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Impact of Window-Wall Ratio on Heating and Cooling Energy Consumption: A Case of Office Building in Kathmandu

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Abstract
Window systems are commonly regarded as the most important part to be properly built for energy efficiency because of the function they play in heat exchange processes and solar gain management. The window-wall ratio (WWR) is one of the most important energy-saving design elements that influence building energy usage. WWR analysis and optimization are crucial for achieving energy efficiency in buildings. It does not matter whether a building is well insulated or poorly insulated; windows are the most vulnerable to energy losses between 48 percent to 61 percent. It has been discovered by studies that by employing the right WWR, building energy usage can be lowered by 9-15 percent, and that improper WWR can increase energy use by 5 percent to 25 percent. Transparent components of building envelopes or fenestration are especially prone to substantial heat gain and loss because they are comprised of highly conductive materials and exposed to direct heat gain from solar radiation.So, window design should be given a prime concern in building design in order to achieve energy efficiency in buildings.

Keywords
Thermal comfort, energy efficiency in commercial building, window to wall ratio, heating/cooling load,

1. Introduction

Window sizes can have a significant impact on task performance and building energy consumption. It is widely known that windows have a significant impact on energy consumption and the indoor environment. It makes little difference whether a building is highly insulated or not; windows are the most vulnerable to energy losses with losses ranging from 48 percent to 61 percent [1]. The window-to-wall ratio (WWR) determines how much energy is used to heat and cool a building. When compared to other construction materials (such as an outside wall), window glass has a low insulation performance since it not only increases heat transfer between indoors and outdoors, but it also increases indoor solar heat if the window size is increased [2]. The exterior window's heat transfer coefficient is many times that of the outer wall's, and heat dissipation through the external window is also very high [3]. This emphasizes the importance of fenestration in building for energy efficiency. So, the windows can be considered as the crucial building component in term of energy exchange with the exterior and energy consumption.

According to Shrestha and Uprety (2019) the use of the full glazing in commercial building facades has been increasing without having a clear understanding of such trend in terms of various other important aspects of buildings such as energy consumption, demand, and the desired indoor comfort level. Butera (2005) has emphasized the importance of window glazing as a significant technological achievement for achieving indoor thermal comfort in confined environments. According to him, it gives a noticeable thermal comfort enhancement in the indoor area as glass can retain solar radiation in the room and improve the indoor thermal comfort even without a source of heat during winter sunny days. This, however, necessitates a proper balance between the opaque and transparent portions of the building envelope in order to achieve the appropriate lighting and thermal performance while also improving the energy efficiency of the building. According to the Commercial Buildings Energy Consumption Survey (CBECS), windows account for 34 percent of space conditioning energy use, and thus 40 percent of CO_2, 54 percent of SO_2, and 17 percent of NOX emissions in the United States [4]. Therefore, windows should receive a lot of attention because they have a big impact on energy savings in buildings [5]. According to a study conducted by Su and Zhang (2010) to analyze the impact of the window to wall ratio (WWR) on energy consumption in commercial buildings stated that the building energy use can be lowered by 9-15 percent by utilizing the right WWR. It's also been discovered that incorrect WWR is responsible for a 5 percent to 25 percent increase in energy use [6].

Several studies have also shown that energy consumption in commercial buildings is increasing as a result of heat loss and gain, as well as the effects on overall comfort and operational expenses [7]. Transparent parts of building envelopes, or fenestration, are especially prone to substantial heat gain and loss because they are comprised of highly conductive materials and exposed to direct heat gain from solar radiation [8].So this research attempts to see how the window-to-total-wall-area ratio affects the thermal performance of an office building.

2. Methodology

The research was initiated with extensive literature review focusing on in-depth study and exploration of the different fenestration system and their impacts on energy efficiency, which was done by going through past researches. The relevant necessary data and information were then collected from the past researches which were later to be used in the study. This research was an experimental study in combination with the field survey which followed the post-positivist research paradigm.

A typical office building was taken as a reference case for the study. The questionnaire survey was carried out among the occupants of different buildings having similar window wall ratio with a set of questions regarding lighting behavior, thermal comfort, equipment used, number of occupants and work schedule. Then, the climatic analysis was carried out to identify the climatic and comfort conditions of the site location. The weather data was obtained from department of hydrology and meteorology and then the data was used in climate consultant software to analyze the climatic condition. The weather file was then further used in Ecotect software for simulating the building models. After obtaining basic building information and analyzed weather data, these information were used to simulate the energy performance of the case study building in its existing state naming it as a base case. After analyzing the base case, other building models were simulated with varying WWR and their results were observed. Ecotect Analysis software was used for this research. The Figure 1 below summarizes the research approach that was used.

