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Directional Sensitivity of Energy Consumption Influenced by Window Wall Ratio

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Abstract

This research is conducted to present multi-storey residential units directional sensitivity towards the energy consumed, influenced by changes in window wall area ratio (WWR) in Northern India. Window-to-Wall area ratio is a crucial factor influencing daylighting, energy consumption, and thermal comfort inside buildings. The purpose of this research is to highlight the importance of orientation-wise window wall ratio with respect to energy consumption. Ground, intermediate, and top floors of the multi-storeyed housing were taken for the study. The window-to-wall area ratio sensitivity towards total energy consumption in summer months was calculated in each direction through Python software. The bar graph plots were customized by calculating the sensitivity of energy consumption per 1% window wall area ratio. The findings reveal different directions for different towers that will strongly impact the energy consumption which will help the designers in optimization as well as in designing. South-East and East directions for south-west and west facing towers and south-west and north-west for south-east and north-east facing towers are highly sensitive towards energy consumption.

Keywords: Window wall area ratio, energy consumption, sensitivity analysis

1. Introduction

Existing multi-storeyed residential units are very high in energy consumption. Population explosion and rapid urbanization has led to the concerns of climate change, global warming, energy sources depletion and exhaustion globally.

India's average temperature has already increased by around 0.7 degree Celsius during the 1901-2018 period due to greenhouse gases and by the end of 2100, it is expected to rise by approximately 4.4 degree Celsius, report by the Union Ministry of Earth Sciences (MoES), Government of India [1]. Residential buildings were consuming 20.4% of total electricity consumption in India, which was 2.3 times more than commercial buildings in 2012 [2]. No. of urban households are expected to be doubled by 2032 according to 2011 census [3]. Around 75% of the total electricity consumed in India is used in residential buildings (ECBC-R, 2017).

The building sector represents great potential to reduce energy consumption in both new and existing buildings by an estimated 30 to 50 percent (UNEP 2009). A considerable reduction in artificial lighting and energy consumption can be achieved through the passive techniques of providing optimum percentages of window openings in different wall orientations.

Many studies have optimized window proportions as an effective strategy to reduce energy use and enhance residents' quality of life. The optimal window wall ratio is between 26% to 33% for the north-facing, 21% to 25% for the south, 54% to 57% for the east and 58% for the west direction in the temperate climate of Rasht city, Iran [4]. Another research depicts direction-wise energy saving ranges improving building intelligence in terms of energy utilization. Recommended WWR for south and east direction walls is 65%, 95% for north and 30% for west direction walls in the summer Mediterranean climate [5]. The impact of window-to-wall ratio in heating demand and thermal comfort was assessed when considering a variety of occupant behavior profiles [6]. Window-to-Wall Area Ratios are location, climate-specific passive factors that influence thermal, visual comfort with energy efficiency.

2. Methodology

A case example of high high-rise residential society in Noida was taken for the research. Ground, intermediate and top floor units in different directions have been studied. Existing drawings with WWR have been documented along with real-time energy consumed for April, May, and June summer months, for four towers of different directions. The towers taken for the study are shown in Fig.. The plots have been created, and the sensitivity of each direction towards energy consumed in a unit has been calculated through Python software. The plots have been customized by calculating the Energy consumed per 1% change in WWR in existing towers.

Figure 1: Towers taken for the study and assessment

2.1 Process

Calculate total energy consumed for each tower
Data ['Total consumption'] = data.iloc[:, 5:].sum(axis-1)
#Define WWR columns and their labels
wwrs = ['56 degree NE', '326 degree NW']
wwr_labels = ['NE', 'NW']
# Calculate sensitivity for each direction

```
for wwr in wwrs:
data[f 'sensitivity_(wwr)'] = data['total_consumption'] / pd.to_numeric(data[wwr].str.rstrip('%')
# Create the plot
fig, ax = plt.subplots (figsize = (15,8))
# Set width of each bar and positions
bar_width = 0.2
r = np.arange(len(data))
# Colors for each direction
Colors = ['red', 'blue', 'green', 'orange']
# Plot bars for each direction
for i,wwr in enumerate(wwrs):
sensitivity = data[f 'sensitivity_{wwr}']
bars = ax.bar(r + i*bar_width, sensitivity, color=colors[i], width=bar_width,
label = f '{wwr_labels[i]} ({wwr})')
```

3. Results

The sensitivity of Energy Consumption per 1% change in average WWR in all the directions of each flat was plotted for the summers.

