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The Effect of Window to Wall Ratio and Orientation on Thermal Performance of Residential Building: A Case of Butwal

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Abstract
The glazing area and orientation of building have significant effect on indoor visual and thermal comfort which also affects the energy consumption of the building. Windows is sensitive spot for the exchange of energy through the skin of the building. Increased use of glazed window leads to increased solar gain inside the building, which is becoming a major problem in warm climate regions. Thus, the effect of the window to wall ratio for different building orientation on the thermal performance of residential buildings are studied. For this, a typical residential building located in warm temperate climate of Butwal was chosen as the study building in this paper. Window to wall ratio of glazed windows in north and south façade varied with 9 different values from 0.1 to 0.9 with constant increment of 0.1 and the building orientation was also changed for the comprehensive study. 80 different test scenarios were created in the simulation tool. By using Ecotect Analysis 2011, annual thermal energy consumption was computed for each test scenario. Findings from the research showed that increasing WWR results in increased energy consumption. The research also concludes that South orientation is the best orientation for all WWR whereas North-East orientation had the poorest result.

Keywords
Thermal comfort, Building orientation, WWR, Energy consumption

1. Introduction

Buildings and operations account for the largest share of both global final energy consumption (36%) and energy-related CO_2 emission (39%) [1]. In 2008/09, total energy consumption was approximately 9.3 million tons of oil equivalent (401 million GJ) in Nepal , 87% of which were derived from traditional resources [2]. Thus, responding aggressively to global warming, rising carbon emissions, and limiting fossil fuel burning has become a global strategic option [3].

Historical research shows that prior to the Renaissance, windows were not fitted with glass panes and the glass panel after the fire was the most important technological innovation in human history in terms of comfort in enclosed spaces [4]. Building Orientation (BO) is a basic factor affecting sun exposure and thus thermal acquisition, ventilation, and lighting [5].

The combination of opaque and translucent areas in building envelopes is a technique (i.e., passive strategy) aimed at controlling and regulating the infiltrated solar radiation and ventilation to create a healthy indoor environment [6]. Thermal comfort is that mental state which expresses satisfaction with the thermal environment [7]. Glazed windows provided a noticeable thermal comfort improvement in the indoor space since glass was capable of trapping solar radiation in the room, and in the winter sunny days indoor thermal comfort was improved even without a source of heat [4].

To design efficient fenestration, the climate, building type, and physical properties of glazing and framing materials such as visual transmittance, coefficient of solar heat gain, and thermal conductivity must be taken into account. Building design considerations, such as window orientation, window location, room dimensions, shading size and position, and floor plan configuration are much less considered despite the importance [8].

Nepal shows a diverse topography which leads to a variety of climatic conditions. Bioclimatic chart analysis showed that in four different bioclimatic zones of Nepal, Terai has warm temperate climate [9].

