Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan *Vol. 29 No. 1-2024*
ISSN:1813-1786 (Print) 2313-7770 (Online)

Studying the Impacts of Windowto Wall Ratio (WWR) on the Energy Consumption in a Residential Unit Located in Bahria Town, Lahore

S. Abid[1], A. Arshad[2], M. Altaf[3], M. Rashid[4]

[1,2,4] *School of Architecture,University of Lahore, Punjab Pakistan*
[3]*Loughborough University, United Kingdom*

[1]Sundas.abid@arch.uol.edu.pk

Abstract- The residential sector is consumer of 15% of total cooling and heating energy consumption globally which necessitates the need to save energy in the residential sector for a sustainable future. This study was conducted to investigate the lowering of energy consumption in the household sector by using windows that are suitable for the environment in Lahore, Pakistan. An existing double-story 4356 sq ft house located in Bahria town, Lahore was selected for the analysis of energy performance. In order to determine the peak heating and cooling loads, the window-to-wall ratios (WWR) of the house were simulated using the REVIT model. This study also examined how limiting WWRs will affect to 10%, 20%, and 30%. It was noticed that up to 35% cuts in peak heating and cooling loads are possible on all orientations in comparison to existing WWRs by limiting the window size to 20%.But an increase in peak cooling and heating loads was observed with 30% WWR on all orientations. The methodology used in this study aims to provide a framework to help architects and engineers choose the appropriate WWR for each orientation for energy conservation.

Keywords- WWR, Peak heating and cooling load, Simulation tool, domestic sector

I. INTRODUCTION

Building energy usage makes for a major portion of overall global energy use resulting in increased CO2 emissions. According to research on energy use, buildings are responsible for around 40% of the world's total energy usage.[2-3]As the world's energy demand rises, fossil fuels become the most viable source of energy. Fossil fuels are burned to produce 80% of the energy used in the globe., which contributes significantly to global warming and produces one-third of global greenhouse gas emissions[2]. The exhaustion of fossil fuel resources, as well as their rising prices and harmful impact on ecological footprint, necessitates the use of renewable and non-conventional energy sources. Globally a vast amount of energy is used in residential homes[8].The rise in global population causes that the energy consumption and associated carbon emissions will rise in the future [8]. The aforementioned problem can be addressed by using energy-saving techniques, buildings have excellent chances to lower carbon emissions. [10].

Pakistan is experiencing a serious energy crisis. The scenario is similar to all other developing countries of the world. With each passing year, the energy imbalance between supply and demand widens. In Pakistan, the residential building industry accounts for around 47% of overall energy use[6] With an annual growth rate of +2.9%, Pakistan's power usage in buildings has climbed by 26.46% since 2006 [5]. The adoption of efficient construction standards and techniques is necessary due to the steadily rising energy consumption of residential buildings. Understanding the electricity usage of residential structures can aid policymakers in the development of appropriate construction rules. There are many factors that affect how much energy a home uses, such as the number of people living there, the size of the home, and the tools that are used. These factors are related to and with people affect how much heating, cooling, and lights a home needs. Building fabric, which is the actual structure of a building, also has a huge impact on how much energy it uses.

Parameters like walls, roofs, and windows are part of the building foundation. How well these materials insulate or let sunlight through, for example, affects how much energy is needed to keep the inside of a building livable. The most important of these parts are the glazed ones, like windows and doors.

Glazed parts do two things that are related to energy. They let sunshine in, which heats the house naturally in colder places. But controlling this sun heat gain is important so that heating and cooling systems aren't used very extensively. Coatings on window surfaces and other new technologies help control the flow of heat and make insulation better, which means that less energy is needed to keep rooms at the right temperature.

The main thing that determines how much energy a home uses is how human factors interact with the building itself, especially glass parts. To find the best mix between saving energy and making sure people are comfortable, you need to know how these things work together. In the future, it will be easier for homes to use less energy because people are always working to make materials and tools better.

These glazed components of the building envelope are more susceptible to heat loss and gain compared to other elements of the building envelope (e.g. doors, walls, roof, etc.). Therefore, the design and selection of window systems are very crucial for conserving energy in buildings [8].

Numerous studies have been conducted to investigate how glazing affects a building's energy usage in hot and cold areas.[1][4]. There is little research on windows and how they affect a building's energy use. in Pakistan and specifically in a hot semi-arid (Bsh) environment such as Lahore. The understanding of the link between residential architecture's energy consumption and glazing system largely remains unexplored in the context of Lahore. This paper is an attempt to bring forth the pressing issue of energy consumption in the residential sector of a widely spreading urban city, Lahore, and how it can be reduced to make dwellings more energy friendly. It also attempts to encourage local architects and scholars to conduct research in this particular area. This study will determine the impact of window-to-wall ratio (WWR) on cooling and heating loads in a residential unit located in Bahria Town which is in the partly industrial part of the city adding to the already semi-arid hot climate of Lahore.

