EFFECT OF WINDOWS TO WALL ORIENTATION ON ENERGY EFFICIENCY IN INSTITUTIONAL BUILDINGS IN YOLA

Marafa, U.G[1], Mohammed, S.A,[2] and Tugga, M. B[2]
[1]*Department of Architectural Technology, Federal Polytechnic, Mubi*
[2]*Department of Architectural Technology, Adamawa State Polytechnic, Yola*
Corresponding Author: ugmarafa@gmail.com
Phone: +234 708 540 7293

ABSTRACT

Globally, a significant proportion of building energy is economically consumed for achieving the required thermal and optical comfort. The most important parameter affecting the thermal comfort and lighting energy is the window to wall ratio (WWR) of the building. It is important to keep in mind the "economic" factors, which can greatly impact the quality of a home's space and therefore the quality of life of the homeowner. Empirical studies show that WWR of 10% is recommended for hot and humid climate region. The aim of this study is to investigate the level of conformity of orientation of 40 selected buildings in MAU with regards to energy conservation. Case study research design was adopted to analyze the purposively selected buildings. The result revealed that North and South Cardinal have the highest mean value of WWR as compared with East and West and Sub-Cardinals. Therefore, it depicts that most of the studied buildings were oriented in tenant with the bioclimatic principles. It was recommended from the findings that incorporation of shading plants and vegetation among other passive measures that will help in minimizing energy consumption.

Keywords: *Energy efficiency, WWR, Economic challenges, Orientation, Thermal, Cardinal Points*

INTRODUCTION

Orientation, from Latin (*orens, orientum)* meaning "The rising sun". While in architecture, it is the position of a building in relation to an east-west axis. In Mesopotamia and Egypt, as well as in pre-Columbian Central America, the important features of the buildings, such as entrances and passages, faced east; in the direction of the rising sun as reported in Encyclopedia Britannica [3]. The orientation of a building is the direction faced by its external facades. Windows have a significant influence on building energy performance. The proper design of windows can greatly reduce energy consumption in buildings.

Often the considerations of these two factors may lead to contradictory orientation requirements especially for hotter climates where one orientation may provide the required higher velocities but on the other hand elevating the temperatures as well. Studies by Givoni [5] suggested that in hot and humid conditions the priority of orientation with regards to indoor climate is "to a greater extent dependent on ventilation and therefore orientation is more important with respect to winds than in relation to the patterns of solar radiation." This suggestion was also previously established by Koenigsberger *el at.* [9], recommending that orientation for wind is more advisable to low-rise buildings that do not get much solar radiation. Sustainable Energy Efficient Building Advisory Committee [14] opines that the building's shape, orientation and location on the proposed site need to be studied in the early design phase to determine how these factors may affect heating and cooling loads. *East/West facing* ***windows:*** Windows placed in east and west-facing walls are penalized twice. Not only do they lose a significant amount of heat in the winter, but they are also a source of significant heat gain in the summer, increasing air conditioning costs. This is because the sun rarely shines directly through east and west-facing windows in the winter, but shines strongly on these facades in the morning and afternoon during the summer.

Energy use m buildings accounts for a large percentage of total energy consumption worldwide, which leads to increasing CO_2 emission into the atmosphere. Studies in Europe on energy consumption have shown that buildings are responsible for 40% of energy end use and 30% of CO_2 emission as indicated by Maccari & Zinzi, [12].Windows have a significant influence on building energy performance. The proper design of windows can greatly reduce energy consumption in buildings. In order to encourage the development and the appropriate use of high performance glazing and windows, many window energy rating systems (WERS) have been developed in different countries. Window-wall ratio is the specific value of the area of the window and that of the room facade. Unit area of room facade indicates the area enclosed by the room height and the standard width of the bay China according to Academy of Building Research, [1].The natural lighting performance is better when the window-wall ratio increases. However, windows also play a critical role in terms of building thermal insulation which needs to be clearly considered. Many studies have focused on the relationship between window-wall ratio and building energy consumption. Hou and Fu [7] studied the relationship between the window-wall ratio in hot summer and cold winter zone and the power consumption of air conditioning. Jana and Jiang [8] considered the effect of window-wall ratio on the building yearly heating energy consumption, yearly air conditioning energy consumption, and total annual energy consumption for different orientations in residential buildings in Shanghai. Feng and Yang [4] analyzed how different solar radiations influence the thermal process of windows. Furthermore, they presented the design principles of window-wall ratios on building energy efficiency in the hot summer and cold winter zone. Wang et al. [17] explored the energy saving effect of building envelope in summer through experiments and simulations. As a result of advancement of computational capability, the optimum window size and types to minimize energy consumption of buildings have been explored using computer simulation.

