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Effect of Shading Device and Opening Size in Thermal Comfort of Residential Building, a case of Biratnagar

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Abstract
While world is marching on with the population growth and urbanization issues, it has witnessed the high energy demand in trying to satisfy people with thermal comfort. In the warm and temperate city like Biratnagar, Nepal which has been rapidly urbanizing since the 1990s where the random construction practice has led most of population high time trouble in dealing with indoor comfort. The deal of achieving thermal comfort in the residential building of Biratnagar primarily by the means of passive design strategies is obtained through the application of strategies like suitable opening size and proper shading devices in the existing building.This study used both qualitative and quantitative methods which included field survey of both the vernacular and contemporary buildings of Biratnagar followed by the questionnaire tools based on which refernece building was selected. The data collected from the department of Hydrology and meteorology were analyzed using climate analysis tool bioclimatic chart and primary design guidelines were withdrawn using Mahoney table. The energy simulation for existing building and retrofitted building is carried out through Ecotect software where the results obtained through the application of the shading device and suitable openings were considerable in energy saving up to 21.32% annually to achieve indoor thermal comfort.

Keywords
Thermal comfort, energy efficiency, passive design strategies, climate responsive design

1. Introduction

As building consumes about 40% of total energy around world [1] and is also one of the major Green House Gases (GHGs) emitter [2], people are looking forward for alteration or designing measures to minimize or control the impact of climate change on building. While considering the case of Nepal, the residential sector in Nepal consumed 89.1% of energy [3] contributing to major exploitation of forests and deforestation in rural areas in year 2008/09. Biratnagar a metropolitan city in south eastern part of Nepal with population growth rate of 2-3% and population densities 2-5,000 [4] has recorded annual temperature rise with an experience in high residential energy demand. However, the need of climate responsive building design is the most in perspective of energy minimization There are no universal passive house design guides for different locations and climates. Passive house design guidelines should be related to the major thermal problems of local climate conditions and local housing design, structure and materials [5]. To obtain an optimum thermal performance of a building, it should incorporate the design strategies according to its climatic need where the building shall be designed to respond the natural environment that can provide a desire level of comfort in the prevailing environment [6]. Maintaining a comfortable environment within a building in a hot climate relies on reducing the rate of heat gains into the building and encouraging the removal of excess heat from the building [7]. Passive building design strategies in such case is the most efficient way to minimize the energy consumption without compromising the occupants' indoor thermal comfort as these days the adaptation of new and inefficient construction materials those are not suitable for particular climate and the architecture. Focused on aesthetic completely avoiding the functionality has unpredictable affected the thermal performance of the buildings. This research aims to make an understanding of the passive design strategies to achieve the thermal comfort for Biratnagar with warm and temperate climate witnessing few strategies adopted in vernacular buildings of that particular region.

2. Methodology

This study has adopted both the qualitative and quantitative research. As a part of qualitative research, literature study was done through various research reports, journals. Further the quantitative data (temperature, humidity, rainfall) were collected from meteorological department. The data collected from the department of Hydrology and meteorology were analyzed using climate analysis tool bioclimatic chart and primary design guidelines were withdrawn using Mahoney table. The study included field survey of the contemporary and vernacular residential buildings and the elements of passive design were studied. The questionnaire tools were used for the particular survey to understand how the traditional architecture has behaved in providing thermal comfort with the viewpoint of climate-responsive design and how the contemporary architecture is behaving and will treat this issue. However the questionnaires were also performed to study the energy consumption pattern of those residential buildings. Selecting one of the contemporary building, detail study have been performed and the building was simulated and building energy performance modeling was done using energy performance modeling tool Ecotect.

3. Literature Review

3.1 Thermal comfort

The word ' thermal comfort' is described as a feeling of being too cold or too hot for people with an outer climate. According to ASHRAE (American Society of Heating, Refrigeration, and Air Conditioning Engineers), "Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation". As thermal comfort is a subjective matter, it varies on individual experience. It is maintained when the heat generated by the human metabolism is allowed to dissipate at a rate that maintains thermal equilibrium in the body. Thermal comfort is one of the most important aspects of the indoor environmental quality due to its effects on well-being, people's performance and building energy requirements [8]. According to [9], residential buildings can vary much more in thermal comfort than public and commercial building.

3.2 Passive design strategies:

Passive Design is method of adopting the design process which optimizes the natural resources and promotes the natural ventilation and day lighting. The building elements like windows, walls and floors designed to obtain, store and release the solar energy in the form of heat in the winter and abandon heat in the summer can be understood as passive solar design where mechanical and electrical devices are not operated [10]. In order to design the passive building in warm and temperate region the intellectual way is to avoid the direct solar gain and adopt passive cooling strategies.

