climate on the building site. The rate of heat transfer through a material depends on the effectiveness of the thermal properties of the material. The higher the insulation and mass of the material the more the storage of heat through the material and the less the heats transfer. So. the ability of the material to store heat during the day and effectively dissipate it at night is determined by its thermal performance. Designers have to minimise the heat gain through the building elements by proper choice of colour. type and composition of the material.

2.0 Federal University Birnin Kebbi, Kebbi state. Nigeria

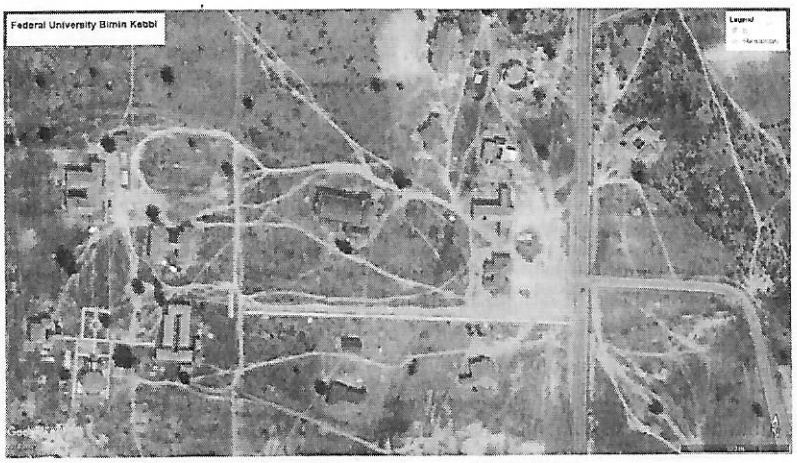

Figure 1: google earth picture of the study area 18/09/2018
Source: Google earth.com (2018)

Federal University Birnin kebbi is located in Birnin Kebbi, capital of Kebbi State. The school was established on 23th February 2013 with the aim to increase access to education for the people of this region. The region falls under the hot and dry climatic conditions of the north-western Nigeria. The State is characterised with high temperature that can rise up to 45°c, with low precipitation, low humidity and intense sunlight in most of the periods. Three (3) faculty buildings have been constructed on permanent site in the study area, most of which are facing the same direction (East-west) where the sun rises and sets. Designing for this kind of climate requires careful examination of the dynamic movement of the sun in relation to the buildings on site. As high sun intensity can affect the performance of the buildings on site which results to heat discomfort to the occupants of these buildings. This paper therefore seeks to determine the effectiveness of these faculties on site to identify and then analyse the elements of the buildings that are responsible for the heat temperature consumptions in the buildings.

3.0 Methodology

The methodology that best suits the research is case study method and software simulation of the buildings (Aleksandrowicz, 2015); this is to examine the manifested design intentions of the Architect and actual performance of the buildings when compared with the extreme climate. Three buildings were selected randomly: faculty lecture hall, school of environmental and school of art and science. The buildings were modelled with Revit in their existing forms, materials and orientations, then imported to Ecotect software using Sokoto climatic modules gotten from the Nigerian meteorological agency, subjected the buildings to peak period

of solar radiation so as to identify the elements of the buildings that are exposed to the climate and further simulated on hottest recorded temperature of the day (10th April-45°C, 2011) to examine the moderation level of the buildings when compared to the microclimate.

3.1 School of Environmental

This is a faculty building located in the temporary site of the Federal University Birnin Kebbi having coordinate (12°19'53" N, 4°09'16"), housing three departments of the environmental studies namely Architecture, Building and Quantity Survey. The structure comprises of partitioned offices as separate wing departments with studio rooms separated from the offices forming a ring like structure. The offices are located along the north eastern direction and studio rooms at the south west direction as shown in figure 2.

Table 1 shows the features of the building elements that were applied in Revit architecture in modelling the structure:

Table1: Physical properties of simulated building materials.