Szokolay [15] suggested that in order to ensure maximum cross ventilation in a building, the major openings should face within 45° of the prevailing winds. All the above suggestions from these authors are for naturally ventilated buildings. Hawkes [6] suggested two groupings for buildings, the exclusive and selective modes. The shape is dispersed and seeks to maximize the use of ambient energy. Further, a study conducted by Lam et al. [10] on the impact of solar radiation on the facades of buildings in the tropics revealed that North and South facades have the lowest sun intensities. This varied from 43.6 and 74W/m2 respectively. The eastern and western facades recorded the highest intensities ranging between 86.1 and 89.6W/m2. From the study above, optimized orientation of buildings in the Tropics should be away from the direction of solar radiation. Orientation is therefore tied in with aspect ratio which is the ratio of the longer dimension of an oblong plan to the shorter Szokolay [15]. Szokolay [15] further explains that depending, on the temperature and radiation conditions, North and South walls should be longer than the East and West with an aspect ratio of about 1.3 to 2.0 (ibid).

The aim of this study is to investigate the level of conformity of orientation of some selected buildings in regards to energy conservation. The objectives area as follows:

i. To determine the exposure of windows to walls ratio along the North and South main cardinal.
ii. To determine the exposure of windows to walls ratio along the West and East main cardinal
iii. To determine the exposure of windows to walls ratio along the sub-cardinals

Cardinal and sub-cardinal orientations

South facing windows: South-facing, high-performance windows (U-value less than 0.32 and SIIGC higher than 0.40) can collect solar energy and provide a net heat gain over the winter. But even a high performance window, when placed in any other orientation (north, east, or west), will lose significantly more heat over the course of the winter than a standard R-19 wall. Because south-facing windows can collect solar heat and are easy to shade during the summer, their use and area should be maximized.

***East/West facing windows*:** Windows placed in east and west-facing walls are penalized twice. Not only do they lose a significant amount of heat in the winter, but they are also a source of significant heat gain in the summer, increasing air conditioning costs. This is because the sun rarely shines directly through east and west-facing windows in the winter, but shines strongly on these facades in the morning and afternoon during the summer. West-facing windows are particularly problematic in summer because the heat gain is maximized during the later afternoon, typically the hottest part of the day.

North facing windows: North-facing windows are the biggest energy losers, but are often valuable because of their ability to provide indirect daylight to interior spaces. Efforts to provide day lighting with east/west windows and even south windows can often be thwarted when people close interior shades to block strong direct light. North windows provide a comfortable indirect light source, which reduces the need for electric lights. In addition, operable north windows pair well with south windows to create cross-ventilation in the summer.

In general, a window-to-floor area ratio close to 15% is recommended for conventional construction. This window-to-floor area ratio balances energy, first cost, and indoor environmental quality. Houses implementing passive solar strategies using thermal mass and south orientation must be evaluated on an individual basis and may require a different overall window-to-floor area ratio to achieve maximum benefit as shown in the chart below by the Center for Sustainable Building Research, [2].