3.2.1 Passive cooling of the buildings

In hot climate where maintaining the comfortable indoor environment can be extremely effective through the passive cooling of the building which also have proven to greatly contribute in decreasing the cooling loads of the buildings. Efficient passive systems and techniques have been designed and tested to achieve the excellent thermal comfort and indoor air quality together with very low energy consumption [11].To prevent heat from entering into the building or to remove once it has entered is the underlying principle for accomplishing cooling in passive cooling concepts[7].This depends on two conditions: the availability of a heat sink which is at a lower temperature than indoor air, and the promotion of heat transfer towards the sink[7].However the incorporating the passive cooling techniques is the easiest way to deal with the uncomfortable indoor environment. The various methods can be adopted for cooling down the indoor temperature, those have been in practice since centuries. These methods are proved to be much more effective in reducing the peak cooling load in buildings. Some of the concepts of passive cooling are discussed below:

- Orientation: Orientation is an important variable affecting energy performance in a building. Building orientation will have impacts on the building's heating, cooling, and lighting, as well as relating it to the natural environment in terms of access to daylight, ventilation and views [12]. The hot – humid climate has very low heat transfer rate between body and environment which creates uncomfortable feeling.

- Building Envelope: The building envelope is the physical barrier between the exterior and interior environments enclosing a structure [13]. Design features of an envelope strongly affect the visual and thermal comfort of the occupants, as well as energy consumption in the buildings. Building envelope components are always design with an objective to achieve environmental, technological, socio cultural, functional and aesthetic design determinants to achieve its highest workability, efficiency and sustainability[14].

- Window-wall ratio: Window – wall ratio is the specific value of the area of the window and that of the room façade. Unit area of room façade indicates the area enclosed by the room height and the standard width of the bay [15]. Window area or window-to-wall ratio (WWR) is an important variable affecting energy performance in a building. Window area will have impacts on the building's heating, cooling, and lighting, as well as relating it to the natural environment in terms of access to daylight, ventilation and views.

- Solar Shading: Solar shading either by roof overhangs or horizontal and vertical shading devices are the easiest means to avoid unwanted solar radiation entering the building. The study regarding the solar shading device and other passive cooling techniques, found out that the indoor temperature is reduced by about 2.5 °C to 4.5 °C with solar shading only[16].

4. Case Study and Research Context

In order to understand the existing residential building construction technology, materials and vernacular and contemporary architectural styles in case of Biratnagar, questionnaire survey has been performed among 120 houses in a particular area of the city called Bihibare as that area was newly urbanized and have 120 houses and 20 vernacular style houses were studied in Ekhraik village those were the only vernacular houses available at that place as other houses have adopted modern technologies. The selection of reference building was based on the most practiced building type among 120 houses of Bihibare, maximum houses were east facing and mostly practiced houses were of Reinforced Concrete with 1.5 storey. This led to the selection of reference building with 1.5 storey Reinforced Concrete house of Bihibare for analysis. The building is oriented towards east direction. It's total built-up area is 1108 sq.ft where the ground coverage is 792 sq.ft. it is reinforced concrete building with brick infill with cement mortar in both the external and partition walls and a plaster finishing on both sides. The roof for first floor is constructed of rein-forced concrete with cement plaster finishing where as second floor has used Corrugated Galvanised Iron (CGI) sheet covering. Windows are of single glazed.

Figure 1: Front view of reference building

On the ground floor , the building has living room , bathroom, two bedrooms and a verandah facing east.On the second floor it has a kitchen.

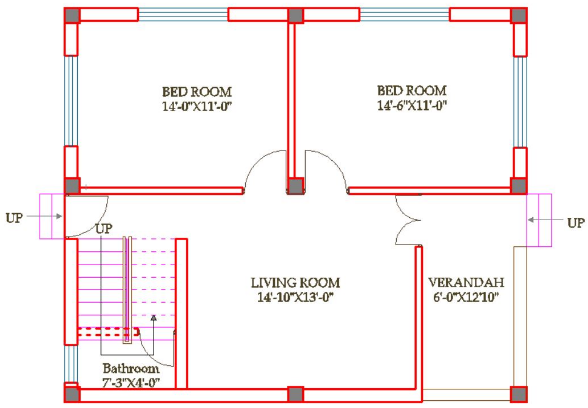

Figure 2: Ground floor plan of reference building

5. Simulation and Analysis

5.1 Climatic Analysis:

Climatic analysis for Biratnagar was done through bioclimatic chart and Mahoney table.

