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Solar Radiation Control Techniques in Public Building: A Case Study of Ward Office Buildings in Kathmandu

Bishal Adhikari [a], Ajay Kumar Jha [b]

[a, b] *Department of Architecture, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] adhikaribishal2015@gmail.com, [b] ajaykumarjhaphd@gmail.com

Abstract

This article is about the investigation of heat impact on ward office buildings with the changes in window wall ratio and the application of insulation materials in building envelope. The study was performed based on the case study of an existing ward office building in Tarakeshwor Municipality, Kathmandu performing energy analysis modeling in Ecotect. The window wall ratio and insulating materials of the building are discussed and the optimum design and materials for solar radiation control are recommended. Experiments and simulations were carried out on the two most popular ward buildings. The building design is important for saving energy by applying passive design principles for cold climates and using the right materials and appropriate design tools. This will make the home healthier and more comfortable. The research aims at analyzing the influence of window wall ratio and insulation for public buildings in Kathmandu. Kathmandu is chosen as an area of study. The climate of this area is studied after which bioclimatic analysis is carried out. The analysis gave comfort limits which were used to analyze the performance of different scenarios of the selected building. Five scenarios including a base case scenario are developed. Using the simulation tool, i.e., Autodesk Ecotect, the reduction in cooling load, reduction in heating load, passive gains, and loss are evaluated and compared. The results show that the application of polystyrene sheet insulation reduced the heating and cooling loads by 2564.63 Kwh in ward office building 9 and 3201.46 Kwh in ward office 11 when compared with the base case. According to the cost analysis, the polystyrene sheet insulation method resulted in an energy-efficient design.

Keywords

Solar Radiation, Window Wall Ratio, Insulation, Heating Load, Cooling Load, Energy Consumption, Gypsum board, Polystyrene Sheet

1. Introduction

solar radiation is one of the main factors that exert an important influence on heating and cooling loads. Buildings and transportation form the greatest share of energy consumption worldwide as the total world fuel consumption in 2019 has increased by 2.9% [1]. The impact on average citizens is unbearable costs for heating, gas, transportation, food, etc. Buildings consume about 40% of global energy, and they emit approximately one-third of greenhouse gas (GHG) emissions(ENERGY EFFICIENCY FOR BUILDINGS, n.d.). Building heating and cooling accounts for more than 50% of energy consumption(International Energy Agency, n.d.). Energy consumption in buildings can be reduced by using proper thermal insulation and proper window-to-wall ratio.

Building materials have also contributed to the destruction of the urban thermal environment and increased energy consumption [2]. Currently, numerous new building materials have been proposed as alternative thermal barriers including lightweight concrete, insulated metal panels, and insulated wood panels, gypsum board, polystyrene sheet, polyurethane form. Building orientation, building form, window wall ratio, shading, vegetation, thermal mass, etc are the key components of passive solar design strategies. It is recommended to all the owners to follow the Passive solar building design strategies while constructing the buildings. Passive buildings though have slightly higher initial costs (5-10%) than contemporary buildings as it adds the cost of materials and technology but in the long run, passive buildings are less costly than contemporary modern buildings. [3]

This article is based only on data from the case studies and simulation results from energy modeling software ecotect. Among many, only two parameters of solar radiation control measures i.e, window wall ratio and thermal insulating materials are taken for this research. The weather data is not available for the exact location so we have to consider the data of the whole city (Kathmandu valley). Since this research is conducted in Kathmandu only, the results and output will be applied only to this climatic zone. This research will help to analyze the influence of WWR and thermal insulation materials on heating and cooling load demand in ward office buildings.

2. Methodology

The literature study was done through different reports and journals available. The base model was created from the case study of two ward office buildings ward 9 and 11 of Tarakeshwor Municipality, Kathmandu and it is recognized as scenario 1.