II. Literature Review

Window Wall Ratio, often known as WWR (windowwall ratio), is an essential factor that influences the energy consumed by the building. The amount and type of glass in the windows will impact the structure's heating and cooling load, window area is the percentage of the total area of the window compared with area of the room façade (Fig. I). Whenever the window size is increased, the natural daylight performance will improve. Since the window influences the heating and cooling demand of the building which must be taken into account.

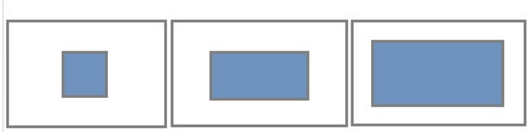

Fig I: Window-to-Wall Ratio

The link between WWR and building energy usage has been the subject of different studies. Kin, S.H et. al.found that certain window features, such as orientation and window-wall ratio, had an impact on energy usage. [7]. The heat transmission coefficient of windows is typically 2–3 times that of walls, meaning consequently transport more heat per unit area. Altaf & Hill [9] concluded that by using the best WWR, significant energy savings in buildings in hot climate regions are attainable. The study determined that the ideal size for reducing energy use is a WWR of 10%. Different orientations with the potential of 28% to 57% of energy savings in comparison to a conventional 80% WWR. Homoud [10]. Homoudperformed an optimum evaluation of building design factors to minimize yearly energy usage in hot climates of the U.S. and Saudi Arabia. Except in cold climates where higher glass usage was necessary to harness solar gain for heating, his research found that a minimal level of glass surface area at a proportion of 15% was indeed the optimum to lower the annual energy usage of office buildings for all orientations. Summer season heat gain from the window area is a problem that a cooling air conditioning system manages. It is advised that the main goal should be to prevent a high cooling demand when defining the glazed surface in hot climates to achieve low overall energy consumption [2].Through Literature reviewit was established that residential units also consume a significant amount of energy and it must be documented and studied further. Referencing [4] a possibility was found that energy usage could be minimized to 40% by installing windows that are the proper size for the room. For all kinds of facades and orientations, the optimal size of windows varies from 10 to 50 percent of the total area. The amount of heat gained and lost via the window design has an impact on the degree of interior comfort. Especially in hot regions like Lahore, the size of the windows (WWR) is a crucial component in determining the degree of interior comfort. [1][6-8].

This Research is focused to find an optimum WWR for dwellings in the climate of Lahore.

III. Methodology

This study adopted quantitative method and analyzed the numerical data. The research is carried out by using dynamic method of calculation using computer simulation. The recent developments in energy software have made computer simulation more appealing as a method of conducting meaningful research, particularly in the area of energy. The goals of this study were met using the potent BIM (building information modelling) tool Autodesk REVIT. The advantage of using REVIT is that the program provides a complete, integrated solution for wall-window ratio analysis of building heat gain. Revit simplifies design scenario research with its exact building geometry and parametric modelling. Built-in energy analysis tools provide detailed simulations, and climate data integration permits weather-based assessments. Revit's visualisation and reporting improve stakeholder communication by revealing simulation findings. It also simplifies project team collaboration with BIM concepts. Revit's fast workflow eliminates the need for several software packages and ensures accurate and insightful building performance analysis.The investigation is being carried out for the climate of Lahore, which is located at 31.56° latitude and 74.35° longitude. When it comes to climate, Lahore belongs to the semi-arid (Steppe) zone, which has scorching summers and moderate winters. It has a hot temperature for eight months of the year and a pleasant winter for the remaining four months. As a result, the hot season predominates throughout the year. For the simulation purpose, weather data of Lahore was used. Extensive literature was explored on the topic[7-6],[2] to help develop a baseline idea and was aided by discussions with professionals already working in the relevant field of study. For the analysis of energy consumption of the residential building in Lahore, an existing double-story 4356 sq. ft house located in Bahria town was selected. The building type is a single-family house having 2102 square feet of area. The plans of the house are shown in Fig. II (a) and Fig. II (b).