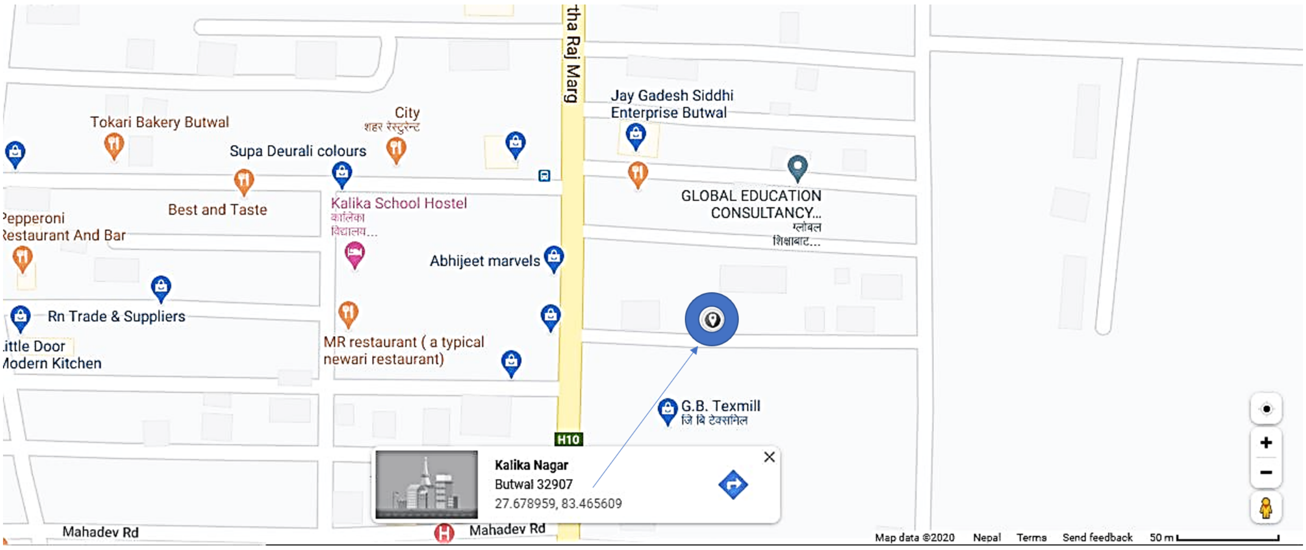

Figure 1: Location Map of case study building

This study aims to provide some Window to Wall Ratio (WWR) and Building Orientation (BO) decision-making advice for both new-build construction and retrofitting of warm and humid climate zone of Butwal to create better thermal comfort for the internal spaces, which is helpful in reducing the running cost of active systems.

1.1 Literature Review

The effect of fenestration geometric factors on building energy consumption in warm and humid climate analysed by [10] shows that with the increase in WWR in south-facing air conditioned building cell of dimension 5m x 5m x 3m heating and lighting energy consumption decreased whereas the cooling energy consumption increased. The simulation was carried out by using Energy Plus software. Eighteen building orientation interval and eight WWR intervals combination was analysed through Ecotect 2016 and PHOENICS 2012 by [6] revealed that the best WWRs for N-W 80 and S-E 80 are 0.39 and 0.4 respectively.

According to the research performed by [11] using Design Builder and Energy Plus software, the South orientation and 15% WWR showed the best effect in case of the composite climate of Rajasthan. Likewise, Experimental and Simulation Study for Thermal Performance Analysis in Residential Buildings in Hot-Humid Climate (Comparative Study) conducted by [12] shows that rooms with high WWR are relatively cool during night time only whereas low WWR performs well results during daytime and night-time. Nearly Zero Energy Building's most energy-saving WWR design scheme in severe cold areas is that the east WWR ranges from 10% to 15%, the south WWR ranges from 10% to 22.5% and decrease the north WWR appropriately if the conditions of light and ventilation allow it [3]. Although energy consumption has been strongly influenced by climatic conditions, structural insulation characteristics, façade configurations, presence of shading devices, the optimal WWR opt does not seem to vary significantly if the effect of each factor is evaluated individually [13].

1.2 Objectives

Glazed window is sensitive for solar gain and indoor heating. So, WWR and orientation of the window are key parameters for quantity of solar gain. For the purpose the objectives of this study are:

1. To analyse the effect of window to wall ratio in thermal energy consumption of building.
2. To analyse the effect of orientation of building in thermal energy consumption.