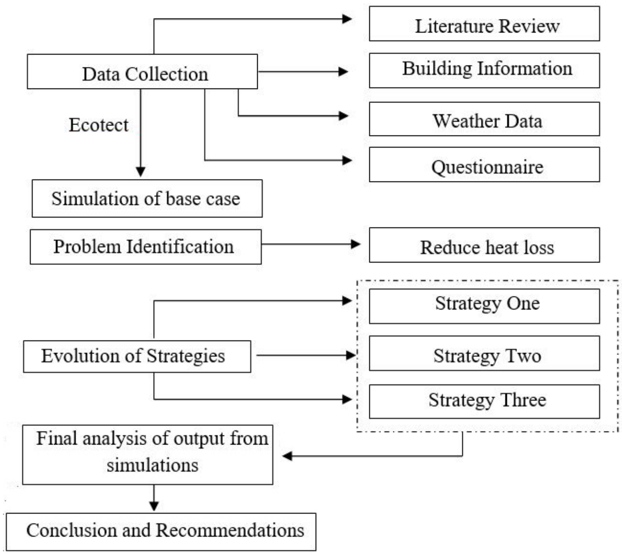

Figure 1: Research Workflow

3. Literature Review

3.1 Relation between energy consumption and window to wall ratio

Window systems are often regarded as a critical component that must be properly built for energy efficiency because of the function they play in heat exchange processes and solar gain management. The window-wall ratio (WWR) is one of the most important energy-saving design elements that influence building energy usage. WWR analysis and optimization are crucial for achieving energy efficiency in buildings [9]. The building WWR and total energy consumption are inextricably linked, hence lowering the WWR. lowers total energy consumption. Adjusting the WWR also results in decrease or increase in heating/cooling consumption [10].

Many research on the WWR have been conducted based on climatic features. Susorova et al. (2013) simulated office buildings in six different climate zones across the United States. The findings revealed that when the WWR increases, so does the total energy use. Poirazis, Blomsterberg and Wall (2008) evaluated WWR of 30 to 100 percent with different glasses, shading, and orientations in office building energy consumption simulation in the cold location of Goteborg. The findings revealed that an office building with a lower WWR will save energy and It was also mentioned that the highest performing designs require both day lighting and energy efficiency [11]. According to Marino, Nucara and Pietrafesa (2017), climate conditions, structure insulation, façade configurations and the presence of shading devices all have a significant impact on energy usage. Al-Homoud (1994) conducted an optimization study on building design variables to reduce annual energy consumption and found that a minimum glass area of 15 percent was the ideal, except in cold climates where a larger glass area was required to use solar gain for heating [12]. Johnson et al. (1990) researched into the most cost-effective window size and orientation and found that a WWR of less than 20 percent resulted in the lowest lifecycle cost. Furthermore, for large glass-to-wall ratios, the north orientation was preferable [13].

3.2 Effect of Windows on Energy Use Pattern

The glass divides the external from the interior of a window, so it must have features that are acceptable for the prevailing circumstances, including climatic and building properties and usage [13]. It is also vital to have a rudimentary awareness of the properties that are associated with glass and windows. The following are some common parameters for defining windows in terms of energy efficiency.

3.2.1 Thermal Transmittance (U Value)

The thermal transmittance, also known as the U-value, is a measurement of the rate of heat flow or thermal transmission through a material or assembly in units of heat flow per unit area per unit of temperature difference between indoor and outdoor temperatures. It is measured in BTU/hr sq.ft. or W/sq.m.K. It is responsible for the quantity of energy transferred by conduction and convection through a glazing system. This value is also known as the R-value, which is the reciprocal of the u-value and stands for resistance to heat transfer

3.2.2 Solar Heat Gain Coefficient (SHGC)

The transparent components, such as glazing are primarily concerned with the solar heat gain coefficient. For a certain incidence angle and environmental condition (indoor and outdoor temperature, wind speed etc.), it is defined as the ratio of solar heat gain through a window to solar radiation striking the outer surface. The total solar energy transmittance is the sum of two components: solar radiation transmitted by the glazing unit and solar energy absorbed in the glazing which is then subsequently transferred as heat to the indoor environment [14].

The shading coefficient (SC) was once the most used name for describing the sun control properties of window glass; now, the solar heat gain coefficient (SHGC) has taken its place. The lower the SHGC value, similar to the U-value, the better the performance. Glazing systems with high SHGC values provide significant solar gain, whilst those with lower values provide less solar gain. As a result, SHGC is a more essential element in hot regions.