Building elements	Type	Thickness	Colour	Texture
Wall	Hollow Sandscrete block	230mm (Density2002.21kg/m^3)	Light	Rough
Window	Single glazed	8mm	Reflective blue	Reflective
Ceiling	P.V.C panels	5mm	Light	Smooth
Roof	Long span Aluminium	0.55mm	Light	Smooth

Source: Author (field work), 2018

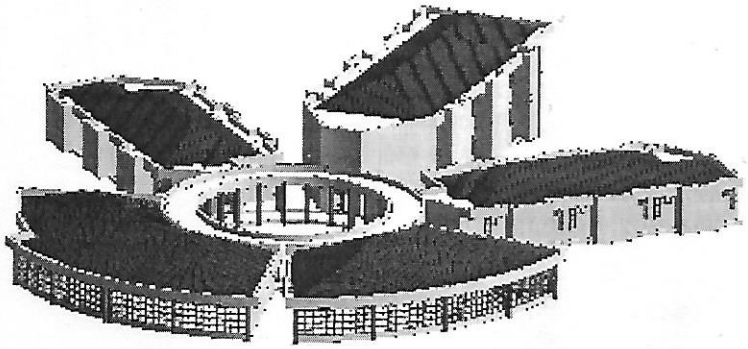

Figure 2: Revit model of school of environmental
Source: Author (field work), 2018

3.1.1 Effect of orientation on building elements

The Building was simulated based on the peak solar access radiation. The sun path direction was maintained East-West facing the structure as the orientation of the building could determine the elements of the building that are exposed to solar radiation. The colour bar located on the top right corner of figure 3 shows the amount of heat gain from yellow to deep blue. The roof which is the component of the buildings mostly exposed to solar radiation has yellow colour, followed by the windows and walls facing the sun direction with different shades of brown colour while the shaded walls areas have the least effect of sun radiation from the colour brown to blue.

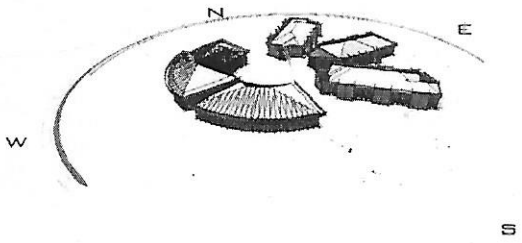

Figure 3: Showing a Rendered image of the simulation model
Source: Author (field work), 2018

3.1.2 Effect of temperature on building elements

Table 2 shows the differential moderation temperature level of the building indoor spaces and the general outdoor temperature of 45°c. On the ground floor, the north Eastern rooms alongside the east room and east south rooms have the highest differential temperature as shown in the figure 4 chart. However, the west south and west north rooms have the joint lowest moderation.

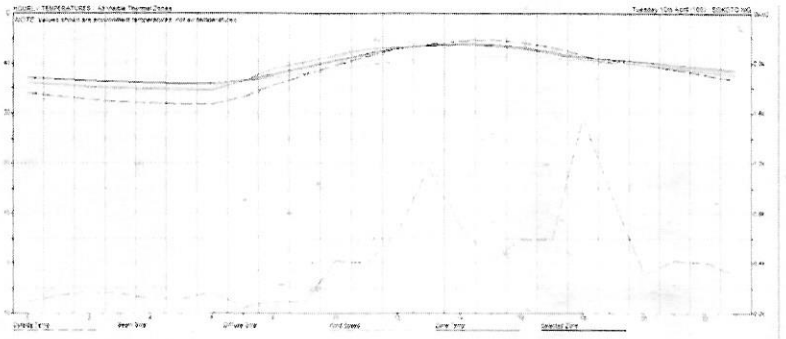

Figure 4: Simulated indoor temperatures for a hottest day (10th April)
Source: Author (field work), 2018

Table 2: Showing Deferential Temperature at Average Temperature of 45°C

	North East Rooms	East Rooms	East South Rooms	West Rooms	South West rooms	North
Ground Floor	3	3	3	1	1	

Source: Author (field work), 2018

3.2 Faculty of Art and Social science

The Faculty of Art and Social Science building of Federal University Birnin Kebbi is located on coordinate (12°19'53" N.4°09'16" E). it houses staff offices for school of art and social science. Table 3 shows features of the building that were applied in Revit architecture in modelling the structure:

Table3: Physical properties of simulated building materials.

Building elements	Type	Thickness	Colour	Texture
Wall	Hollow Sands Crete block	230mm (Density2002.21kg/m^3)	Light	rough
Window	Single glazed	8mm	Reflective blue	reflective
Ceiling	Hardboard ceiling	3mm	Light	smooth
Roof	Long span Aluminium	0.55mm	Light	smooth

Source: Author (field work), 2018

The building is cross like shaped with the head form which is the main entrance is oriented to face the east direction and the tail end facing the west direction. As shown in figure 5. the use of vertical and horizontal sun shading devices were not employed in the building's exterior walls except for the roof eaves overhang.

