Environmental Technology & Science Journal
Vol. 12 No. 1, June 2021

Determination of Window-To-Wall Ratio of Fully-Enclosed Courtyard Residential Buildings in Kafanchan

Markus, B. & Duniya, S. D.
Department of Architecture,
Kaduna State University. Kaduna-Nigeria.
Email: markusbulus8@gmail.com

Received: 6/2/2021 **Revised: 18/4/2021** **Accepted: 30/4/2021**

Scholars has revealed that the courtyard in a building, the fully-enclosed courtyard in particular can enhance thermal performance provided that the appropriate Window-to-Wall-Ratio (WWR) is determine. To determine the WWR, the window-area and wall-area of the architectural space are required. This study, therefore, investigates the types of Window-to-Wall-Ratios (WWR) by identifying the types of window-area and room-area in fully-enclosed courtyard buildings in Kafanchan. A descriptive checklist was developed and used for an inventory survey of sixty-nine (69) fully-enclosed courtyard residential buildings. The data were analysed and interpreted statistically. The results show five types of window-areas, three types of room-areas and five types of WWRs. WWR3 has the highest percentage (39.1%), while WWR1 has the lowest percentage of (6%). The findings suggest that the larger WWRs are being used than the smaller ones. This study has provided the types of WWRs used in fully-enclosed courtyard residential buildings in Kafanchan and such could be simulated to determine the optimum in future studies. It also suggests that WWR3 is most preferred, but it thermal performance need to be established via simulation to confirm whether it is the optimum. Simulation studies to determine the optimum WWR for each of the types of room-area(s) and WWRs as obtained in this study is also important.

Keywords: Fully-Enclosed Courtyard; Window-to-Wall Ratio; Thermal Comfort; Simulation; Buildings

INTRODUCTION

Conducive thermal performance of a building is key to promoting the wellbeing, efficiency, and productivity of its occupant. But, when the architectural design of the building is compromised due to insufficient design awareness, thermal discomfort may abound (Olutoa, 2015). Therefore, for conducive architectural building delivery, the design awareness for thermal comfort is required (Wang *et al*., 2007). Kabiru (2011) argued that the architect must acquire a greater design awareness on passive architecture and by extension, climate-responsive architecture. The thermal performance of the building should not be compromised due to the architect design design. The productivity, efficiency and wellbeing of the end users of the building is enhanced when the building is harnessed to respond to thermal comfort. Such is necessary because mitigating thermal discomfort in buildings, especially in the tropical region is a major challenge (Akande, 2010).

The choice of window-size, Window-Wall-Ratio (WWR), building orientation, choice of building materials, building form, paint, and the built environment are some of the important factors that should be fully understood by the architect (Olutoa, 2015). Such factors can contribute to the thermal performance of the building tremendously. Among these factors, the WWR is the most critical because because it suitability varies form one building design to another (Yasa *et al*., 2010). It is the most critical because more effort is required to understanding its suitability (Berkovic *et al*., 2012). WWRs of different dimensions and proportions may contribute to the thermal performance in of buildings different ways. Chan (1995) argued that the architect will always require additional knowledge of WWR as regarding to each of his design scheme, because such knowledge are not included in the curriculum of architectural training of most schools of architecture. He concluded that simulation may by one of the best tool for acquiring the appropriate WWR for a particular building proposal.

The fully-enclosed courtyard residential building offer conducive thermal performance because of the courtyard space which create its own microclimate, thereby, enhancing air-circulation (Markus and Sam, 2017). This is true because of the microclimate of the courtyard space which is capable of impacting on the thermal performance of the courtyard building (Markus and Sam, 2017).