Figure 2 Sensitivity of Energy Consumption to WWR (KM11 236° SW)

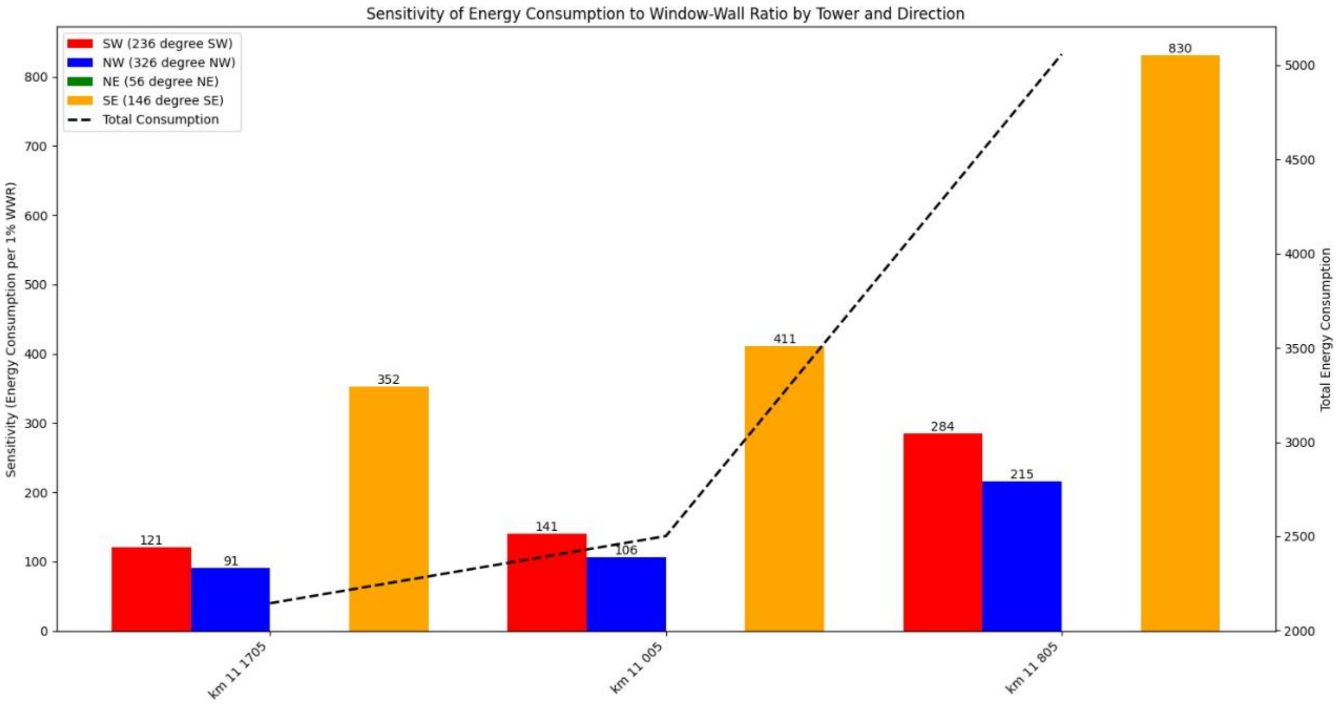

Table 1 Directional impact on Energy Consumption KM11 (236° SW facing)

	South West (236°)	**North West (326°)**	**South East (146°)**
KM11 005	141 units	106 units	411 units
KM11 805	284	215	830

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KM11 1705	121	91	352

The southeast WWR shows the highest sensitivity, followed by the southwest façade of this tower, as shown in Table 1.
Any change in the SE WWR will strongly impact energy consumption.