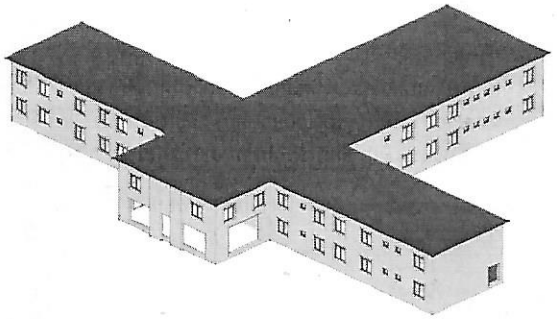

Figure 5: Revit model of school of art and social science
Source: Author (field work), 2018

3.2.1 Effect of orientation on building elements

Building was modelled to mimic existing as-built orientation with regards to the sun and its component materials from the roof, wall and windows.

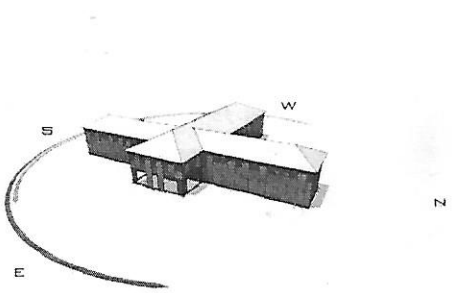

Figure 6: rendering of the simulation model
Source: Author (field work), 2018

Results from the simulations showed that the roof has the highest exposure to radiation from the sun as indicated on the high to low meter bar in figure 6, this represents the radiation level of the roof in yellow. The windows and walls with the colour red are directly facing the sun direction while elements that are shaded away from the sun having colour meter brown to blue.

3.2.2 Effect of temperature on building elements

From the chart in figure 7, there is an appreciable variation in temperature moderation along the North, East West and Southern ends of the building at 45°C outdoor temperature. On the ground floor, the south room has the highest moderation followed by the north and west rooms on the first floor. Subsequently the east rooms on the ground floor and first floor are with the least moderation.

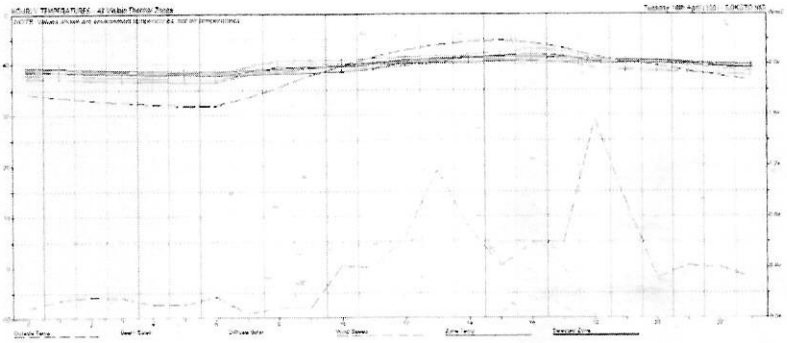

Figure 7: simulated indoor temperatures for a hottest day (10th April)
Source: Author (field work), 2018
Table 4: Showing Deferential Temperature at Average Temperature of 45°C

	North Rooms	South Rooms	East Rooms	West Rooms
Ground Floor	3	4.5	2	3
First Floor	3.5	4	2.5	3.5

Source: Author (field work), 2018

3.3 Faculty Lecture Hall

The faculty lecture hall is located in the school of Federal University Birnin Kebbi (12°19'49" N, 4°09'02" E). The building houses classrooms, offices and conveniences for the faculty building of art and social sciences. Table 5 shows features of the building that were applied in Revit architecture in modelling the structure.

Table 5: Physical properties of simulated building materials.

Building elements	Type	Thickness	Colour	Texture
Wall	Hollow Sandscrete block	230mm (Density2002.21kg/m^3)	Light	rough
Window	Single glazed	8mm	Reflective blue	reflective
Ceiling	Hardboard ceiling	3mm	Light	smooth
Roof	Long span Aluminium	0.55mm	Light	smooth

Source: Author (field work), 2018

The building form comprises of a combination of rectangular and square shape with open courtyard forming the central area as depicted in figure 8. It is oriented with the shorter side facing east-west and longer side facing north-south.