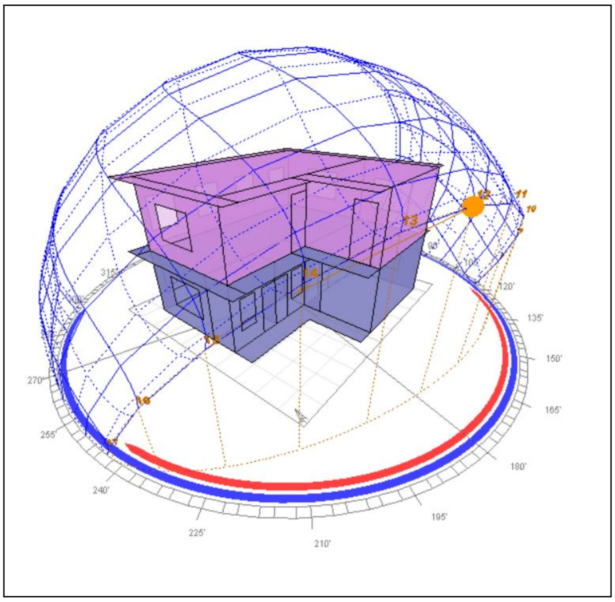

Figure 1: Base case ecotect model of ward 9 (Scenario 1)

Scenario 2 is generated with the variation of wwr to 20-30% whereas scenario 3 is generated by the variation of wwr to 15-20%. Scenario 4 is generated in ecotect by the application of 10mm gypsum board insulation whereas scenario 5 is created by the addition of a 50mm polystyrene sheet insulation in the building envelope. The results obtained from the base model and other scenarios were then compared and analyzed.

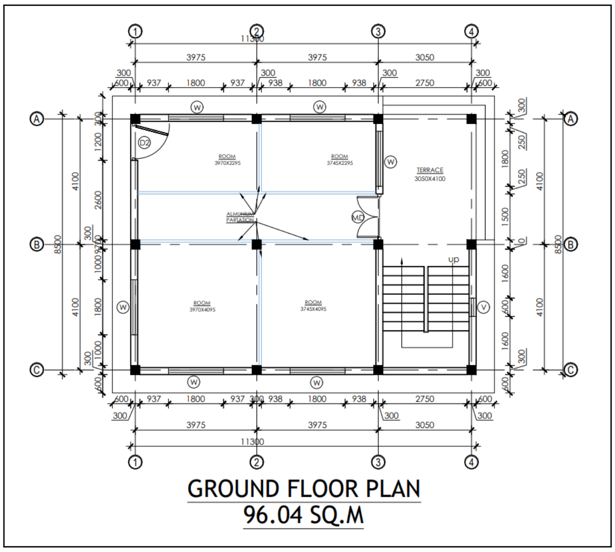

Figure 2: Ground Floor Plan, Ward Office 11

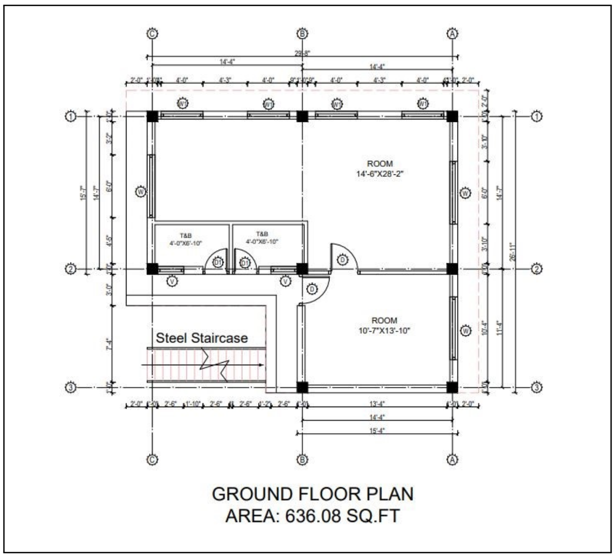

Figure 3: Ground Floor Plan, Ward Office 9

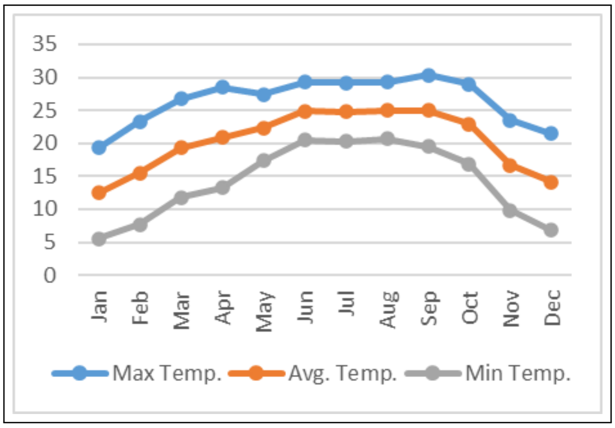

Figure 4: Monthly temperature of Kathmandu (Source: DHM, 2021)