KM08
281° W garden facing

Figure 3 Sensitivity of Energy Consumption to WWR (KM08 281° W)

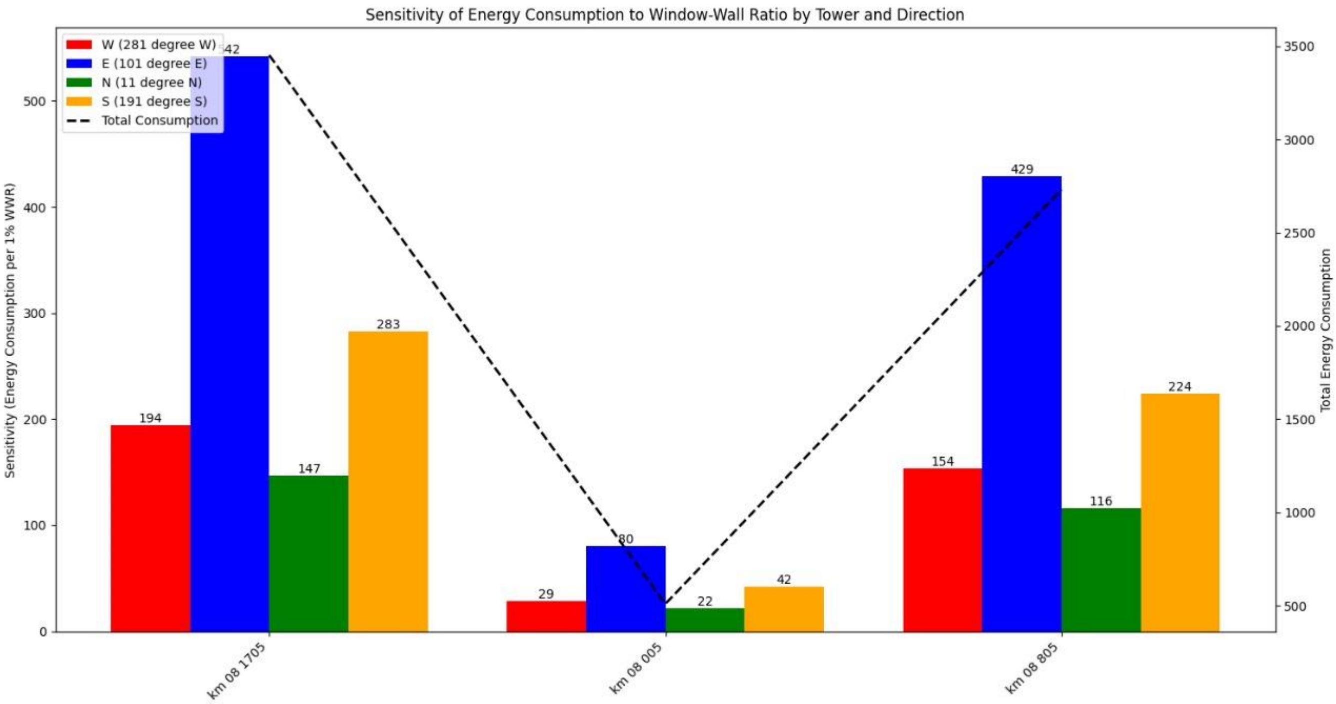

Table 2 Directional impact on Energy Consumption KM08 (281° W facing)

	West (281°)	**East (101°)**	**North (11°)**	**South (191°)**
KM08 005	29 units	80	22	42
KM08 805	154	429	116	224
KM08 1705	194	542	147	283

The East WWR shows the highest sensitivity, followed by the South WWR for this tower. Any change in the window-wall ratio in the East and South directions will strongly impact energy consumption, as shown in Table 2.