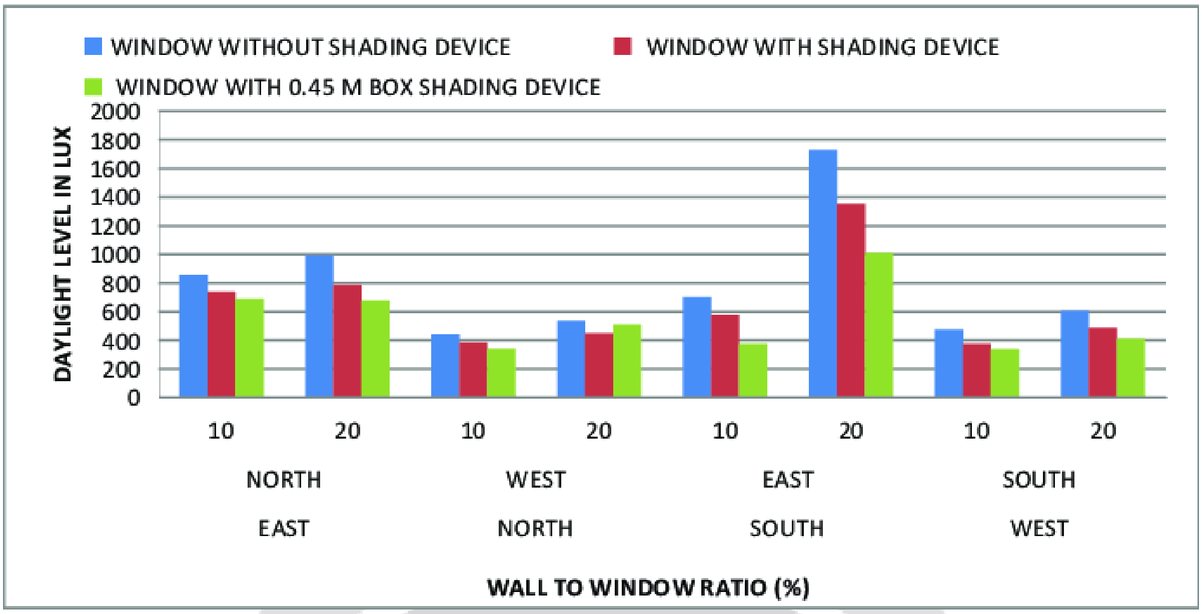

Chart 1: Comparison between daylight walls to window ration %

Methodology

The field study was conducted in Modibbo Adama University, Yola. Different categories of buildings were studied. An inventory of the extent to which orientation of walls and windows exposure are made in line with energy efficiency from empirical studies of the study area was carried out through observation and use of camera. 40 selected buildings of different categories which include Academies, Administrative, Library, Hostel and Lecture Theater were studied.

- **A.** Academic buildings: Consist of 22 numbers of different departmental buildings, in which some department buildings are prototype.
- **B.** Library building: Consist of 2 numbers of buildings.
- **C.** Administrative building: Consist of 6 numbers of buildings.
- **D.** Hostel building: Consist of 4 numbers of buildings.
- **E.** Lecture theater building: Consist of 6 numbers of buildings.

Data collected for the study was principally on orientation of window/wall ratio in all the cardinal-North, South, West and East; as well as the sub-cardinal-North-East, South-East, South-West and North-West sub cardinals of forty studied buildings in MAU,Yola. This was achieved through data collection technique, the use of two instruments: Camera and participant observation strategy adopted in this study, to ascertain the orientations of the window/wall ratio in cardinals and sub-cardinals. The raw data were gathered through the use of camera and observation. Which were later used for analysis Photographs were taken with Nokia Lumia 520x handset which has a sharp and clear image output for the North, South, East, West and sub-cardinal. 40 buildings photographs were taken at a distance of 10m away from the building, the stand point to capture the image was at the centre of most of the buildings, due to larger sizes of some of the buildings, and images were taken at different direction to bring out complete image. The 40 buildings photographs were printed for the above cardinal point under consideration, the images were subjected to scale measurement. Scale rule was used to ascertain the measurement of window and wall area ratio. The procedure used to obtain and calculate data was illustrated below.