2. Research Methodology

Purposive sampling was done for the study. Eighteen houses of two to three storey has been taken for the meeting the objective. Thermal sensation data were collected from questionnaire survey. Out of eighteen surveyed house a typical residential building located in Butwal Municipality with latitude 27° 40' North

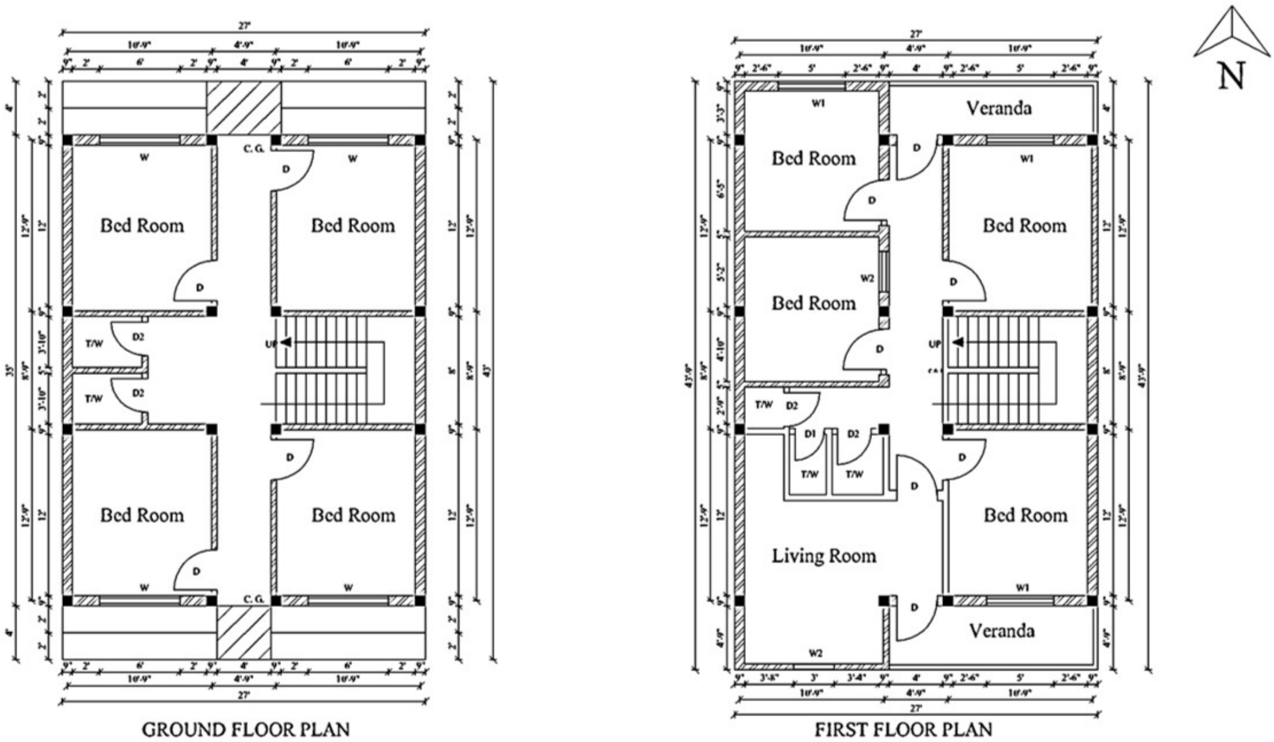

Figure 2: Plan view of case study building

and longitude 83° 27' East was purposefully selected for convenient for the study as seen in Figure 1 which was analysed using Ecotect Analysis 2011 simulation software.