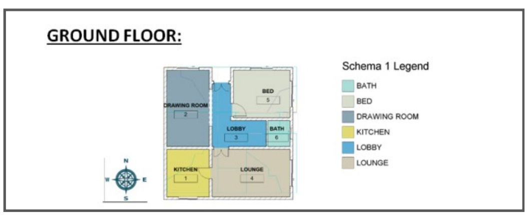

Fig. II (a): Ground Floor plans of selected house

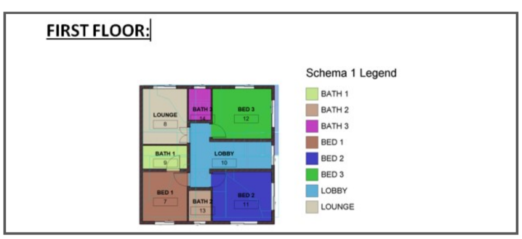

Fig. II (b): First Floor plans of selected house

3.1. Simulation Methodology

This study analyzes the effect of the glazing area on energy consumption in a residential unit for the climate of Lahore. The simulation methodology was divided into two sections to achieve the objectives of this study.

3.1.1: Section-1; Study of WWRs of Selected House

The selected house has large windows in east, south, and north orientation. The house has 26% WWR on the east, 24% on the northern side, and 13% on the southern side. there was a dead wall with no windows on west side. An energy analysis of the existing house was done to understand the energy consumption and the contribution of current WWRs on the peak heating and cooling loads. Peak heating and cooling loads of the complete house and individual rooms were calculated through simulation. For that purpose, a model of that house was created in REVIT and simulated with the existing WWRs. The house has single-glazed reflective glass therefore; the same glass was used for simulation purposes. Its glazing properties are shown in table-I.

Table-I: Glazing Properties

Glass Type	Glazing Properties		
Single-glazed Reflective glass	U value (W/m2 K)	SHGC	VT
	5.9	0.25	0.12

3.1.2: Section-2; Study of Different WWRs

In section 2, the best window size to decrease building energy consumption was examined using computer simulation. The variable (WWR) was altered to determine its impact on energy consumption. The impact of modifying the WWRs on the usage of energy required for heating in winter and cooling in summer was investigated. For studying the impact of varying WWRs, the WWRs for the house were limited to 10%, 20%, and 30%, and Peak heating and cooling loads were calculated and compared for the energy analysis. The height of the Sill level was kept constant.

IV. RESULTS AND DISCUSSION

4.1. Study of WWRs of Selected House

The peak cooling and heating load of the existing house was found to be 27843 Watts and 20768 Watts respectively. The contribution of present WWRs on the total peak cooling and heating loads was also analyzed and the results are shown in Table-2. Table-3 further highlighted the contribution of each room's WWR on peak cooling and heating load. It is evident from table-2 that the contribution of present WWRs on the total cooling and heating load is 21.21% and 24.04% respectively in the selected house.

Table-II: Total peak cooling and heating load of the selected house with existing WWR

Building component	Window peak cooling load (W)	Peak cooling load through present WWRs according to Orientation (W)			
		North	South	East	West
Window	5906	2655	993	2258	0
	Window	Peak heating load through present			

	peak heating load (W)	WWRs according to Orientation (W)			
		North	South	East	West
	4993	1657	1000	2336	0

Table-III: Peak cooling and heating load through WWRs of different rooms and their percentage contribution to the total load

Sr. No.	Description of the space	Building component	Peak cooling through present WWRs (W)	Percentage contribution in total cooling load %	Peak heating through present WWRs (W)	Percentage contribution in total heating load %
2	Drawing room (GF)	Window	669	26.6	408	20.8
4	Lounge (GF)		433	20.3	476	24.9
5	Bed room (GF)		1100	44.18	883	42.89
7	Bed room (FF)		411	16.1	340	18.1
8	Lounge (FF)		666	23.13	408	20.38
11	Bed room (FF)		853	26.54	951	37.7
12	Bed room (FF)		989	29.4	815	33.2

4.2. Study of Different WWRs

The peak cooling and heating load of the complete house with 10%, 20%, and 30% WWR were calculated through simulation. Peak cooling load was found to be 24694 W, 26693 W, and 27363 W with 10%, 20%, and 30% WWR respectively. However, the peak heating load was 18594 W, 20707 W, and 21327 W with these WWRs. The contribution of each WWR on the total peak cooling and heating loads was also analyzed and the results are presented in Table-4.