3.3 Impact of Windows on Indoor Environment

The impact of fenestration on indoor environment of building can also be influenced due to follow factors [15]:

3.3.1 Building Orientation

The overall performance of windows in terms of the amount of daylight that reaches them is influenced by the building's orientation. This is an important consideration to make throughout the design phase.

3.3.2 Window Glazing Size

The amount of light that enters the building is greatly influenced by the size and number of windows. The sort of window building has can make a big difference.

3.3.3 Glass Performance

Recent advancements in the glass manufacturing process have resulted in a wide range of options that has improved the window performance in respect of Solar Heat Gain Coefficient, U-Factor, and Visible Transmittance.

4. Case Study and Research Context

The commercial building taken as a case study to carry out the research was a four and half story commercial building with buildup area of 941.05 square meters at Gwarko, Lalitpur. The ground floor was allocated for retail shops and rest of the uppers floors for offices.

It also consisted of basement serving as the parking amenity to a limited number of vehicles. The building was constructed in 2020 A.D and was a RCC frame structure with blank facade at south and tinted full glazing windows at east, north and west facade. The second floor of the building was taken for analysis which has the floor area of 199.81 square meters.

Figure 2: Commercial building at Gwarko, Lalitpur, taken as a case study for the research

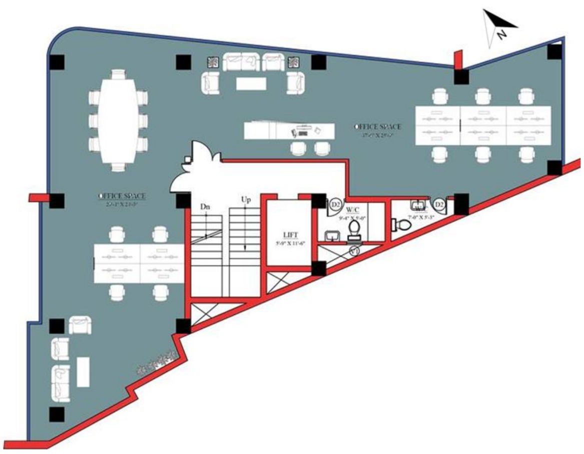

Figure 3: Second floor plan of commercial case study building

5. Simulation and Analysis

5.1 Climatic Analysis

The climatic analysis was carried out to identify the climatic and comfort conditions of the site location. Firstly, the weather data was obtained from department of hydrology and meteorology. The weather data was used in climate consultant software to create .epw format file which was then used to analyze the climatic condition in the same software. The weather file was then further used in Ecotect software in .wea format for simulating the case study building model.

5.2 Simulation

After obtaining basic building informations and weather data, these details were used to simulate the energy performance of the existing buildings in their current state naming it as a base case. The data obtained from questionnaire survey and climatic analysis were used to fill the parameters required in the simulation software. After analyzing the base case, other models were simulated with varying WWR and their results were observed. Ecotect Analysis software was used for this research. This simple energy simulation program can be used to make quick design judgments about a building's energy efficiency. It offers a user-friendly interface and can simulate energy consumption using only the building shell, thermal zones, and climatic data as input.

5.2.1 Simulation Parameters

All the parameters were made as per the existing building condition of case study building and then the building model was simulated to analyze its thermal performances in existing conditions. The parameters used for the simulation are given below in Table 1:

Table 1: Simulation Parameters

Clothing: 1.00 clo	**Activity**: Typing (65W)
Humidity: 76.5 percent	**Activity System**: Mixed- Mode System
Air Speed: 0.5 m/s	**Thermostat Range**: 18°C-28°C
Occupancy: 10 people	**Operation**: 10am – 6pm

5.2.2 Base Case Scenarios

The base case was simulated with all the parameters and zone properties as in the existing state without any changes being made. The materials properties of the building are mentioned below:

- **Walls**: The walls were made up of 110mm brick with 10mm cement plaster on both sides with the U-value of 2.620 W/m2K. The bricks walls were used for the blank southern façade and the internal partitions
- **Floor and Ceiling**: The floor and ceiling are made up of concrete slab of 152mm thickness

with 10mm plaster on both sides.

- **Windows**: Full glazing window were used in east, north and west façade of the building. Single glazed blue tinted glass pane of 6mm thickness with aluminum framing was used for the glazing with U-value of 6.0 W/m2K ,solar heat gain coefficient of 0.94 and visible transmittance of 0.53.