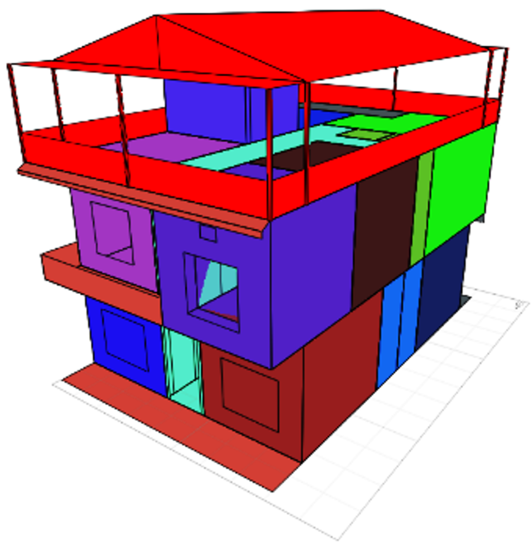

Figure 3: 3-D view of Thermal zones by Ecotect

Ecotect is one of the most important tools for building analysis, which can help to provide thermal and energy performance of buildings in which users will eventually work [12]. Thermal performance analyzes in Autodesk Ecotect are based on the admittance method of the Chartered Institution of Building Services Engineers (CIBSE) [14]. This software (tool) is based on thermal zone so building was modeled in such that each room as a zone. There are total sixteen zones with different colours as shown in Figure 3. The verandas in first floor and top floor are considered non thermal zone as it does not occupy volume . Ground floor plan and first floor plan of case study building is shown in Figure 2.

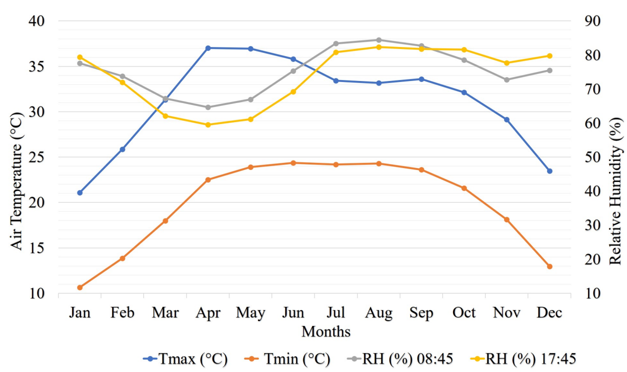

Figure 4: Average monthly air temperature and relative humidity [15]

Comfort band is assigned as 22.5 °C to 27.0 °C for a mixed-mode system in all thermal zones except corridor and stair. Comfort band is calculated by neutrality temperature for case study area. Occupants with activities are assigned according to field data. A mixed-mode system is a combination of air-conditioning and natural ventilation, where the HVAC system shuts down whenever external conditions are within the specified thermostat. This study can be conducted under a natural ventilation system which is unable to determine heating and cooling load to compare different scenarios. So, mixed-mode system is used. In this system active system is run when the comfort limit is not maintained in the thermal zone.

Weather data like dry bulb temperature, relative humidity, rainfall from 2007 to 2017 was collected from department of hydrology and meteorology (DHM), Babarmahal. Average monthly air temperature and relative humidity data obtained from DHM as shown in Figure 4 is input in weather file.

Table 1: Thermal performance of building materials

Components	Materials	Thickness (mm)	U-Value (W/m^2k)
Roof	CGI	2.6	5.62
Wall	Brick Plaster	130	2.8
	Brick Plaster	250	1.9
Door	Solid core timber	30	3.11
Ceiling	RCC with plaster	125	3.25
Floor	Stone soling PCC	260	2.78
Timber frame Windows	Timber pane	30	3.11
	Single glazed	6	5.44

The residential building selected for study is three-storied, north-oriented with a floor height of 3.35m. The top floor is unoccupied and covered with Corrugated galvanised iron (CGI) roofing. The ground floor has timber pane with timber frame windows whereas the first floor has single glazed timber frame windows. Both windows are operable to outside in the north and south-facing walls. Building materials are assign as field data and thermal properties are taken from Ecotect Analysis 2011. Thermal performance of building materials given by simulation software itself is shown in Table 1.

3. Scenario Description

Existing scenario of building is modeled as field measured data, building is rotated in eight different orientation i.e. North (N), North-East (NE), East (E), South-East (SE), South (S), South-West (SW), West (W) and North-West (NW) for existing WWR. Heating and cooling energy consumption for 8 test scenarios are obtained after simulation.