The climatic data used for simulation was collected through the meteorological department. Climatic data validation is done by the measurement of temperature and humidity for a week. The maximum relative humidity of Kathmandu is 84.3% in July whereas the lowest relative humidity is in April i.e 55.34%.

3. Literature Review

3.1 Insulation

Energy consumption in buildings can be reduced by using thermal insulation which prevents thermal transmittance from the indoor comfortable environment to the outside environment from building envelopes such as floor, wall, roof, door and windows. Both external and internal thermal insulation significantly reduces the total energy requirement, but they bring different benefits in terms of wall protection and mold formation, and the installation of thermal insulation is more suitable on the exterior. [4]

Figure 5: Wall Insulation (Source: sandbeps.com)

Both external and internal thermal insulation significantly reduces the total energy requirement [4] . up 50% of energy can be saved with wall insulation materials like polystyrene, polyurethane, and glass wool. [5]

3.2 WWR

Window wall ratio (WWR) is one of the key energy-saving design parameters affecting the energy consumption of a building.

As WWR increases solar heat gain will increase that also results in the increment of heat exchange for the heat transfer coefficient of the window is usually larger than that of the wall. The artificial lighting consumption will decrease with the increase in WWR. It has a significant effect on total energy consumption as well as on thermal energy. The building W.W.R and total energy consumption are directly related, i.e., reducing the W.W.R lead to a reduction in total energy consumption. [6]

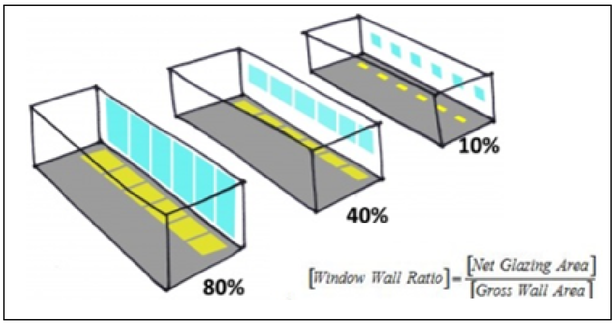

Figure 6: Window to Wall Ratio (Source: sustainabilityworkshop.autodesk.com/buildings/apertures-daylighting)

4. Results and Discussion

From the above analysis and comparison, it is seen that among the four scenarios 2, 3, 4 and 5, the three scenarios don't have significant differences. The last scenario has comparatively better performance decreasing the heating and cooling loads of the building by a significant percentage. The scenario 2 ,3, 4 and scenario 5 in ward 9 results in the reduction of 7.72%, 8.17%, 17.74% and 26.88% respectively whereas in ward office 11 the scenarios 2 ,3, 4 and scenario 5 results in the reduction of 5.89%, 7.94%, 12.35% and 27.94% respectively.