5.2.3 Other Cases

Different cases were set for energy optimization where the scenarios adopting different window to wall ratio keeping all the other elements unchanged. The other cases were created with WWR 40 percent to 20 percent as per the analysis made on Mahoney table which suggest the optimum opening size for the particular location to be in the range of 40-20 percent.

6. Results and Discussion

6.1 Base Case

The result from the simulations showed that the maximum heating of 12002 watt is required at 11 am on 5th January whereas maximum cooling of 15370 watt is required at 3pm on 30th May. The simulation further gave the following results as shown in Table 2:

Table 2: Energy Consumption of base case

Total load consumption	1144701 Wh
Total heating load consumption	631845 Wh
Total cooling load consumption	512856 Wh
Total load per sq. m	7486 Wh
Total heating load per sq. m	4132 Wh
Total cooling load per sq. m	3354 Wh

From the simulation output, it was found that the need of heating load in building is comparatively more than the cooling energy load. From Figure 4, it can be observed that there is more need of heating as compared to cooling in the building.The building was seen more critical in terms of heating as the its south façade was blank with no openings which limited the solar radiation in the building and was also provided with full glazing on three of its façade which further made it vulnerable to huge heat loss from the glazing since the single glazed glass pane of 6mm was used in the building which has poor thermal insulating property as compared to solid walls. The building was required to be heated for 6 months, where January needed the maximum heating load while the building needed to be cooled for 4 months, where month of June required maximum of heating load. The month of April and Sept neither needed heating nor cooling.

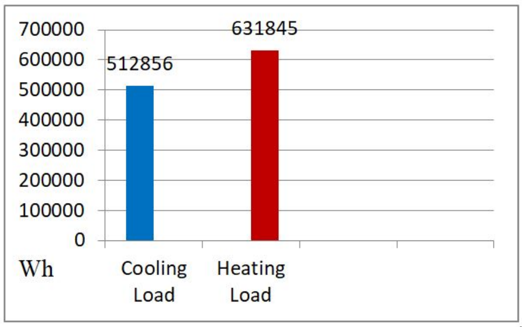

Figure 4: Heating/cooling load comparison (base case)

The Figure 5 represents monthly passive gain and loss through the building. The analysis result showed that the month of January, February and December has large amount of heat loss through conduction where January in its early days has maximum conduction heat loss of 2295 Wh/m2. Since here the conduction heat loss is comparatively high which is 77.2 percent in this case, makes the need of high heating load during colder months.

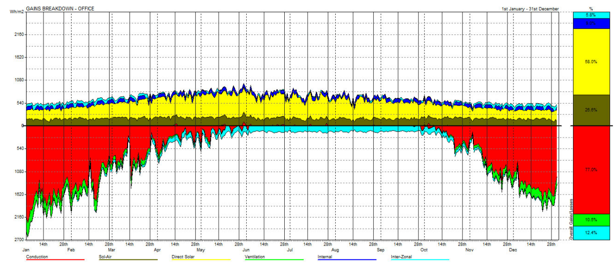

Figure 5: Passive gain breakdown (base case)

6.2 Simulation Result of Other Cases

After analyzing the base case, other case scenarios were created with 40 percent to 20 percent WWR which gave the following results as compared to the base case scenario which is shown in Figure 6.

As it can be observed from the simulation results of all the cases as shown in Figure 6 that the total energy consumption is significantly decreasing with alteration of WWR made in every cases. Since the south façade is blank and there is not direct solar gain in the building except from the east and west side for a limited duration, the building is in need of more heating than cooling. Though the heating load is dominant in the building than the cooling load in every case, the overall amount of energy consumption was being reduced with the decreasing WWR in the building. Similarly, the conduction heat loss from the building was also reducing with the decreasing WWR in the building as compared to the base case

	Case I: Base Case	Case II: 40% WWR	Case III: 35% WWR	Case IV: 30% WWR	Case V: 25% WWR	Case VI: 20% WWR
Total load consumption (Wh)	1144701	602952	585491	579524	572028	541500
Total heating load (Wh)	631845	320163	326248	338778	360170	377832
Total cooling load (Wh)	512856	282788	259243	240747	211857	163668
Total load per sq.m (Wh)	7486	3943	3829	3790	3741	3541
Heating load per sq.m (Wh)	4132	2094	2133	2215	2355	2471
Cooling load per sq.m (Wh)	3354	1849	1695	1574	1385	1070
Total load reduction (%)		47.32%	48.85%	49.37%	50.08 %	52.69%
Conduction heat loss reduction (%)		29.08 %	30.28%	32.46%	34.64%	37.25%

Figure 6: Energy consumption of all cases)

Figure 7 shows the decreasing total energy consumption with decrease in window to wall ratio in the case study building.But as the WWR was being reduced, it was observed that the cooling load in the building was gradually decreasing with decrease in WWR whereas the heating load was being further increased with decreasing WWR.