The mean, range and standard deviation of 40 building were also calculated

Window area = Height x breadth
Wall area = Height x breadth
Window/wall ratio = (Height x breadth)/ (Height x breadth)

The observed data of the buildings were analyzed with descriptive statistics including means and standard deviation.

Analysis of Results

This is where the results were presented and the presentation was made on the research objectives.

Objective 1: The extent to which exposure of windows to wall ratio along the North and South main cardinal.

Table 2 shows that the mean and the range of window to wall ratio for North cardinal are 0.15, 0.38 at (0.09S.D) respectively. Also, the Mean and the range of the window to wall ratio for South cardinals are 0.14, 0.27 (0.06S.D) respectively.

Objective 2: The extent to which exposure of window to wall ratio along the West and East main cardinal.

Table3 below shows that the mean and range of window to wall ratio for West cardinal are 0.07, 0.31 at (0.06S.D) respectively. Also the mean and the range of window to wall ratio for East cardinal are 0.11, 0.31at (0.18S.D) respectively.

Objective 3 The extent to which exposure of window to wall ratio along the sub-cardinal, North-East, South-East, South-West.

Table 4 shows that the mean and range of window to wall ratio for North-East cardinal are 0.08, 0.05 at (0.04 SD) respectively. Also the mean and the range of window to wall ratio for South-East cardinal are 0.03, 0.01 at (0.01 SD) respectively. The mean and range of window to wall ratio for South-West, North-West cardinal are 0' 0 at (0 SD).

Table 2: The extent to which exposure of window to wall ratio along North and South cardinals

Cardinals	Mean	**Range**	**Standard Deviation (S.D)**
North	0.15	0.38	0.09
South	0.14	0.27	0.06

Sources: Author's field work (2024)

Table 3: The extent to which exposure of window to wall ratio along West and East cardinals

Cardinal	**Mean**	**Range**	**Standard Deviation (S.D)**
West	0.07	0.31	0.06
East	0.11	0.31	0.18

Source: Author's field work (2024)

Table 4: The extent to which exposure of window to wall ratio along sub-cardinal

Cardinal	Mean	Range	Standard Deviation (S.D)
North-East	0.08	0.05	0.04
South-East	0.03	0.01	0.01
South-West	-	-	-
North-West	-	-	-

Source: Author's field work (2024)

Result and Discussion

The discussions are based on the research objectives as follows:

Extent to which exposure of window to wall ratio along the North and South cardinal

The result in summary revealed that north cardinal has the highest mean value of window and wall ratio as 0.15, mean difference of 0.01 and the range of 0.38 which was obtained from the difference between building 35 (Academics) as building with the highest window/wall ratio value (0.39) and building 34 (Academics) as building with the lowest window/wall ratio value (0.01), the range difference were 11. The north cardinal also has the highest value of standard deviation at 0.09 as compared with the south cardinal. Hence north cardinals were relatively having a very good orientation which will reduce the effect of solar radiation in building. These is in line with Hou and Fu [7] who revealed that North and South natural lighting performance is better when window-wall ratio increases and windows play a critical role in terms of building thermal insulation which need to be clearly considered. Therefore this study shows relationship with their findings.

Extent to which exposure of window to wall ratio along the East and West cardinal

The result in summary revealed that east cardinal has the highest mean value of window and wall ratio as 0.11 the mean difference is 0.04, the range of 0.31 which was obtained from the difference between building 22 (Academics) as building with the highest window/wall ratio value (0.30) and building 4 (Academics) as building with the lowest window/wall ratio value (0.01), the range difference is 0. The east 'cardinal also has the highest value of standard deviation at 0.18 as compared with the West cardinal. Hence the difference is not quite appreciable and is relatively having a very bad orientation. Sustainable energy efficient building advisory committee [14], revealed that window placed in east and west facing wall are penalized twice, because the sun shine strongly directly through east and west facing window and wall which increasing air conditioning cost. Jan and Jiang [8] also revealed that east and west exposure (window/wall especially glazing) should be minimized since they are difficult to shade and receive longer period of direct radiation. Of which their study is in line with the study results. Therefore this study shows relationship with their findings.