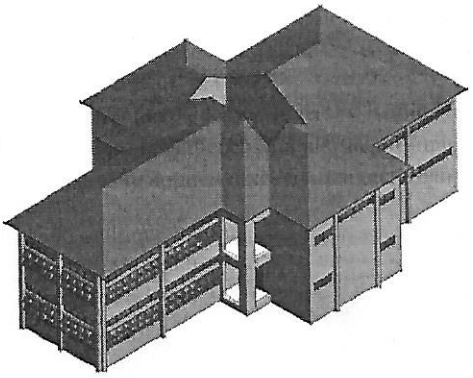

Figure 8: Revit model of school of art and social science
Source: Author (field work), 2018

3.3.1 Simulation result: effect of orientation on building elements

From figure 9, the building was simulated based on peak period of solar radiation in which the sun path direction along the East-west axis facing the structure. As consistent with the other two buildings simulated the roof with colour yellow is the most exposed component, followed by the windows and walls in the sun direction with colour yellow to red while the shaded walls are least exposed with the colour ranging from brown to blue.

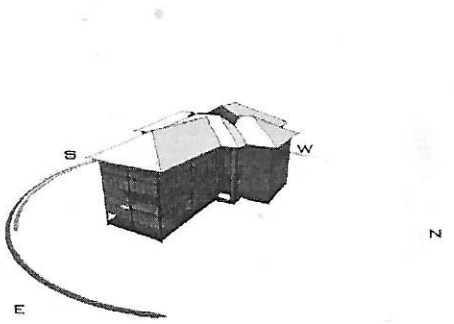

Figure 9: rendering of the simulation model
Source: Author (field work), 2018

3.3.2 Effect of temperature on building elements

Figure 10 shows the differential moderation temperature level of the building functions. At outdoor temperature 45°c, the north and south rooms on the ground and first floor have the highest temperature moderation in the building while the east and west rooms have a lower moderation compared to the others. There is also a slight difference in the result between the ground and first floor as shown in table 6.

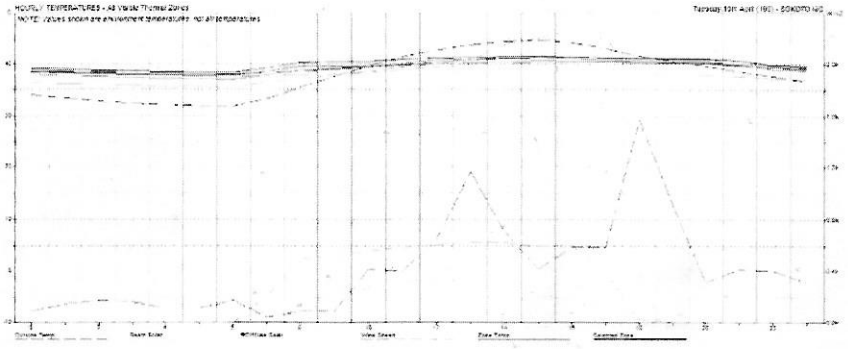

Figure 10: Simulated indoor temperatures for a hottest day (10th April)
Source: Author (field work), 2018
Table 6: Shows the differential Temperature of the building functions at average temperature of 45°C.

	North Rooms	South Rooms	East Rooms	West Rooms
Ground Floor	6	5	3	1
First Floor	6	5	4	1

Source: Author (field work), 2018

4.0 Findings and discussion

The findings from the research reveals that the designers of the building did not put orientation with regards to the direction of the sun into consideration during the design of the buildings as shown with building orientation in figures 3, 6 and 9. From this perspective the buildings proved to be climatically ineffective as the major functions of the building are facing the east-west direction. Furthermore, a larger number of the windows in figures 3, 6 and 9 are located along the east-west axis of the sunrise and sunset causing the slight moderation in

temperature of these spaces as revealed in tables 2. 4 and 6. The exposure of the roof to solar radiation is responsible for difference in temperature between the ground floor and the first floor as shown in Table 4.
Besides orientation. the application of sun shading devices in figure 3 was among the reason behind the appreciable moderation temperature of the building's wing: north east. east and east south wing axis as shown in table 2. The functions of the building on those axes are entirely masked from sun penetration when compared to west south and west north rooms. Furthermore.
Courtyard and verandas application have significant impact on the north and south rooms of the building in figure 9. as remarkable temperature moderation is achieved in table 6.

5.0 Conclusion and Recommendation

From the findings. it can therefore be concluded that the faculty buildings of the study area were not designed to suit the climate as shown with the lack of good orientation. It is apparent that the designers did not put into consideration the extreme micro climate of the site as the major important functions are facing the east-west direction and spaces with lesser importance facing the North South direction. More so the lack of sun shading devices in two of the three case studies simulated proved to be a major factor in the heat gain within these buildings. There is therefore. the need to adopt climate responsive building functions such as courtyards. verandas and sun shading devices during conceptual design and integrated in construction stage in order to suit the climate of the region. Hence, adjusting the form and orientation of the subsequent buildings yet to be constructed on the existing master plan would have a positive impact on the existing performance moderation level of the buildings within the microclimate. Preferably, the enclosure of the major functions of the buildings should be taken completely away from sun direction; openings of the buildings also should be positioned in a place where sun is not penetrating. Trees can as well be planted around expose building elements as they serve as a shield to cool down effect of the climate.