It is evident from the table-4 that the peak cooling load is in the range of 6.9% to 24.6% and the peak heating load is in the range of 10.05% to 31.9% with 10%-30% WWRs. A comparison of peak loads through varying WWRs is presented in Fig.3. It is clear that there is a significant reduction in both peak heating and cooling load by limiting the WWRs to 10% and 20%. Results show that 62.5 to 71% savings in peak heating and cooling loads are possible by limiting the WWR to 10% on all orientations in comparison to existing WWRs. Savings in peak cooling and heating loads are 18.9% and 3.2% with 20% WWR in comparison to existing WWRs. However, there is an increase of 12.4% and 26.7% in peak cooling and heating loads with 30% WWR on all orientations (Fig-IV). Simulation results show that the quantity of energy consumed in cooling and heating is substantially influenced by the size of the windows as well as the direction of the windows. The results reveal that for all orientations, the heat gain reduces as the window size lowers. It may be deduced that when the window size lowers, the cooling burden reduces. This is desirable in hot areas such as Lahore. Smart window design and orientation may help minimize the amount of energy used in buildings. Therefore, the selection of appropriate window sizes is very important for controlling the energy consumption of the building.

Table-IV: Total peak cooling and heating load with 10%, 20%, and 30% WWRs.

Building component	WWR	Window peak cooling load (W)	Peak cooling load through different WWRs according to orientation (W)			
			North	South	East	West
Window	10%	1724	402	926	397	0
	20%	4786	1456	1621	1517	0
	30%	6743	2133	2432	2178	0
	WWR	Window peak heating load (W)	Peak heating load through different WWRs according to orientation (W)			
			North	South	East	West
	10%	1870	388	1045	436	0
	20%	4830	1432	1673	1531	0
	30%	6813	2102	2509	2203	0

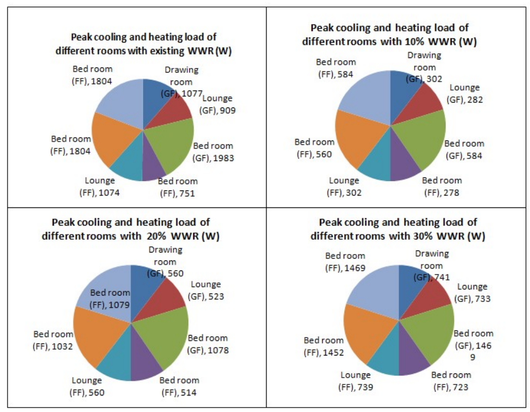

Fig.III:Peak cooling and heating load through WWRs of different rooms

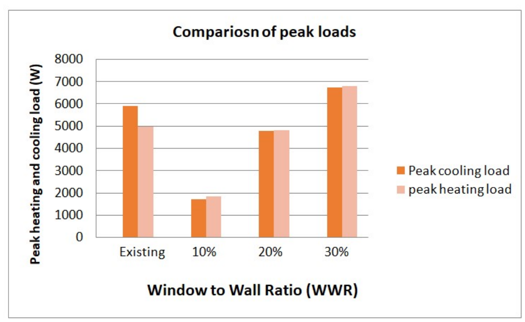

Fig. IV: Comparison of peak cooling and heating load through different WWRs.

V. CONCLUSIONS

Energy consumed by buildings plays a significant role in the world's energy requirements. Generating more energy cannot be a solution as the energy demand is increasing day by day. Energy conservation is the only feasible option under this scenario. Heat gain via windows is a phenomenon that manifests itself differently based on the wall-to-window ratio. The size of the windows has a significant impact on the building's need for heating and cooling. The size of the window in this study was varied and the change in heat gain in each orientation of the house was observed. It has become possible to compute the yearly heating and cooling load requirement for a residential building as a result of window size due to simulation. The simulation's findings indicate that the overall peak cooling load represents a major percentage of the total load. The effect of window size, orientation, and form on the overall heating and cooling load demand of a facade should be carefully considered in the future design of a residential building. According to our findings, the WWR of 10% has the minimum energy loads for heating and cooling. Significant reductions in both heating and cooling are observed by limiting the WWRs to 20%. However, there is an increase in peak cooling and heating loads with 30% WWR on all orientations in studied residential unit. It is deduced from the results that window size will allow considerable energy saving as the heat gain is less and cooling losses are also reduced. Up to 70% energy can be saved in the selected house with carefully selected window size.

Heat gain is also inextricably linked to daylight. However, the quality and quantity of daylight are not investigated in this study. To Study the impacts of WWR on energy consumption an already built structure (Residential Unit Located in Bahria Town) was selected for the analysis so the orientation of the building is fixed. Considering the window assembly, the type of glazing was also kept constant.

REFERENCES

[1] J. Duan, N. Li, J. Peng, Q. Liu, T. Peng, and S. Wang, "Clustering and prediction of space cooling and heating energy consumption in high-rise residential buildings with the influence of occupant behaviour: Evidence from a survey in Changsha, China," *J. Build. Eng.*, vol. 76, p. 107418, Oct. 2023, doi: 10.1016/J.JOBE.2023.107418.

