Proceedings of IOE Graduate Conference, 2017
Volume: 5 ISSN: 2350-8914 (Online), 2350-8906 (Print)

Passive solar approaches for New Town Development: A case at Baireni-Galchhi (400-500m)

Prerana Tuladhar [a], Sudarshan Raj Tiwari [b], Sushil Bahadur Bajracharya [c]

[a, b, c] *Department of Architecture, Energy for Sustainable Social Development (MSESSD), Pulchowk Campus, Institute of Engineering, Tribhuvan University, Nepal*
Corresponding Email: [a] 072mses458@ioe.edu.np, [b] srtiwari@ioe.edu.np, [c] sushil_bajracharya@hotmail.com

Abstract
Buildings consume about 40% of the world's energy use and the major part of energy is used in the residential cum commercial building for space heating and cooling. In our traditional towns, buildings are found to be thermally sensitive whereas the contemporary buildings are being built with little consideration of climate. Hence, are thermally insensitive leading to the high energy cost. The government of Nepal has proposed to develop new town along the mid-hill highway at Baireni-Galchhi, where 18,000 additional houses are required to accommodate a hundred thousand population according to government plans and policies and these houses could be made energy efficient through various passive approaches. Also, the building guidelines for the energy efficient designs have not received much attention in the context of our country. Thus, this research has been conducted.
This paper aims to explore energy efficient solutions for the minimal modifications to the existing buildings and develop guidelines in terms of passive solar approaches for modern buildings at three major levels: Settlement, Building design and Building component level. The research follows case study methodology with the qualitative and quantitative data analysis. The various passive solar literature is reviewed, psychrometric chart and Mahoney tables are developed to analyze the climatic parameters, field data is analyzed, three existing building cases are selected and finally computer generated models are tested in the energy analysis software "Ecotect". Based on these, findings are obtained on the various passive criteria which lead to the significant energy consumption in a long run. The findings of this paper will guide the practitioners in Architecture, policy makers and urban designers to incorporate passive design approach towards improving thermal comfort, thus providing a better quality of life.

Keywords
Passive solar approaches – New Town – Settlement planning – Building design – Building components

1. Introduction

Buildings consume about 40% of the world's energy use and the major part of energy is used in the building for space heating and cooling[1]. For the building and settlement design, climate and environmental conditions are the most important parameters. The historical trend of the energy consumption from 2004 – 2014 shows that there is increase in the import of petroleum products that has reached up to 138% by 2014 from 24% in the year 2004. This is against the principle of sustainability and effective decision for the energy efficient design and construction material has to be considered seriously.

"Building construction methods have changed greatly in the last two or three decades and modern designers often choose to ignore fundamental aspects such as climate."[2] The traditional construction techniques with the thicker walls, jhingati roofs, wooden or stone floors, perforated wooden windows such as tiki jhya etc. were focused on providing the comfortable environment indoors but with the advancement in the building materials and technologies, heating and cooling have become easier and the major focus has been shifted to the other aspects such as cost, faster and easier methods of construction, larger indoor space with the reduction in wall thickness.But these are forcing direct negative impact on the thermal comfort of the buildings. This may be due to the lack of knowledge on locally available building materials, construction technology and proper guidelines regarding the thermal efficiency of the buildings in the context of Nepal.

A town, in a simple definition, is a human settlement larger than a village but smaller than a city, however, its definition might vary according to the author, country, region, etc. In the context of Nepal, a town has been defined by the planning norms and standards 2013 [3] as a city having population up to a hundred thousand. The government has proposed to develop ten new towns along the mid hill highway for the settlement development, providing infrastructure, facilities and services [4]. But there is no inclusion of energy aspect in the building.

Considering the need of the study, the number of houses to be constructed as calculated was found to be 18,000 which if constructed in an energy efficient manner could reduce the energy load of the new settlement and the buildings residing in the area. Not only for the newer construction, but for the existing buildings too, the materials could be modified in such a way that it could reduce indoor temperature to some extent. These aspects could be considered for preparing the building guidelines in terms of thermal comfort.

1.1 Research Objective

The main objective is to provide the Recommendations on Passive Solar Approaches for the Baireni-Galchhi New Town at Neighborhood level and Building level. The specific objectives are:

- To study the energy side effect of the existing buildings and compare it with the alternative case scenario especially for the building envelope and compare the cost analysis.
- To provide the energy efficient solutions and recommendations for the minimal modifications to the existing residential cum commercial (mixed) buildings in the various building elements such as roof, wall, openings etc.
- To develop the building regulations and guidelines based on possible implications to indoor energy efficiency and passive approaches at three major levels: settlement planning, building design and building components.

2. Climate of Baireni-Galchhi

Baireni-Galchi is located between longitude of 27.76°N and latitude of 84.98 ºE and has warm and humid climate. There is very little seasonal variation throughout the year in this region. The topography varies from 400m-1280m above the main sea level[4]. The temperature in summer ranges from 30°C to 35°C during the day and in the night it ranges from 25°C to 30°C. In winter, day and night temperature is normally found as 25°C - 30°C and 20°C - 25°C respectively. The relative humidity remains as high as 75% for most of the time. But it may vary from 55 -100%. Solar radiation is quite strong. This region has mostly overcast sky. The dissipation of the absorbed heat by earth during day is also less due to the overcast sky. This is causing the region to be warmer at night and as a result of this, there is not much of diurnal temperature variation. Although, the temperature is not excessive, high humidity causes discomfort. Precipitation in this region is very high and the wind is strong. Most of this area falls in the monsoon region and has rainfall of more than 1200mm per year. Generally, strong wind can be sensed before the monsoon season. The data obtained from the meteorology department shows three months to be the coldest, five months the hottest and four months with the comfortable temperature.