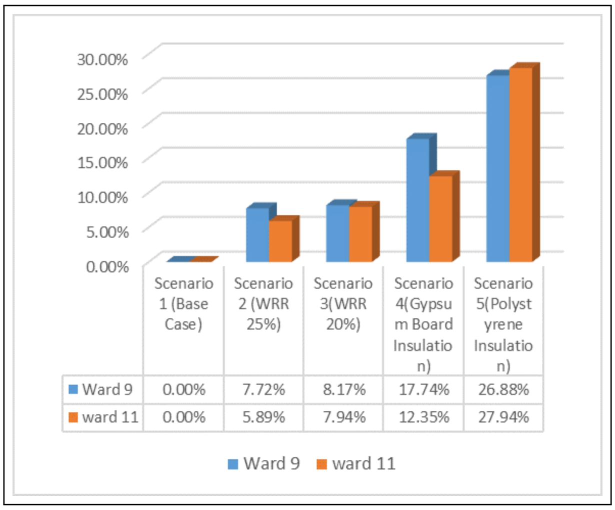

Figure 7: Load Depreciation Comparisons between five scenarios in ward 9 and 10

In ward office 9, The comparison of annual heating and cooling loads of base case with scenario 2 with the variation of WWR(20-30%) and glazing is 736.72 KWh less, Scenario 3 with the variation of WWR(15-20%) and glazing is 779.94 KWh less, Scenario 4 with the application of 10mm gypsum board insulation is 1692.14 KWh less and Scenario 5 with the application of 50mm polystyrene insulation is 2564.62 KWh less.

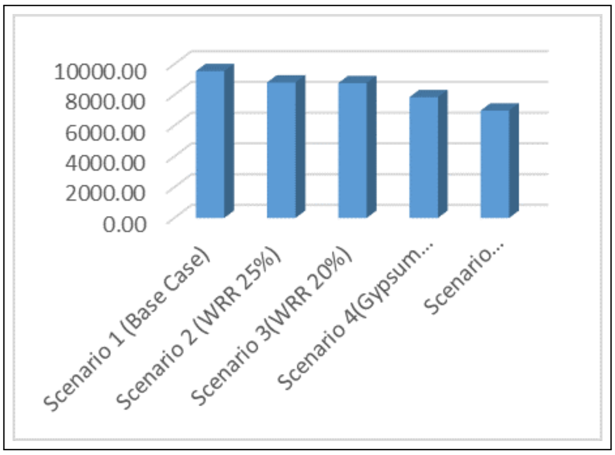

Figure 8: Heating and Cooling Loads Comparisons between five scenarios in ward 9

In ward office 11, The comparison of annual heating and cooling loads of base case with scenario 2 with the variation of WWR(20-30%) and glazing is 675.32 KWh less, Scenario 3 with the variation of WWR(15-20%) and glazing is 909.19 KWh less, Scenario 4 with the application of 10mm gypsum board insulation is 1414.69 KWh less and Scenario 5 with the application of 50mm polystyrene insulation is 3201.46 KWh less.

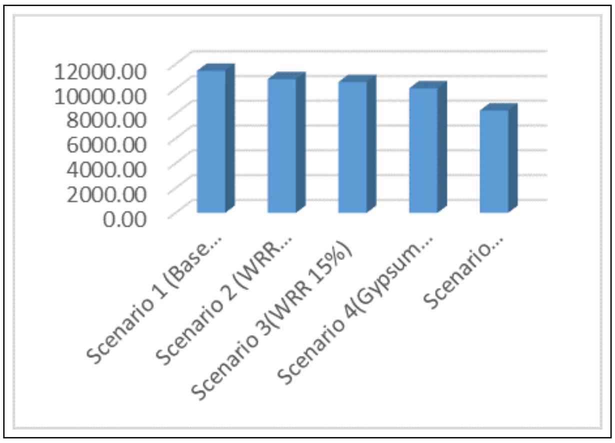

Figure 9: Heating and Cooling Loads Comparisons between five scenarios in ward 11

The annual heating and cooling load reduce with the application of insulation material and double-glazing windows in both ward offices. Hence, both types of insulation techniques could be used for a better result for thermal comfort in the building. Since these two have shown better performance, cost analysis and the payback period are done for all the scenarios which show that both the scenarios save money as compared with the base case scenario. The wall insulation and the double-glazed windows prevent heat transfer from the thermally controlled internal environment of the buildings. The results obtained from the analysis in this research when compared with the results obtained from the literature review of articles by [7] and [6] show that the reducing window wall ratio also reduces energy consumption in a building. As analyzed by the findings of articles [8] and [4] and the analysis results of this research, up to 50% of energy can be saved with wall insulation materials like polystyrene in a cold climate, whereas the savings of about 20% can be achieved by the insulation of gypsum board insulation.

The cost analysis for all five scenarios is done. Scenario 5 with the application of polystyrene has better performance. First, the construction cost for each of the types of scenarios is calculated according to the rate analysis provided by Tarakeshwor Municipality, Kathmandu which gives the initial investment cost. Annual energy cost is obtained for different scenarios including base case. It is calculated from the total annual heating and cooling load and unit cost given by the Nepal electricity authority.