- Bioclimatic Chart: Based on climatic data climatic data (temperature and humidity) of ten years,2010 to 2019 for Biratnagar collected from Department of Hydrology and Meteorology, bioclimatic chart was developed.

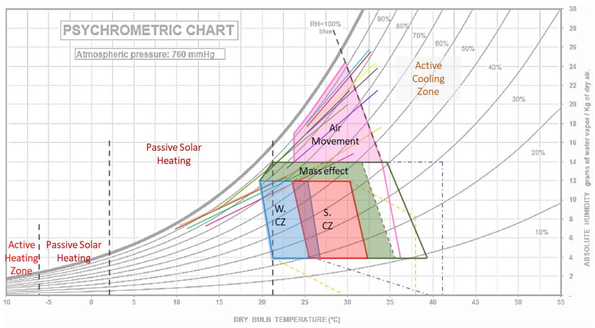

Figure 3: Bioclimatic chart of Biratnagar

  The result from bioclimatic chart shows that the summer comfort zone for Biratnagar lies between 24.5° C to 29.5 ° C whereas winter comfort zone lies between 20.4° C to 25.4° C. From the analysis it is confirmed that most of the months are hot and air movement must be incorporated in the design. However , daytime of three months January to March falls under comfort zone.

- Mahoney Table: Mahoney table was developed using the climatic data for the Biratnagar of ten years, 2010 to 2019 from Department of Hydrology and Meteorology. The Mahoney tables provide results of thermal comfort analysis using primarily temperature and humidity data and recommendations of design guidelines. Design Guidelines obtained from Mahoney table which are suitable for Biratnagar is shown below:
  - layout: Orientation north and south (long axis east-west)
  - spacing: Open spacing for breeze penetration but protection from hot and cold wind
  - Air movement: Rooms single banked, permanent provision for air movement
  - Openings: medium openings (20-40%)
  - Wall: light walls, short time-lag
  - Roofs: light, insulated roof
  - Rain Protection: Protection from heavy rain necessary
  - Position of openings: In north and south walls at body height on windward side
  - Protection of openings: Exclude direct sunlight, Provide protection from rain

5.2 Simulation

Building simulation is done using Autodesk Ecotect Analysis software version 2011 . It is a building energy performance simulation and modeling tool where the weather file is input to study the thermal analysis and other energy performance. To study the comfort level in the house monthly discomfort loads were calculated for different scenarios for thermal analysis. For building modeling, different scenarios were created by adding shading devices and altering opening size.

5.2.1 Base Case Scenario:

Base case model is considered as scenario 1. The base model was divided into different zones in Ecotect analysis modeling where depending upon the activity inside the room , parameters were set. The general parameter setting includes

- Clothing: trouser and shorts
- Humidity: 60%
- Air speed: 0.5m/s
- No. of people : Depends upon the room
- Activity: sleeping, walking, sedentary

5.2.2 All Scenarios

Different scenarios were set for energy optimization where the scenarios based on the adopting shading device and optimizing opening to 20% from existing 30% keeping all the other elements unchanged. All visible thermal zones includes living room and bedrooms on ground floor.Table 1 describes the different scenarios for energy.

Table 1: Different Scenarios for energy optimization

Scenario	openings(%)	Shading device
1	30% (base)	-
2	20%	-
3	30%	2’9” horizontal all sides
4	20%	2’9” horizontal all sides

6. Result and Discussion

The calculation made through ECOTECT analysis in all visible thermal zones for base case scenario, the results displayed on figure 4 shows the maximum heating of 2.21KW at 5am on 4th January where the maximum cooling of 3.41KW at 1pm on 4th October. The total annual heating load is 1022.54 KW and the total annual cooling load is 1911.14 KW. The total annual heating cooling load of the building is 2933.91KW. It consumes 36.86 Kwh per meter square annually

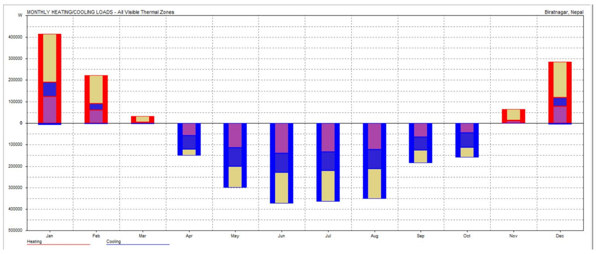

Figure 4: Monthtly heating cooling load/discomforts for all visible thermal zones of basecase scenario

Similarly for scenario 2 in which the openings has been altered to 20% from 30% analysis is shown in figure 5. The total annual heating load is 1010.64 KW and the total annual cooling load is 1763.2KW. The total annual heating cooling load of the building is 2773.85KW. It consumes 34.85Kwh per meter square annually . The analysis shows total heating and cooling load is less than base case scenario with suitable openings.