Extent to which exposure of window to wall ratio along the sub-cardinal North-East, South-East, South-West, North-West

The result in summary revealed that North-east cardinal has the highest mean value of window to wall ratio as 0.08, the mean difference is 0.05 and range of 0.05 which was obtained from the difference between building 9 (Academics) as building with highest window to wall ratio value (0.5) and building 22 (Academics) as building with the lowest window to wall ratio value (0.01) the range difference is 0.04. The north - east cardinal also has the highest value of standard deviation as compared with the south- east cardinal. However, for the remaining two sub-cardinal, there exist none of the window/wall ratio oriented along such sub-cardinals for the forty buildings studied, this show that is having a bad orientation. Lam et al [10] revealed that The winter sun spends all of its time in the southern sky, and the summer sun spends much of its time in the northern sky (the sun crosses over into the southern sky during part of the day, depending on latitude). In the Southern Hemisphere, all of these directions are reversed, so the winter sun rises and sets in the northeast and northwest, respectively, and the summer sun rises and sets in the southeast and southwest, building should be minimized been oriented along the cardinals. Of which their study is in line with the studied results. Therefore these study shows relationship with their findings. Thus, North and South having the highest window to wall ratio as compared with East and West and sub-cardinal ,the result summary depicts that most of the studied buildings in MAU were oriented with a very good orientation regards to the tenet of bioclimatic principles, to minimize the energy consumption required in the buildings.

Conclusion and Recommendations

It was noticed that the major decisions architects and engineers took during the design process and construction of the buildings were taken with energy consumption minimization and users thermal comfort enhancement at heart, leveraging on taking the advantages of bioclimatic principle. However, the absence of environmental regulations as regarding ideal orientation has prompted architects and developers to be influenced by orienting some of the studied buildings along the North to South cardinals, instead of East to West for energy efficiency as a bioclimatic measure. Due to the neglect of the environmental aspects, in line with orientation, the amount of energy required for operating some of this building stock in MAU is substantially much, for buildings that do not; leverage on bioclimatic principles.

i. As the increase of the buildings energy consumption leads to an increase in the carbon dioxide emissions, the University should have a new environmental vision that would control consumption and emission of GHGs, through leveraging on orienting the buildings with the longer sides of the walls/windows facing the North/South cardinals.

ii. Architects and allied environmental professional in MAU must work synergistically to ensure adherence to orientation by giving more attention to ensuring that any new project to be implemented must conform to a proper orientation.

iii. Incorporation of shading strategies, planting of vegetation, among other passive measures that will help minimizes energy consumption at the same time upholding the tenets of bioclimatic principles.

REFERENCES

1. Academy of Building Research, (2010). Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone, China Architecture & Building Press, Beijing, China.

2. Centre for Construction Research, (2006). Optimizing the configuration of a facade module for office buildings by means of integrated thermal and lighting Simulations in a total energy perspective. *Applied Energy. 108:515-527.*

3. Encyclopedia Britanica: Dictionary.com http://www.indepth.energy

4. Feng,Y. and Yang H. (2001). Defining the area ratio of window to wall in `design standard for energy-efficiency of residential buildings in hot summer and cold winter zone. *Journal of Xi 'an University of Architecture & Technology.33: 348-351.*

5. Givoni, B. (2006). Climate Considerations in Building and Urban Design. 1" Ed. New York, Van Nostrand Reinhold Publishers Ltd

6. Hawkes, D. (1996). The Environmental Tradition; Studies in the Architecture of Environment, and FN SPON, *London. 36 - 45.*

7. Hou,Y. and Fu, Z. X. (2002). Affection of window-wall ratio on energy consumption in region of hot summer and cold winter," *Architecture Technology. (32),661-662.*

8. Jana, Y. & Jiang, Y. (2006).Influence of WWR on annual energy consumption for heating and air conditioning in residential buildings," Heating Ventilating and Air Conditioning. *ASHRAE Transactions.* 36, 1-5.