Ward 9	Additional Cost (Nrs.)	Annual Loads Saving KWh)	Payback Period (Yrs.)
Scenario 1 (Base Case)			
Scenario 2 (WRR 25%)	286872.62	736.73	32.45
Scenario 3(WRR 20%)	185729.89	779.94	19.84
Scenario 4(Gypsum Board Insulation)	293955.13	1692.15	14.48
Scenario 5(Polystyrene Insulation)	375862.08	2564.63	12.21

Figure 10: Construction cost and Payback period comparison, ward 9

The energy cost is high in the base case compared to the other four scenarios. The additional construction cost for scenario 5 with the application of polystyrene sheet in ward office 9 is Rs. 375862.08 and the energy cost after the installation of polystyrene sheet is Rs. 30775.54 for a year. The additional construction cost for scenario 5 with the application of polystyrene sheet in ward office 11 is Rs. 580664.53 and the energy cost after the installation of polystyrene sheet is Rs. 38417.56 for a year. The total money required annually for energy for the base case is compared to the total of scenarios 2, 3, 4 and 5 in both the ward offices and it is found that the payback period of scenario 5 is less as compared to scenarios 2, 3 and 4.

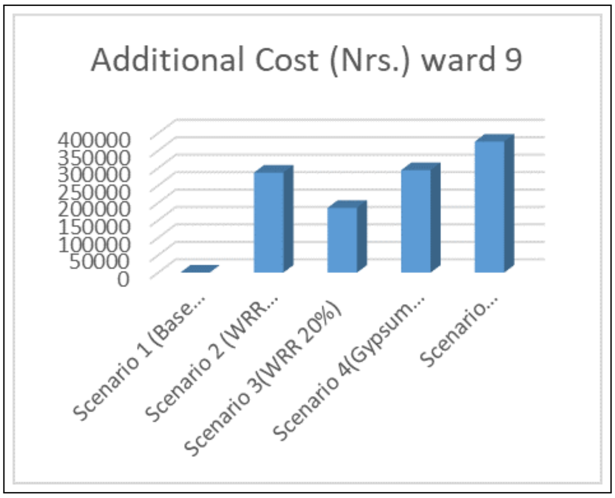

Figure 11: Additional Construction Cost Comparisons between five scenarios in ward 9

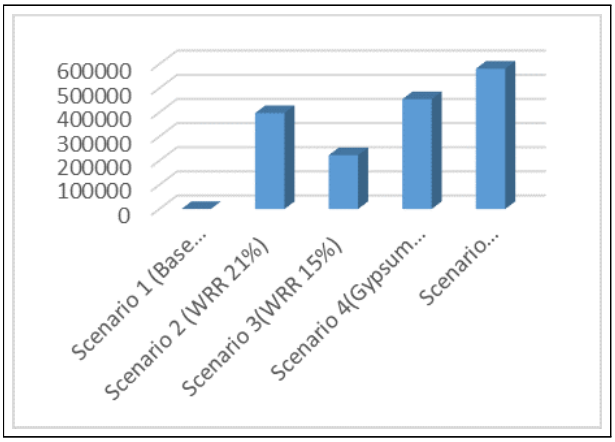

Figure 12: Additional Construction Cost Comparisons between five scenarios in ward 11

5. Conclusion

As the window wall ratio decreases the total load consumption in the building also decreases. Among two scenarios 4 and 5 with the addition of the insulation scenario, 5 is the best one. Although the initial investment is high the payback period will be less for scenario 5 with the application of 50mm thick polystyrene membrane in the wall. 2564.62 KWh energy loads in ward office 9 and 3201.46 Kwh in ward office 11 can be saved annually by the application of 50mm polystyrene insulation. 779.94 Kwh loads in ward office 9 and 909.19 in ward office 11 can be reduced by the variation of wwr to 15-20%. Thus, to conclude building envelope insulation and the properly designed window wall ratio can be an energy efficient technique in a public building in Kathmandu if used properly.

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