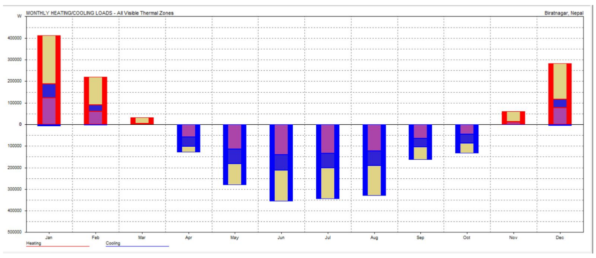

Figure 5: Monthtly heating cooling load/discomforts for all visible thermal zones of Scenario 2

For Scenario 3 where the horizontal shading of 2'9" has been provided on all sides calculated from solar chart for Biratnagar climate, the analysis is shown in figure 6. The total annual heating load is 834.15 KW and the total annual cooling load is 1682.11 KW. The total annual heating cooling load of the building is 2516.26 KW. It consumes 31.61 Kwh per meter square annually. The analysis shows the considerable decrease in total heating and cooling in scenario 3 as compared to base case scenario.

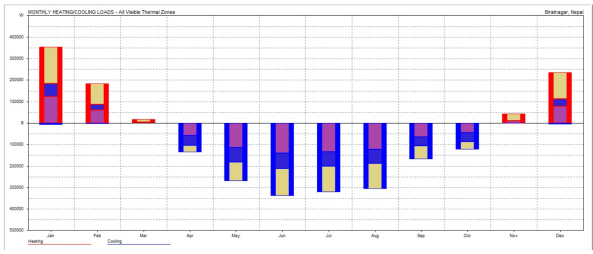

Figure 6: Monthtly heating cooling load/discomforts for all visible thermal zones of Scenario 3

Also for Scenario 4 in which both the alteration in opening size and the addition of solar shading to the base case has been done, the analysis is shown in figure 7. The total annual heating load is 796.55 KW and the total annual cooling load is 1511.383KW. The total annual heating cooling load of the building is 2308.39KW. It consumes 29 Kwh per meter square annually. The analysis shows the huge amount of energy savings and decrease in total heating and cooling load.

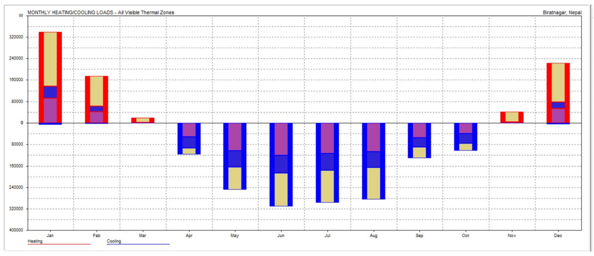

Figure 7: Monthtly heating cooling load/discomforts for all visible thermal zones of Scenario 4

The total annual energy saved in terms of percentage is calculates for energy optimization is explained in the table below.

Table 2: Optimized energy scenarios

Energy per year	Scenario 1	Scenario 2	Scenario 3	scenario 4
Total KW	2933.9	2773.8	2516.2	2308.4
Difference	-	160	417.6	625.5
Savings	-	5.4%	14.23%	21.32%

The table 2 explains that 20% of opening is more suitable as compared to 30% in case of warm and humid climate as obtained from the research. Result also shows that the best-optimized case is scenario 4, which is when the horizontal shading of 2'9" is given and opening size optimized to 20%Energy saving up to 21.32% can be optimized.

7. Conclusion

The study concludes that adopting some of the basic passive design measures can contribute to the considerable amount of energy saving without compromising the thermal comforts of occupants. In the case of Biratnagar, with warm and temperate climate, where the random urbanization and modern construction practices are mushrooming as well in such scenarios adaptation of energy efficiency measures has shown positive signs. The study of base model before and after retrofitting has come up with the certain result in support of the research. Adopting only shading device and solely opening size adjustment in the existing base case residential building has resulted in total annual energy saving of 14.24% and 5.4% respectively. Whereas in combination of both the strategies the total annual energy saving is 21.32%. However practicing passive design strategies have long term benefits in energy saving and decreasing energy demand. Study can be aditionally explored by changing the orientations and the building form, altering the size and type of the shading devices and also materials of the shading devices with different thermal insulation.

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