Huang *et al*. (2014) defined the WWR as the percentage of the square of window-area and the gross wall-area as illustrated in equation 1.

$$\mathbf{WWR} = \frac{\mathbf{Window\ Area\ (m^2)}}{\mathbf{Gross\ Exterior\ Area\ (\ m^2)}} \times \mathbf{100}$$

The equation connotes that the WWR is a function of the Window-Area (WA) and Gross External Area (GEA). This function determine the contribution of the WWR to thermal performance of the courtyard building because the WA and GEA determines the dimension and proportion of the WWR (Huang *et al*. 2014). Therefore, the architect is required to use the appropriate WWR for optimum thermal performance of the building. The choice of the suitable WWR to be use in a courtyard residential building design is also critical because of the courtyard microclimate which differs due to the dimension and proportion of the courtyard. Therefore, simulation of divers WWR models to determine the optimum may be require for conducive thermal performance of the fully-enclosed courtyard residential building (Aldawoud & Clark, 2008).

The aim of this study is to investigate the types of Window-to-Wall Ratio (WWR) in fully-enclosed residential courtyard buildings in Kafanchan. For such to be achieved, determination of the window-area and room-area of the buildings in the study area are required. This study is important because it will provide a background information regarding to the types of WWR of as built courtyard residential buildings in Kafanchan. Such information could be used for simulation studies in future studies, because generating the simulation models has to be justified and this study will provide the basis for such (Abdulbasit *et al*., 2015).

LITERATURE REVIEW

The literature has shown that thermal comfort in buildings is very paramount to the wel-being and productivity of the occupants of the building. The Window-to-Wall Ratio (WWR) has been identified as one of the most important fator for thermal comfort in buildings (Yasa *et al*., 2010). According to Huang *et al*. (2014), WWR can be explained by defining the window-area and room-area of an enclosed space (room). The differences between the WWR, room-area and window-area should not be ambiguous, rather, clarity should be emphasized. Huang *et al*. (2014) explained that the window-area is the dimension and proportion of the window size used in a particular architectural design while the room-area is the product of the room length and width. Therefore, to determine the WWR, the window-area and that of the perimeter wall which defines the enclosed space is required. This suggests that the window-area and the gross wall area are two determinant factors to be considered for calculating the WWR of any particular building.

Berkovic *et al*. (2012) asserted that the optimum WWR for a particular courtyard building may differ from one to another because their enclosed space(s) may not be the same. Equally, the dimension and proportion of the courtyard may not be the same. The window size may be the same, but if the dimensions and proportions of the enclosed space (room) are not the same, then the WWR will definitely vary. With such variability, Yasa *et al*. (2010) advocated the use of the optimum WWR for the design of each courtyard building. Huang *et al*. (2014) corroborated the position of Yasa *et al*. (2010) opinion by asserting that the expertise required for determining the optimum WWR is a major challenge. It is a challenge because such knowledge requires the use of simulation software which may not be attained except training on how to use the software for simulation experiment is achieved.

According to Aldawoud and Clark (2008), the application of the optimum WWR for a particular courtyard building design can guarantee effective thermal performance within the courtyard space and the interiors of the courtyard building. The scholars continued that architects should use the ideal WWR for courtyard buildings based on simulation research-based findings rather than depending on their intuitive and creative skills. Zanzan (2015) opined that overdependence on the intuitive skill alone could lead to the conception of an architectural space that lacks the basic requirement for comfort. He continued that although the intuitive skill constitutes the making of a good architect, the use of such should be linked to some sort of innovations derived from research findings to improve the quality of the architectural product. Therefore, the use of the simulation tool and the intuitive capacity can guarantee architectural proposals that are not only appealing to the eye but also comfortable. It could promote delivery of buildings that respond to the thermal comfort of the end users of such buildings and thereby, enhancing their efficiency, well-being and productivity.

According to Ogunsote (2002), climatic regions have different characteristics and design requirements. The scholar opined that the architectural design requirement of the four (4) climatic regions of Nigeria should be clearly understood if conducive thermal performance of buildings is to be achieved. Architectural design of buildings should respond to the climatic design requirements. As defined by Komolafe and Agarwal (1988) in Figure 1, the study area for this study falls within the temperate-dry climatic region. Therefore, its climatic design considerations for architects should not be completely the same with that of the other climatic regions.