KM02
146° SE garden facing

Figure 4 Sensitivity of Energy Consumption to WWR (KM02 146° SE)

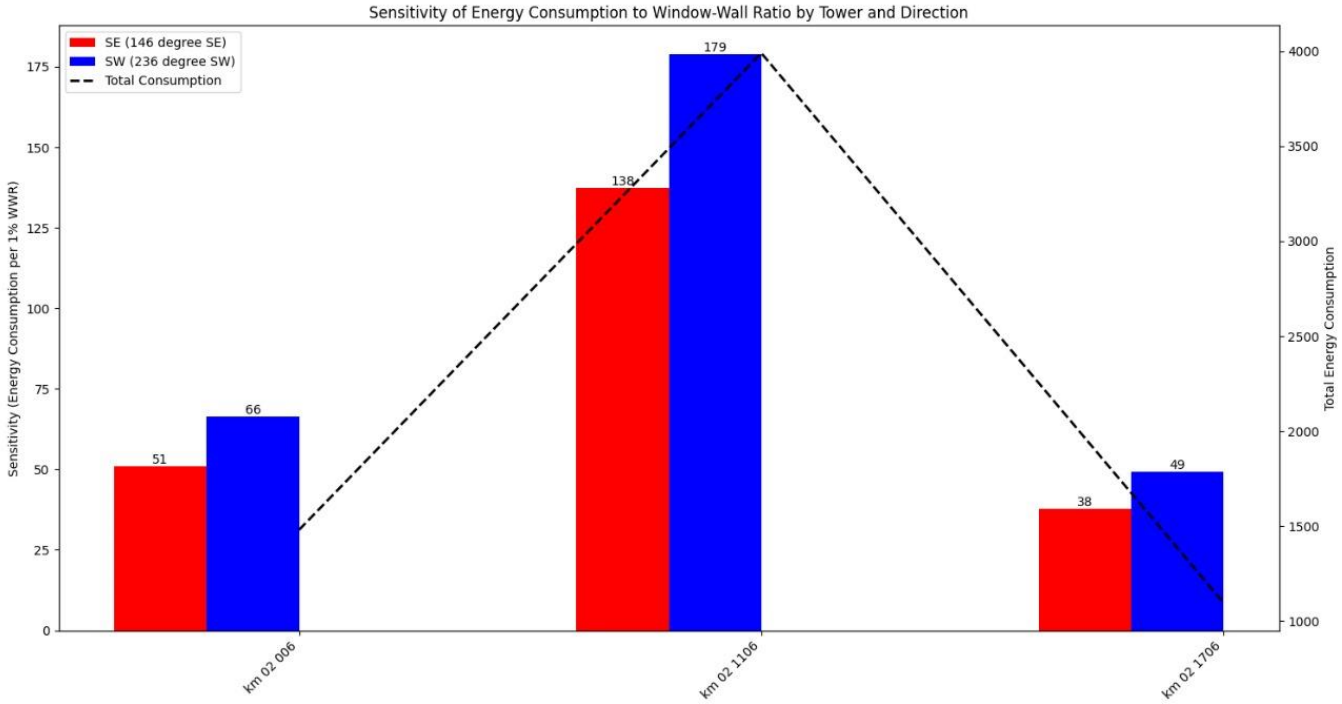

Table 3 Directional impact on Energy Consumption (146° SE facing)

	South East (146°)	**South West (236°)**
KM02 006	51 units	66
KM02 1106	138	179
KM02 1706	38	49

Southwest direction WWR shows the highest sensitivity. Any change in the South-West WWR will strongly impact energy consumption, as shown in Table 3.

KM04
56° NE garden facing

Figure 5 Sensitivity of Energy Consumption to WWR (KM04 56° NE)