Then, WWR is set as 0.1 for all glazed windows in first floor and timber pane windows in groung floor remains unchanged. This building is rotated in a constant increment of 45° clockwise. Heating and cooling energy consumption for 8 test scenarios are obtained after simulation. Similarly, WWR is increased as 0.2 and 8 different orientations as earlier is carried out. Constant increment of WWR by 0.1 from 0.1 to 0.9 in eight different orientations is simulated. In this research, considering the different building orientations and combinations of WWR, a total of 80 test scenarios were proposed for investigation. Two evaluation parameters of heating and cooling energy consumption for each test scenario are computed.

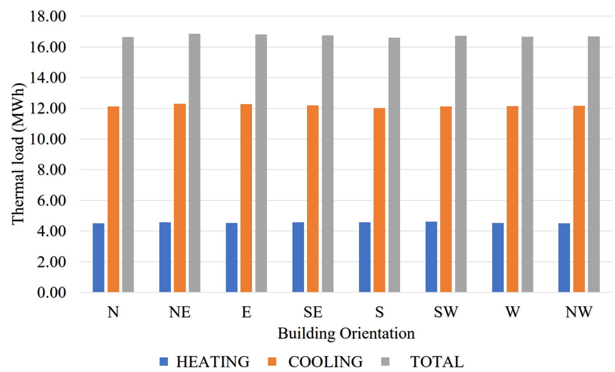

Figure 5: Heating and cooling energy consumption

4. Analysis and findings

The analysis of climatic data obtained from DHM revealed that the warmest month is April with maximum air temperature of 36.9 °C while the coldest month is January with minimum air temperature of 10.7 °C. Although, the relative humidity is relatively high throughout the year, July, August, and September have higher relative humidity due to monsoon. In this regard, it can be concluded that Butwal Municipality has a warm and humid climate.

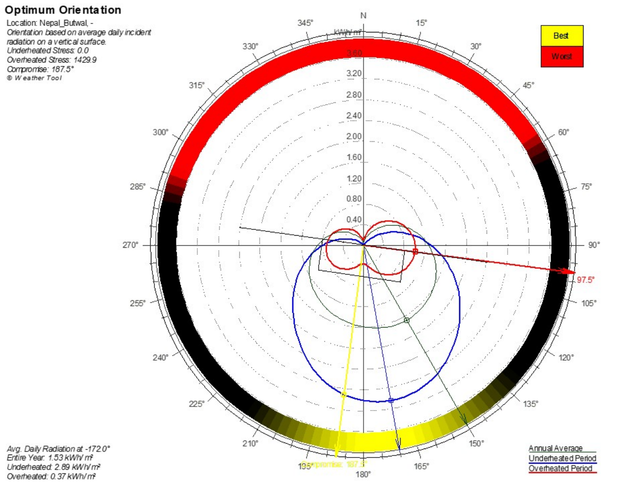

Figure 7: Best and worse orientation by Ecotect

Window to wall ratio of the simulated building for ground floor in north and south face wall is 0.35, 0.27 for first-floor bedrooms and 0.15 for first-floor living room. The building is simulated after loading weather file of Butwal in .wea format and 8 test scenarios are created for 8 different orientations in existing WWR. Annual thermal load obtained from the simulation result is shown in Figure 5.

Figure 7 shows the best and worse orientation given by weather tool for case study area. Best orientation is 187.5 ° clockwise from the north and worse orientation is 97.5 ° clockwise from the north.

Figure 5 clearly shows that the South is the best orientation since annual thermal load is minimum which is supported by Figure 7.

Constant increment of WWR by 0.1 from 0.1 to 0.9 in eight different building orientations are simulated and 72 test scenarios are compared. Result obtained from 72 test scenarios are presented in Figure 6. This result shows that annual thermal load is increased linearly with increased WWR and south orientation is best for all WWR.

5. Conclusion

This study represents the simulation results of a number of WWR and orientation strategies applied to Butwal's warm and humid climate building. The WWR and orientation were varied in order to quantify the effect of those parameters on the building's energy consumption. Annual thermal (both heating and cooling) energy consumption for mixed-mode system when comfort band is set as 22.5 °C to 27 °C were obtained for eight different orientation in existing WWR condition. Simulation result revealed that south orientation is best among all orientation. When building is south oriented 0.2 % of annual thermal load is decreased as existing scenario. Since north façade received less solar gain and south façade windows is shaded which results less solar gain through glazed windows thus cooling load is minimum.