Furthermore, the use of WWRs for courtyard buildings within the temperate-dry climatic region should be different with that of hot-dry, temperate humid and hot-humid respectively. The optimum

WWRs for the different climatic regions should not be the same. Additionally, the optimum WWR of different room-area(s) should not be the same within a particular climatic region, as well as in other regions.

Consequently, research endeavours are required for the architect to fulfil the task of designing buildings with optimum thermal performance. Research effort with findings based on the simulation method are required. The simulation method is considered as the most appropriate because scientific predictions based on testing the thermal performance of different simulation models could be carried out successfully (Abdulbasit *et al*., 2015). Studies that seek to investigate the types of WWRs used by architects in a particular location are significant because it provides the requisite information for further simulation experiment to ascertain the optimum among them (Abdulbasit *et al*., 2015). The findings of such studies could encourage the use of the optimum for effective thermal performance or discourage the application of the types which add to thermal discomfort in buildings. Conclusively, architects and building developers could depend on the recommendations of such simulation studies by applying such in their architectural design and building delivery.

METHODOLOGY

The methodology of this study is divided into two-part; the initial, and the final survey. The first part is the initial survey of fully-enclosed courtyard buildings in Kafanchan to establish the study population and to determine the sample size, while, the second part is the final survey to investigate the types of WWRs, room-area(s) and window-area(s). The full details of the methodology are discussed in the subsequent sections.

The Initial Survey

A descriptive checklist was used in the initial survey to ascertain the study population and to determine the sample size for the survey. The study population constitutes the fully-enclosed courtyard buildings in Kafanchan. One thousand nine hundred and twenty-five (1925) number of fully-enclosed courtyard buildings were ascertained by direct observation. To determine the sample size of the study population, the stratified sampling procedure was used because it gives a good representation of the study population. Bartlett *et al.,* (2001) Table of sample size as shown in Table 1 was used to determine the sample size for the study. The study population of this study is 1,925 of fully-enclosed courtyard buildings which falls within the 2000 study population size in the Table. Therefore, 112 was selected as the sample size because the required data for this survey is continuous data (Viechtbauer *et al.*, 2015; Anelli *et al.*, 2018).

Table 1: Table for Determining Minimum Returned Sample Size

Population Size	**Sample Size**					
	Continuous data (margin of error = .03)			**Categorical data (margin of error = .05)**		
	alpha=.10 t=1.65	alpha=.05 t=1.96	alpha=.01 t=2.58	p=.50 t=1.65	p=.50 t=1.96	p=.50 t=2.58
100	46	55	68	74	80	87
200	59	75	102	116	132	154
300	65	85	123	143	169	207
400	69	92	137	162	196	250
500	72	96	147	176	218	286
600	73	100	155	187	235	316
700	75	102	161	196	249	341
800	76	104	166	203	260	363
900	76	105	170	209	270	382
1,000	77	106	173	213	278	399
1,500	79	110	183	230	306	461
2,000	83	112	189	239	323	499
4,000	83	119	198	254	351	570
6,000	83	119	209	259	362	598
8,000	83	119	209	262	367	613
10,000	83	119	209	264	370	623

Source: Bartlett *et al.* (2001)

The Final Survey

In the final stage of the survey, a checklist was developed and used to determine the types of WWRs, room-area(s) and window-area(s) in Kafanchan. Sixty-nine (69) fully-enclosed courtyard buildings were surveyed. The figure is equivalent to sixty-two percent (61.6%) of the sample size (112). According to Baruch (1999) in Nulty (2008 Pg.306), the average allowable response rate of a sample size of a survey study is 55.6%. Consequently, 61.6% achieved in this study is considered sufficient, adequate and acceptable. The data obtained were computed using the WWR formula as recommended by Huang *et al*. (2014) to determine the types of WWRs with their percentages. The computation was done based on the number of room-area as obtained in the survey. This was necessary for a complete analysis of the survey findings. The WWR formula was used for the data analysis.