References

Abdul-Manan, D. (2016, April). Harnessing passive design for comfortable indoor environments:comparative study of traditional and modern architecture in the northern region of Ghana. *Scientific Research and Studies. .3(4)*, 87-95.

Agboola, O. P. (2011). Importance of climate to architectural design in Nigeria. *environmental issues and agriculture in developing countries, 3.*

Anh-Tuan, N., Quoc-Bao, T., Duc-Quang, T., & Sigrid, R. (2011). An investigation on climate responsive design strategies of vernacular housing in Vietnam. *Building and Environment*, 2088-2106.

Arup, & Design Genre. (2016). *Building Energy Efficiency Guidelines for Nigeria.* Abuja: Federal Ministry of Power, Works and Housing.

Asli, P. B. (2006). Architectural Design Based on Climatic Data. *Built Environment and Information Technologies*, 261-267.

Ateeque, A.B., Anjum, C.D., Bilal., & Sumiya, G.H. (2017). Impact of solar radiation on building envelope using energy plus software. Proceedings of SIMEC, 24-25.

Fathy, H. (1986). *Natural Energy and Vernacular Architecture: Principles and examples with reference to hot arid climates.* Chicago: The University of Chicago Press.

Geetha, N. B., & Velraj, R. (2012). Passive cooling methods for energy efficient buildings with and without thermal energy storage. *Energy Education Science and Technology Part A, 29(2)*, 913-946.

Hanna, M. (2014). *Adaptive building envelopes.* Sweden: Chalmers.

Hasselaar, B. (2006). Climate Adaptive Skins: towards the new energy-efficient facade. *Management of Natural Resources, Sustainable Development and Ecological Hazards, 99*, 351-359. doi:10.2495/RAV060351

Jhaveri, A., & Springuel, Y. (2010). The New Wave in Conference Center Design. *Trends.*

Kabiru, S. D. (2011). Climate responsive architecture: Creating greater design awareness among Architects. *Journal of Environmental Issues and agriculture in developing countries, 3*(1).

Kimmo, K. (2008). *Climate Conscious Architecture: Design and wind testing for climate in change.* Finland: Oulu University Press.

Kwok. A. G.. & Grondzik. W. T. (2007). *The Green Studio Handbook: Environmental strategies for schematic design.* Elsener Inc.

Loonen. R.. Trcka. M.. Costola. D.. & Hensen. J. (2013. June). Climate adaptive building shells: state-of-the-art and future challenges. *Renewable and Sustainable Energy Reviews. 25.* 483-493. doi:10.1016/j.rser.2013.04.016

Olgay. O. (1963). *Design with climate.* New Jersey: Princeton University press.

Or. Alexsandrowicz.. & Ardeshir. M. (2015. December). The Impact of Building Climatology on Architectural design: a simulation-assisted historical case study. *14th conference of international building performance simulation association.* 2150-2157.

Peter . S.. & Richard. H. (2009. June). Towards a new model for climate responsive design at the university of the sunshine coast chancellery. *Green Building Paper*. 1-20.

Remco. L. (2007). Design strategy for the integration of climate-responsive building elements in dwellings.

Remco. L.. Hans. C.. Andy van den. D.. Arjan van. T.. & Martin. T. (2007. November). Climate-responsiveness of building elements. *The 24th conference on passive and low energy architecture.* 22-24.

Richard. H. (2000). *A study of buildings in moderate and hot humid climates.* USA: E and FN Spon.

Rosangela. T. (2007). Enabling the hybrid use of air conditioning: A prototype on sustainable housing in tropical regions. *Building and Environment 42*, 605-613. doi:10.1016/j.buildenv.2005.10.003

Subramanian, C. V., Ramachandran, N., & Senthamil , K. S. (2016, August). Comparative Investigation of Traditional, Modern and Designed Solar Passive Building for Thermal comfort in Thanjavur Region. *International Journal of Innovations in Engineering and Technology, 7*, 283-291.

Varun, K., & Simos, Y. (2007, September). Environmentally responsive architecture; passive design for school in southern India. *2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century*, 537-540.