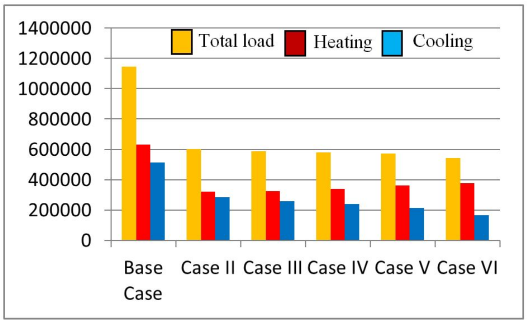

Figure 7: Total energy consumption by all cases (north oriented)

6.3 Change in Orientation

The case study building was then oriented to south which was north oriented in its existing state and was simulated again to analyze its energy consumption pattern which gave the following results as shown in Figure 8.

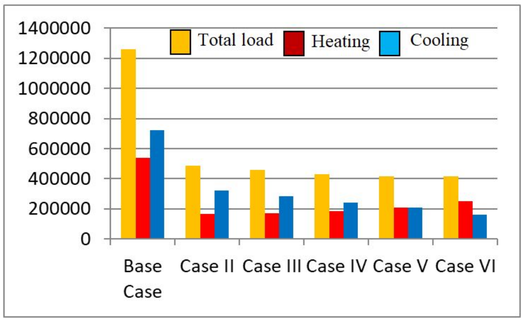

Figure 8: Total energy consumption by all cases (south oriented)

From Figure 8, it can be observed that the need of cooling energy is more than heating energy when the building was oriented to south. As the WWR was changed to 40 percent from full glazing window, there was a significant reduction in both heating and cooling load resulting decrease in total energy consumption which could also be seen in the previous case where the building was north oriented. But as the WWR was further reduced, it was observed that the cooling load in the building was gradually decreasing with decrease in WWR whereas the heating load was being further increased with decreasing WWR which was also the pattern seen in the case where the building was north oriented.But in this case, the overall energy consumption was lesser as compaired to the north oriented case study building.

6.4 Compairing Results of North and South Orientation

Figure 9 shows the comparision of total energy consumption by the building when the building is north and south oriented.

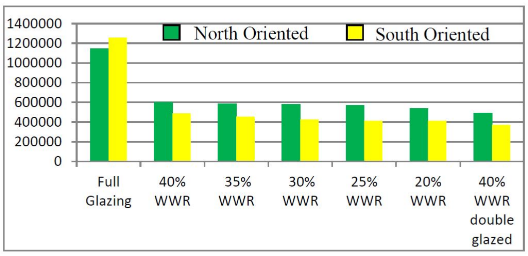

Figure 9: Comparison of total energy consumption on the basis of orientation

In Figure 9, it can be seen that the full glazing south oriented building consumed more energy as compared to north oriented building but when the WWR is reduced, the south oriented building showed more energy saving potentials than the north oriented building.

7. Conclusion

The study concludes that reducing window to wall ratio in building does decreases the total energy consumption in the building. With the reduction in WWR, the conduction heat loss/gain through the building can also be reduced which helps save the energy consumption in the building. In case of 40 percent WWR, both the heating and cooling load was significantly decreased compairing to that of the base case but while moving on to case from 35 percent to 20 percent WWR, it was observed that the heating load in the building was being gradually increased with decrease in WWR whereas the cooling load was being further reduced with decreasing WWR although the total energy consumption in every case was gradually decreasing. The cause of this pattern followed by the heating and cooling load with the reduction of WWR could be due to limitation of direct heat gain from solar radiation in the building. By reducing the WWR, the conduction heat loss was definitely reduced but it also limited the direct solar radiation in the building which as result made the cooling load to further decrease and heating load to gradually increase.

The case study building when oriented to south, it was observed that need of cooling load is comparatively more than heating load. When the same process of analysis and simulation was repeated for south orientation as the north oriented building, analysis result gave better energy savings than the north oriented building. Base case where the case study building was oriented south and had full glazing consumed higher total energy compared to the north oriented building but when the WWR was reduced, the south oriented building showed better energy savings in every case.

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