The Study Area

The study area (Kafanchan and its environs) fall within the temperate-dry climatic region of Nigeria (Komolafe and Agarwal 1988). Therefore, the findings of this study may be applicable not only to Kafanchan alone but the entire temperate-dry climatic region of Nigeria. Figure 1 shows the location of Kafanchan and its climatic zone while Figure 2 shows the Map of Kafanchan with its settlement.

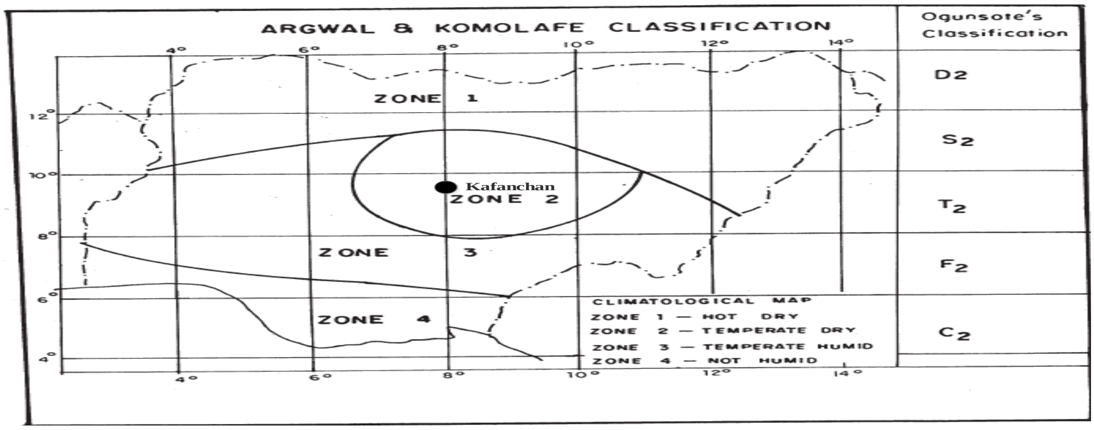

Figure 1: Nigerian Climatic zones (Komolafe and Agarwal 1988)

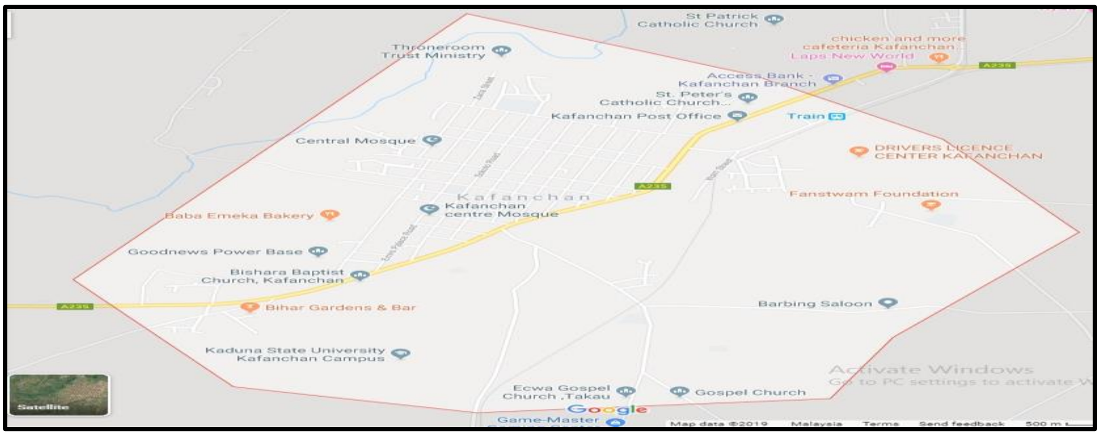

Figure 2: Map of Kafanchan (Google Earth)

RESULTS

This study investigated the types of WWRs, room-are and window-area of the fully-enclosed courtyard residential buildings in Kafanchan. This section presents the findings of the study.