WWR were varied for north and south facing glazed window of building from 0.1 to 0.9 by constant increment of 0.1 and all WWR is rotated in eight different orientation. Simulation result revealed that annual thermal energy consumption is increased with WWR increased. South orientation is best for all WWR whereas North-East orientation is worst for all WWR. Annual thermal energy consumption is increased with increase in WWR.

This study is compared with similar study conducted by various authors. In this study South orientation is best orientation which is same as [5] and [11]. Increased WWR result increase in annual thermal load which is similar with [10] and [11].

The main findings of this paper are summarized as follows:

1. South orientation is best for all WWR whereas North-East orientation is worst for all WWR.
2. Annual thermal energy consumption decreased by 0.24% for south orientation and increased by 1.31% for north-east orientation respectively compared with existing orientation (i.e. North).
3. Annual thermal energy consumption is minimum when WWR is 0.1.
4. Annual thermal energy consumption is maximum when WWR is 0.9.
5. Annual thermal energy consumption decreased by 1.36% for south orientation and increased by 0.23% for north-east orientation respectively when WWR is 0.1 compared with existing scenario.

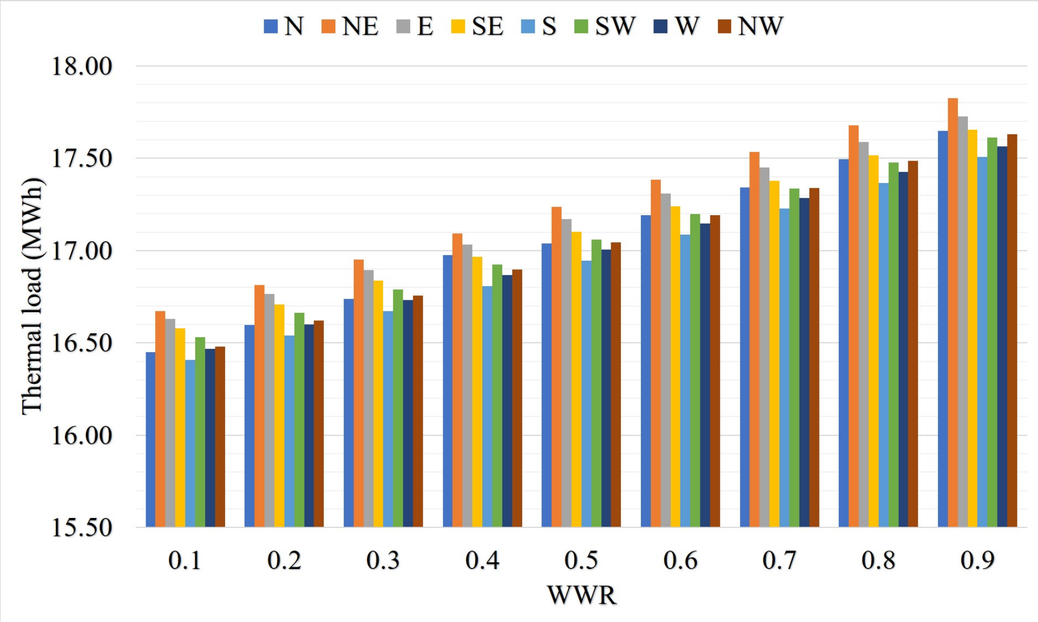

Figure 6: Annual thermal energy consumption (MWh)

6. Annual thermal energy consumption increased by 5.24% for south orientation and 7.16% for north-east orientation respectively when WWR is 0.9 compared with existing scenario.

7. Annual thermal energy consumption is increased linearly with increase in WWR.

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