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Impact of Window Configurations on Heating and Cooling Demands of Building in a Regional Climate—A Case Study †

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Abstract: The energy consumed by building is more than the energy consumed by transportation. The windows are found to be a weak thermal link through which heat is gained in the summer and lost in the winter, consequently increasing the building's energy consumption. This study focuses on the impact of window to wall area ratio (WWR) and orientation of the building on energy consumption under typical Karachi climate conditions. The energy analysis is conducted using Green Building Studio (GBS). The space cooling consumption is observed considerably higher than space heating consumption. It is found that WWR and orientation have a significant influence on the heating and cooling demands of the building. Large openings have been shown to have a negative impact on energy consumption. The north-south axis orientation is determined as the most optimal orientation of the building in this specific climate.

Keywords: sustainability; BIM model; energy efficiency; energy consumption; window to wall area ratio; orientation; Karachi

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1. Introduction

Buildings utilise 40% of the world's energy, which is more than the energy consumed by transportation. This percentage will surely climb, as it is the greatest wave of urban expansion. Currently, more than half of the population lives in cities, and it is estimated that by 2060s two-thirds of the global population will start living in urban areas. As a result, there are more people, more buildings, and more consumption, which leads to greater emission [1].

The Facade opening is the most vulnerable portion of the building envelope. The window, in particular, is the weakest thermal link in buildings envelop. [2]. The main source of heat gain is solar gain coming through a window, which raises the inside temperature above the external air temperature [3]. According to Halder [4], windows are a poor insulator and hence account for 25–30% of a building's heat loss. As a result, windows configuration has a significant influence on a building's overall energy usage.

Generally, architects preoccupied with aesthetic and architectural aspects during the design process, whereas sustainability aspects and energy efficiency are often overlooked [5]. The effect of windows on energy efficiency of buildings is substantial; therefore, this research is conducted to investigate the impact of windows configuration on the energy consumption of residential building in Karachi. Three criteria determine the amount of heat gain and loss through windows: the window to wall area ratio (WWR), the orientation of the window, and the thermal properties of the glass material; however, this study is limited to the first two parameters only.

2. Methodology

A BIM model of a commercial-residential building in Karachi (24°57′17.5″ N, 67°08′35.1″ E) is developed using Autodesk Revit, as shown in Figure 1. The defined window in the model is 1/8 in Pilkington single glazing with U value 3.69 W/(m^2-K). The energy model is created and exported to Autodesk Green Building Studio (GBS) for analysis. GBS is a cloud-based application that allows you to conduct building performance simulations early in the design phase to increase energy efficiency and achieve carbon neutrality. The weather data used in the analysis is shown in Figure 2.

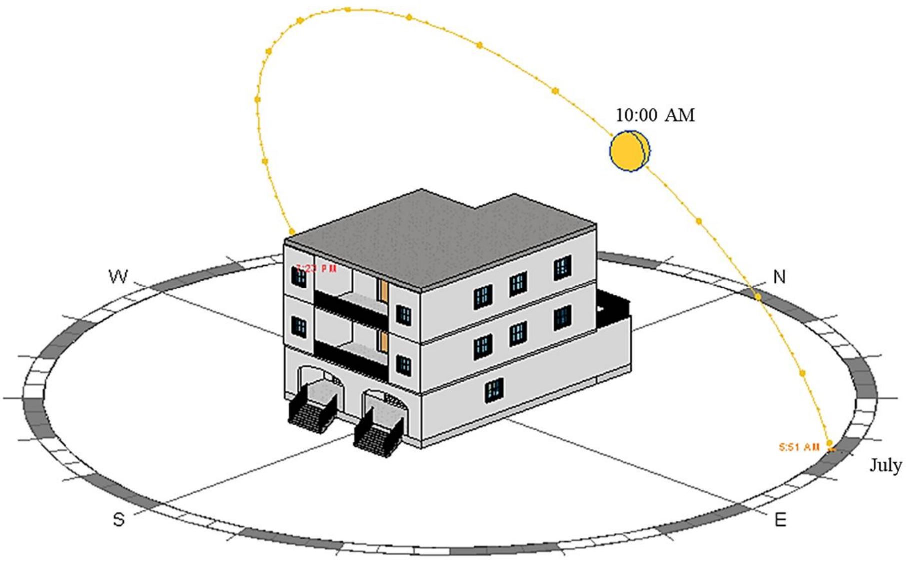


Figure 1. 3D intelligent model of Building located in Karachi.