Types of Room-Area

Table 2 shows the types of room-area for fully-enclosed courtyard residential buildings in Kafanchan. Three categories of room-area were identified; $9m^2$ (rooms within the <3.5 to 3m x 3m range), $12m^2$ (rooms within the >3.5 to 4m x 3m range) and $16m^2$ (rooms within the <4.5 to 4m x 4m range). For $20m^2$ and $25m^2$ room-area, zero was recorded. Approximately, forty-five percent (44.9%) of the survey fully-enclosed courtyard residential buildings have their room-area as $9m^2$, forty-six (46.4%) were of the $12m^2$ while the $16m^2$ scored about nine percent (8.7%).

Table 2: Types of Room Size(s), Area and Percentage Found in Kafanchan

Types of Room Size(m)	Room area (m^2)	Number	`Percentage (%)
<3.5 to 3 x 3	$9m^2$	31	44.9
>3.5 to 4 x 3	$12m^2$	32	46.4
<4.5 to 4 x 4	$16m^2$	6	8.7
>4.5 to 5 x 4	$20m^2$	-	
<5.5 to 5 x 5	$25m^2$	-	
Total		69	100

Types of Window-Area

Table 3 indicate the types of window area for fully-enclosed courtyard buildings in Kafanchan. Five types of window area were discovered; $0.36m^2$ (window size of 0.6m x 0.6m), $0.675m^2$ (window size of 0.9m x 0.75m), $1.08m^2$ (window size of 0.9m x 1.2m), $1.44m^2$ (window size of 1.2m x 1.2m), and $2.16m^2$ (window size of 1.2m x 1.8m). 39.1%, 29.0%, 13.1%, 10.1% and 8.7% represents the $1.08m^2$, $1.44m^2$, $0.675m^2$, $2.16m^2$ and $0.36m^2$ window areas respectively.

Table 3: Types of Window Size(s), Area and Percentage Found in Kafanchan

Types of Window Size(m)	Window area (m^2)	Number	`Percentage (%)
0.6 x 0.6	$0.36m^2$	6	8.7
0.9 x 0.75	$0.675m^2$	9	13.1
0.9 x 1.2	$1.08m^2$	27	39.1
1.2 x 1.2	$1.44m^2$	20	29.0
1.2 x 1.8	$2.16m^2$	7	10.1
Total		69	100

Types of WWRs of Fully-Enclosed Courtyard Residential Buildings

Table 4 shows the types of WWRs of fully-enclosed courtyard residential buildings in Kafanchan. Five types of WWRs for each of the room-area(s) were revealed; WWR 1, WWR 2, WWR 3, WWR 4 and WWR 5 respectively. The $9m^2$ room-area has WWR figures as; 2, 1, 7, 4 and 2, respectively. $12m^2$ room-area has; 1, 3, 9, 8 and 3, respectively. While the $16m^2$ has; 3, 5, 11, 8 and 2 respectively.

As revealed from the Table 4, WWR 3 has the highest percentage (39.1%) of the figures in all the respective room-area(s). WWR 4 followed with 29.0%, WWR 2 has 9%, WWR 5 has 7% and WWR 1 scored 6 %.

Table 4: Types of WWRs of Fully-Enclosed Courtyard Buildings

Room-area	Window-area	WWR 1	WWR 2	WWR 3	WWR 4	WWR 5	Total
	$0.36m^2$	2					
	$0.675m^2$		1				
$9m^2$	$1.08m^2$			7			
	$1.44m^2$				4		
	$2.16m^2$					2	
	$0.36m^2$	1					
$12m^2$	$0.675m^2$		3				
	$1.08m^2$			9			
	$1.44m^2$				8		
	$2.16m^2$					3	
	$0.36m^2$	3					
$12m^2$							
	$0.675m^2$		5				
	$1.08m^2$			11			
	$1.44m^2$				8		
	$2.16m^2$					2	
Total		6	9	27	20	7	69
Percentage (%)		8.7	13.1	39.1	29.0	10.1	100

NOTE: As discussed in the literature, equation 1 ($\mathbf{WWR} = \frac{\textbf{Window Area }(\mathbf{m^2})}{\textbf{Gross Exterior Area }(\mathbf{m^2})} \times \mathbf{100}$) was used to calculate WWR 1, 2, 3, 4 and 5 respectively.