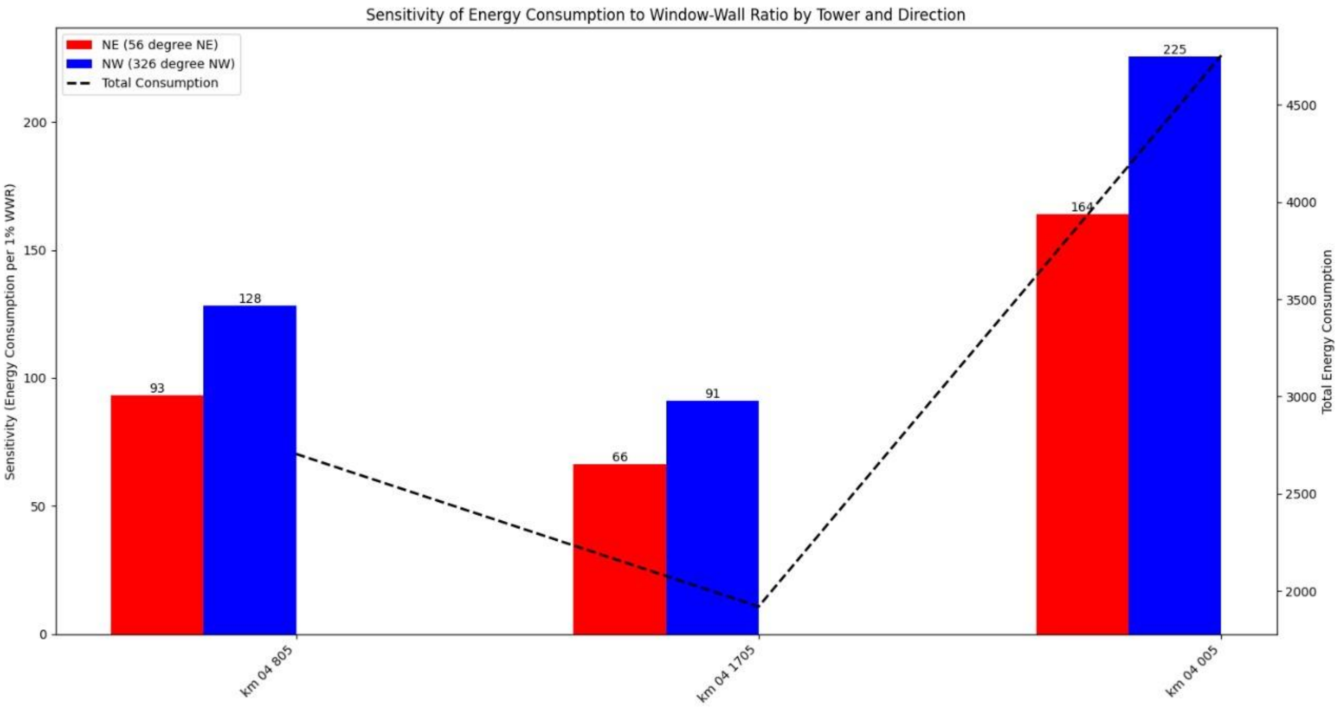

Table 4 Directional impact on Energy Consumption (56° NE facing)

	North East (56°)	**North West (326°)**
KM04 005	164 units	225
KM04 805	93	128
KM04 1705	66	91

The northwest direction, WWR shows the highest sensitivity. Any change in the North-West direction WWR will strongly impact this tower's energy consumption as shown in Table 4.

4. Discussion

General Patterns:

Eastern and Southern orientations tend to have higher sensitivities across most towers. Western orientation shows moderate sensitivity in most cases. Northern orientation generally has the lowest sensitivity during summers in North India.

Interpretation of Sensitivity:

Higher sensitivity means that changes in WWR for that orientation have a greater impact on energy consumption. For example, in KM 11 tower, increasing the WWR on the Southern side would likely lead to a much larger increase in energy consumption compared to other orientations.

Energy Efficiency Implications:

Towers with higher overall sensitivity (taller bars) might be more affected by changes in window design. Top and intermediate floors appear to be the most sensitive to WWR changes, especially for its Southern facade.
Ground floor shows the least variation in sensitivity across orientations, suggesting it might be the most stable in terms of energy performance relative to WWR changes.
Although the graph also depicts highest energy consumed floorwise but this data depends on several other factors in terms of number of air conditioning units, the number of running and occupancy hours, number of equipment and connected load.

5. Conclusions

This research will help designers to evaluate the optimum WWR that should be taken according to the orientation of the towers, which significantly influences energy consumption. All the residential units are designed based on the concept of modularity, rather than energy efficiency or thermal comfort. Energy efficiency and thermal comfort are often neglected by builders and designers for business-as-usual scenarios. This work will influence the designers towards rational thinking towards striking a balance between modularity, energy efficiency, and thermal comfort.

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