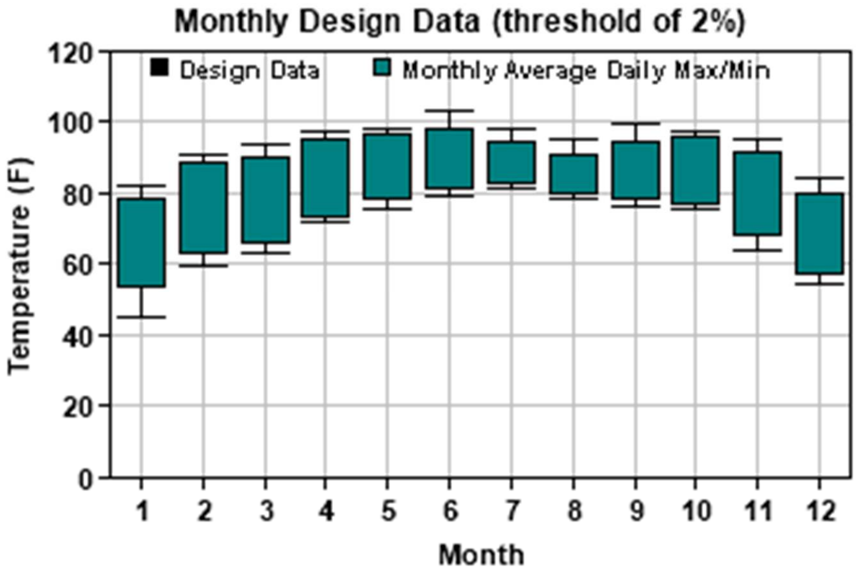


Figure 2. Monthly design data for Karachi (Source: GBS database).

Design alternatives are defined and analyzed. Four (04) different WWR (15%, 40%, 65%, 80%) are defined with respect to different orientations of the building as given in Table 1.

Table 1. Window Wall Ratio (WWR) with respect to orientation.

Design Alternatives	North	South	East	West
N15	15%	-	-	-
S15	-	15%	-	-
E15	-	-	15%	-
W15	-	-	-	15%
N40	40%	-	-	-
S40	-	40%	-	-
E40	-	-	40%	-
W40	-	-	-	40%
N65	65%	-	-	-
S65	-	65%	-	-
E65	-	-	65%	-
W65	-	-	-	65%
N80	80%	-	-	-
S80	-	80%	-	-
E80	-	-	80%	-
W80	-	-	-	80%

3. Results and Discussion

The analyses' findings are tabulated in Table 2. It can be noticed that space cooling consumption is considerably greater than the space heating consumption. The worst-case scenario for space heating consumption is when WWR is 80 percent in north direction, whereas the ideal scenario is when WWR is 80 percent in west orientation. The worst-case scenario for space cooling consumption is when WWR is 80 percent in west direction, whereas the ideal scenario is when WWR is 15 percent in north direction.

Table 2. Space energy consumption.

Design Alternatives	Heating Energy Consumption (KBtu)	Cooling Energy Consumption (KBtu)
N15	4251	116,010
S15	4902	119,713
E15	4393	119,631
W15	4973	122,303
N40	3445	118,898
S40	5019	129,937
E40	3853	129,195
W40	5259	136,620
N65	2962	121,954
S65	5250	141,262
E65	3573	141,059
W65	5553	152,314
N80	2875	123,787
S80	5315	147,191
E80	3624	147,655
W80	5682	160,858

With an increase in WWR, the heating demand for the building facing north decreases while the cooling load increases, as shown in Figure 3.