DISCUSSION

This section discusses the outcome of investigation of room-area, window-area, and the window-to-wall ratio (WWR) respectively.

Types of Room-Area

This result (Table 2) connotes that most of the room-space in the fully-enclosed courtyard buildings in Kafanchan (91.3%) is between 9m^2 to 16m^2. To further determine the optimum WWRs for the fully-enclosed residential courtyard building in Kafanchan, such a room-area should be the main consideration. It should be the focus because WWR is the product of the room-area and the window-area (Huang *et al*., 2014). The optimum WWR for a particular room-area may not be applicable to all kinds of room-areas (Yasa *et al*., 2010).

According to Huang *et al*. (2014), a simulation study to determine the optimum WWR for each room-area(s) is required for conducive thermal performance of the building. Therefore, the WWRs for the 9m^2, 12m^2 and 16m^2 room-area(s) for Kafanchan and its environ should be investigated in future studies. This study has contributed to knowledge about WWR for the space(s) mentioned, however, deeper investigations can be demanded from future studies

Types of Window-Area

These findings (Table 3) revealed that the window-area of 1.08m^2 is the most used in fully-enclosed courtyard residential buildings in Kafanchan, followed by 1.44m^2, 0.675m^2, 2.16m^2 and 0.36m^2 respectively. From the findings, the smallest window-area (1.08m^2) has the highest preference than the others but in terms of contribution toward enhancing thermal comfort, may not be the best. According to Huang *et al*. (2014), larger window-area enhances thermal performance of indoor-space more than the smaller ones. The reason is because the larger window-area tend to have larger perimeter area which enhances air-movement than the smaller window-area.

This study has provided basic information regarding the types of window-areas used in fully-enclosed courtyard buildings in Kafanchan which may be required for future simulation study. This is important because the window-area of a particular space must be known if its optimum WWR is needed (Huang *et al*., 2014). Thus, a further simulation experiment is required in this regard.

Types of WWRs of Fully-Enclosed Courtyard Buildings

The outcomes (Table 4) mean that WWR 3 is most frequently used in all the fully-enclosed courtyard buildings in Kafanchan. Of all the types of WWRs as revealed in this study, WWR 1 is the least used. To optimize the impact of WWR for a conducive thermal performance in a fully-enclosed courtyard building, scholars have advocated that the optimum WWR should be determined and used in a particular architectural design proposal (Berkovic *et al*., 2012; Yasa *et al*., 2010). Such information could be obtained by simulating different WWR alternatives (Huang *et al*., 2014). The alternatives required for Kafanchan and its environs have been provided in this study.

Therefore, future simulation experiments on WWR in the temperate-dry climatic region of Nigeria, Kafanchan, in particular, is a good research gap that requires urgent consideration; this study could be considered as a background for such a study.

CONCLUSION

This study has investigated the types of WWRs of fully-enclosed residential courtyard buildings in Kafanchan. The typology of rooms and windows area(s) of the fully-enclosed courtyard building has been determined. Based on the findings of this study the following recommendations are considered:-

Simulation studies to determine the optimum WWR for each of the types of room-area(s) and WWRs as obtained in this study are important.

The architect should incorporate simulation expertise in his architectural design of buildings because such enhances the delivery of thermally conducive buildings.

ACKNOWLEDGMENT

We acknowledged the effort of 15 research assistants drawn from the 400L Architecture Department of the Faculty of Environmental Sciences of Kaduna State University. Their labour has made this study a success indeed.

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