9. Koenigsberger, O., Ingersoll, T., Mayhew, A.& Szokolay, S., (2021). Manual of Tropical Housing and Building: Climatic Design. India: Orient Longman.

10. Lam, J., Wan, K., & Yang, L. (2004). Solar Radiation Modelling, Using ANNs for Different Climates in China, *Energy Conversion and Management. 49: 1080-1090.*

11. Lee, J. Jung, J., Park, Y., Lee, Y. &Yoon,Y. (2013).Optimization of building window system in Asian regions by analyzing solar heat gain and daylighting elements. *Renewable Energy. 50: 522-531.*

12. Maccari, A., & Zinzi, (2000). Simplified algorithms for the Italian energy rating scheme for fenestration in residential buildings, *Solar Energy. 69:75-92*

13. Ossen, D., Abduhnajid, R. & Ahmad, M., (2008). Tropical Building Design Principles for Comfortable Indoor Environment. Master"s thesis. Faculty of Built Environment, Universiti Teknologi Malaysia.

14. Sustainable Environment Advancement Committee (2010). Environmental Performance Optimization of window-wall ratio for different window type in hot summer and cold winter zone in China based on life cycle assessment. *Energy and Buildings. 42: 198-202*.

15. Szokolay, S. (2004). Introduction to Architectural Science: The Basis of Sustainable Design, Ist Ed, Architectural Press, Oxford, UK. *New York. 64: 124 - 125.*

16. Syed, F. (2003). Enviromnental Performance Optimization of window-wall ratio for different window type in hot summer and cold winter zone in China based on life cycle assessment. *Energy and Buildings. 42: 198-202.*

17. Wang,H. Rui,H.& Xiao,Q.(2012).Energy saving effect of building envelope in summer. *Journal of Central South University of Technology (English Edition). 19: 1370-1376.*

18. Yang,S.& Tao,W.(1998).Heat Transfer, Higher Education Press, Beijing.

19. Yu,Z. Zhang,W.,& Fang,T.(2013).Impact of building orientation and window-wall ratio on the office building energy consumption. *Applied Mechanics and Materials.60: 409-410.*

Table1: Names and Categories of the Studied Buildings

APPENDIX

Building	**A. Academic**	21	Elec/Elect Dpt	Building	**B. Library**	Building	**D. Hostel**	Building	**E. Lecture theater**
1	Department of soil science department	4	Food Sci Dpt	26	Ibrahim Babagida	5	New male hostel	18	Lecture theater
8	Department of Urban and Regional Planning	14	Computer Sci Dpt	27	E-library	6	Kabir Umar	19	Lecture theater
2	Department of Architecture	12	Dept of Agric			7	PG hostel	20	Multi-purpose Hall
10	Old geography	24	Bio Educ Dpt	Building	**C.Administrative**	13	Oba Adetona	37	School of Agric Lecture theater
16	Department of Chemical Engineering	15	Elec Educ Dpt	29	Senate building			39	School of Engineering Lecture theater
22	School of management and information technology (SMIT)	36	Peace & Security	30	Administration			40	Lecture theater 3&4
9	School Of Pure An Applied Science(Spas)	28	Crop Tech Dpt	31	Dean's office SMIT				
11	School of technology and science education	38	Bus Educ Dpt	32	CEMIT				
23	Department of Biotechnology			33	School clinic				
35	Department of bio-chemistry			34	Deanery Office				
3	Department of Building								
25	Old school of Agric science								
17	Mechanical Engineering								

Source: Author`s Work, (2024)