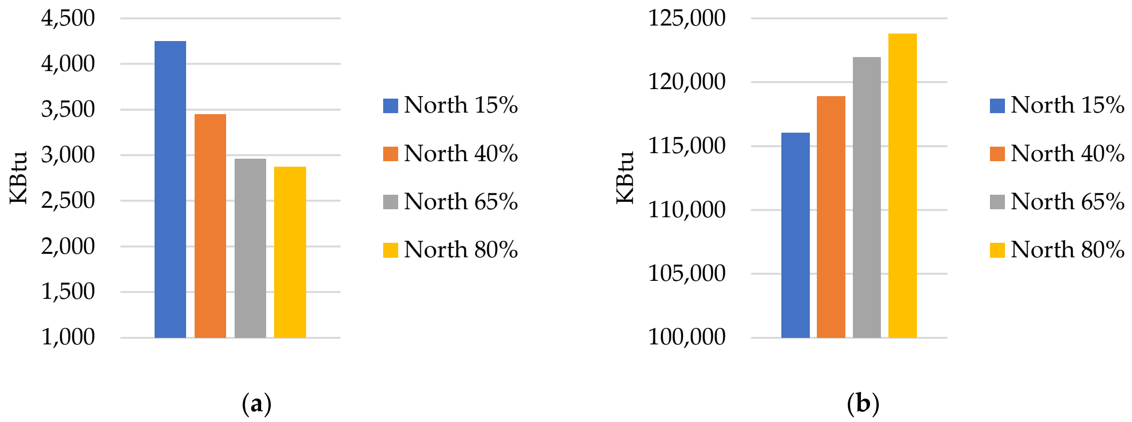


Figure 3. Space (**a**) heating and (**b**) cooling consumption in north facing orientation.

With an increase in WWR, there is a modest increase in heating load but a considerable increase in cooling load for the building facing south, as shown in Figure 4.

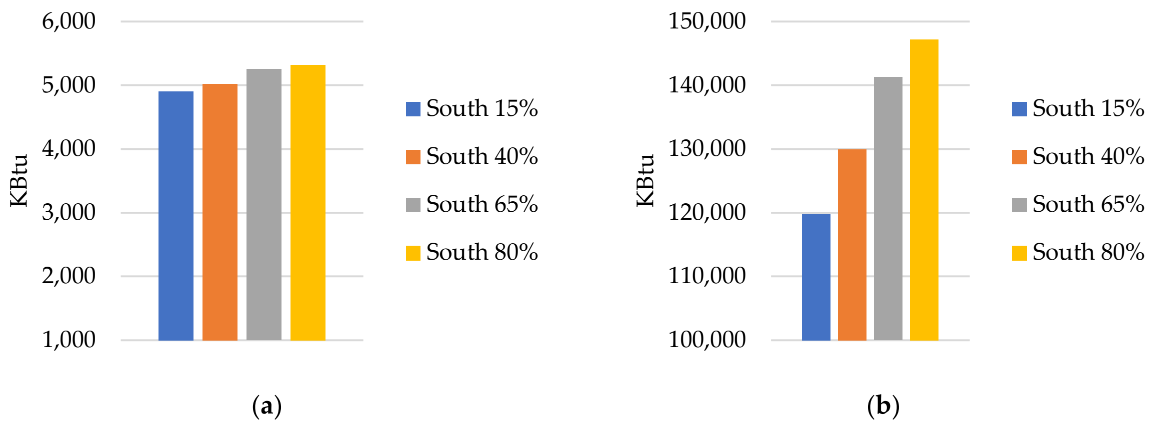


Figure 4. Space (**a**) heating and (**b**) cooling consumption in south facing orientation.

With an increase in WWR, the heating demand for the building facing east decreases while the cooling load increases, as shown in Figure 5.

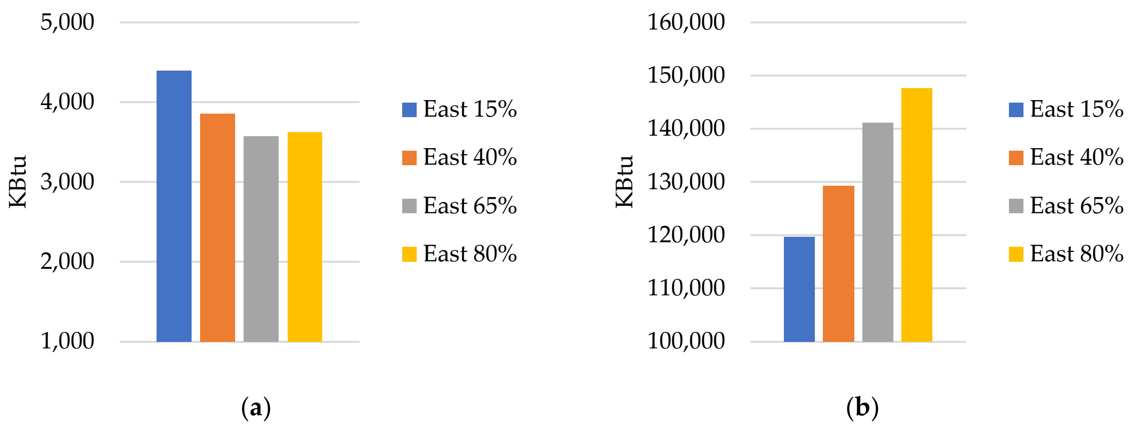
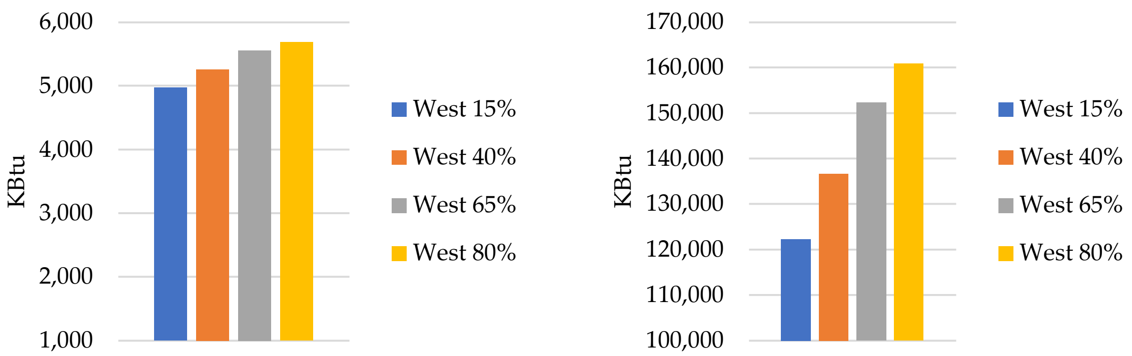