[2] M. Rashid, A. Jalil, S. Gulzar, and A. M. Malik, "The Efficacy of Shading Design in Commercial Buildings in The Semi-arid Climate of Lahore ; Focusing on The Geometry of Horizontal Shade," *Tech. J. UET Taxila*, vol. 24, no. 2, pp. 1–10, 2019.

[3] P. Kishore, N. Selvam, S. Didwania, and G. Augenbroe, "Understanding BIPV performance with respect to WWR for energy efficient buildings," *Energy Reports*, vol. 8, pp. 1073–1083, 2022, doi: 10.1016/j.egyr.2022.10.371.

[4] T. Comfort, "Comprehensive Review and Analysis of Glazing Systems Impact Perspectives," 2023.

[5] R. Ma, R. Ma, and E. Long, "Analysis of the rule of window-to-wall ratio on energy demand of residential buildings in different locations in China," *Heliyon*, vol. 9, no. 1, p. e12803, 2023, doi: 10.1016/j.heliyon.2023.e12803.

[6] K. Ahmad, A. Rafique, and S. Badshah, "Energy efficient residential buildings in pakistan," *Energy Environ.*, vol. 25, no. 5, pp. 991–1002, 2014, doi: 10.1260/0958-305X.25.5.991.

[7] M. Rashid, A. Jalil, M. Z. Ashraf, S. Gulzar, A. M. Malik, and M. A. Baluch, "Impact Assessment of Window Orientation and Aspect Ratio on Building Energy Performance Using Comfen in the Climate of Lahore," vol. 28, no. 1, pp. 1–8, 2023.

[8] E. Aftab, K. Masood, S. Muhammad, and E. H. Altaf, "Consumption in Building Sector of Pakistan," pp. 8–11.

[9] Altaf, M., & Hill, F. (2019). Optimizing window to wall ratio for conserving energy in office buildings for cooling dominant climates with and without daylight utilization. Journal of Green Building, 14(3), 129–142. https://doi.org/10.3992/1943-4618.14.3.129

[10] Al-Homoud, M. S. (1997). Optimum thermal design of office buildings. International Journal of Energy Research, 21(10), 941–957. https://doi.org/10.1002/(sici)1099-114x(199708)21:10<941::aid-er302>3.0.co;2-y

[11] Cao, X., Dai, X., & Liu, J. (2016). Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade. Energy and Buildings, 128, 198–213. https://doi.org/10.1016/j.enbuild.2016.06.089

[12] Eljojo, A. (2017). Effect of windows size, position and orientation on the amount of energy needed for winter heating and summer cooling. Journal of Engineering Research and Technology, 1(1), 1-8.

[13] International Energy Agency. WEO 2017: Key Findings. Available online: https://www.iea.org/weo2017/ (accessed on 15 May 2021)

[14] Khan, M. A., & Asif, M. (2020). Energy Consumption in Residential Sector of Pakistan. Retrieved from https://www.researchgate.net/publication/342734707_Energy_Consumption_in_Residential_Sector_of_Pakistan.

[15] Kim, S.-H., Kim, S.-S., Kim, K.-W., & Cho, Y.-H. (2014). A study on the proposes of energy analysis indicator by the window elements of office buildings in Korea.

Energy and Buildings, 73, 153–165. https://doi.org/10.1016/j.enbuild.2013.12.061

[16] Lee, J. W., Jung, H. J., Park, J. Y., Lee, J. B., & Yoon, Y. (2013). Optimization of building window system in Asian regions by analyzing solar heat gain and daylighting elements. Renewable Energy, 50, 522–531. https://doi.org/10.1016/j.renene.2012.07.029

[17] Maccari, A., & Zinzi, M. (2001). Simplified algorithms for the Italian Energy Rating Scheme for fenestration in residential buildings. Solar Energy, 69, 75–92. https://doi.org/10.1016/s0038-092x(01)00045-7

[18] Poirazis, H., Blomsterberg, Å., & Wall, M. (2008). Energy simulations for glazed office buildings in Sweden. Energy and Buildings, 40(7), 1161–1170. https://doi.org/10.1016/j.enbuild.2007.10.011

[19] Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. Energy and Buildings, 40(3), 394–398. https://doi.org/10.1016/j.enbuild.2007.03.007

[20] Saidur, R. (2009). Energy consumption, energy savings, and emission analysis in Malaysian office buildings. Energy Policy, 37(10), 4104–4113. https://doi.org/10.1016/j.enpol.2009.04.052