Figure 5. Space (**a**) heating and (**b**) cooling consumption in east facing orientation.

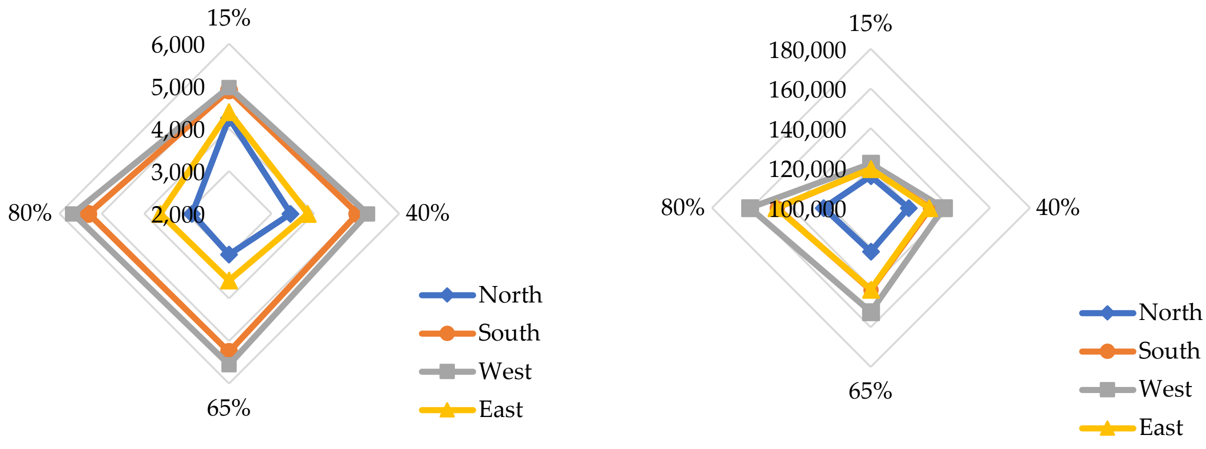
With an increase in WWR, the heating demand for the building facing west increases modestly while the cooling load increases considerably, as shown in Figure 6.



(**a**) (**b**)

Figure 6. Space (**a**) heating and (**b**) cooling consumption in west facing orientation.

Figure 7 depicts multivariate data, WWR in relation to the building's orientation, using radar plots. In terms of energy consumption, it indicates that the optimal building orientation in this specific region is north direction, whereas the worst is west orientation.



(**a**) Space heating consumption (**b**) Space cooling consumption

Figure 7. Space (**a**) heating and (**b**) cooling consumption according to WWR and orientation.

4. Conclusions

Based on the study, the following conclusions and outcomes have been drawn:

1. WWR and orientation have a significant influence on the overall energy demands for heating and cooling in buildings under typical Karachi climatic conditions. It is found large openings increase the overall energy consumption of the building.
2. The space cooling consumption is found considerably higher than the space heating consumption.
3. The best orientation of the building in this specific region is North while the worst orientation is West in terms of energy consumption.

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