3. Study Area

Due to the variation in topography from 400m to 1280 m above the main sea level, there is variation in the climate too. Therefore, the same design recommendation could not be provided for valley and hill. For this research, the climatic file to be inserted in the Ecotect has been taken at an altitude of 441m above the main sea level. Hence considering 441m to be average, the research area has been selected within the altitude range of 400m to 500m as shown in the figure 1.

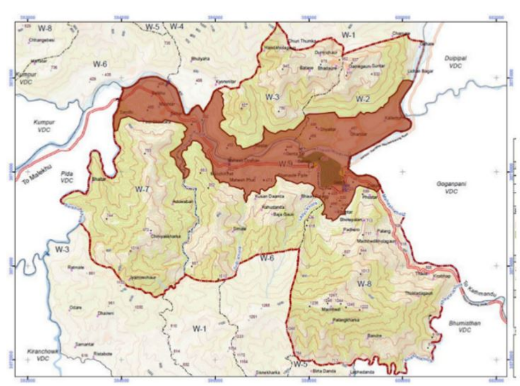

Figure 1: selected area of study

4. Methodology

The ontological position in my research is to understand the role of energy at Settlement, Building design and Building component level. The epistemological position is to acquire knowledge through interaction and quantitative data analysis. The research is based on Positivist and Constructivist paradigm with its objective and subjective reality. For the positivist paradigm, the quantitative data has been collected, whereas for the constructivist paradigm, qualitative data has been collected. Therefore, it is a mixed research.

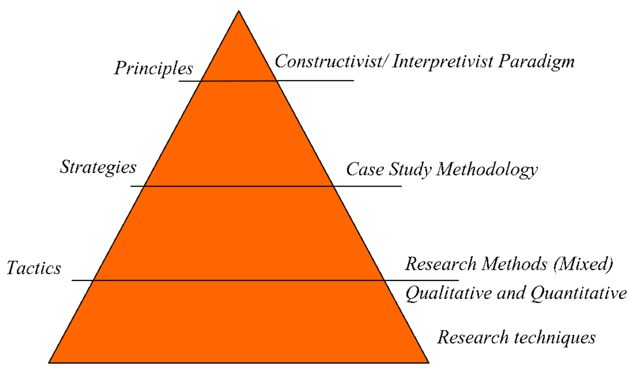

Figure 2: Research pyramid

The positivist paradigm includes the pilot survey, Questionnaire survey, study of the secondary data sources as the methods and for the data analysis the technical tools are used such as Statistical Packages for the Social Sciences (SPSS) and, Ecotect analysis. For the constructivist paradigm, participant observation is used as a method where Participation in the sense means "being there" and "in the middle of the action." Due to the time limitation, the participant observation that immerses into the details being as covert as in ethnographic research could not be done but by being a participant as observer, "where the researcher's identity as a researcher is openly recognized that have advantages of gaining informed consent from those involved and takes the form of shadowing a person or group through normal life, witnessing first hand and in intimate detail the culture/events of interest"[5] the qualitative data have been conducted. Unstructured and semi-structured interviews, direct observation and interactions, fieldwork were performed during the research.

The research follows case study methodology, which investigates a contemporary phenomenon within its real life context, especially when the boundaries between the phenomenon and the context are not evident. The study uses multiple-case design with multiple units of analysis and intrinsic case study was undertaken because better understanding of the particular is important.

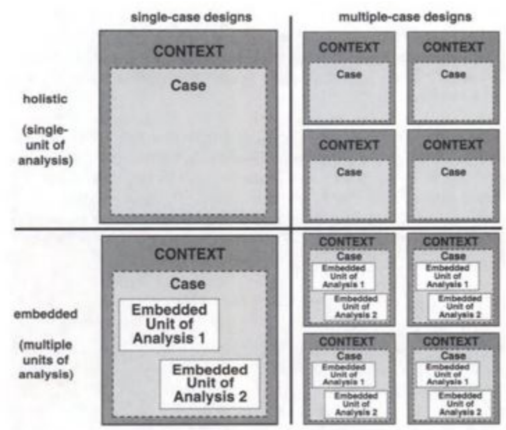

Figure 3: Case study

The three building cases were selected that lie along the prithivi highway with different building materials. The first building is built with the stone and mud masonry and corrugated sheets in the roof. The front open space is semi-covered space with the various household activities and social gathering. There is use of straw mats beneath the CGI roof above one of the common rooms where they spend much of their time. The second case was selected that have rooms on the either side separated by the narrow corridor with the brick masonry and cement mortar as wall material at the ground floor level and Hollow concrete blocks at the upper floor level. The use of different wall material in the same building made me curious to select the second case. The third one also have similar wall materials in the ground and first floor level as in the second case but it is single bayed and from the literature, for the hot and humid area the third case is preferred.

The approach followed is inductive that begins with observation in the field followed by pattern, then tentative hypothesis and finally leads to theory which is shown in the figure 4.

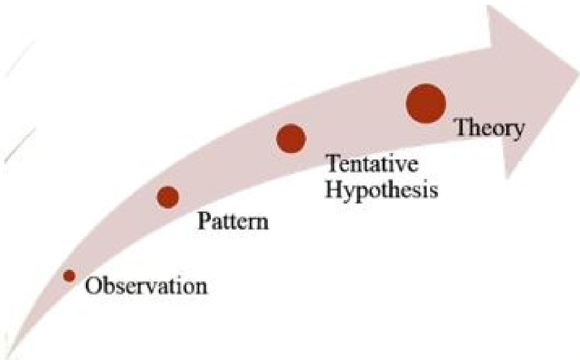

Figure 4: Inductive approach

The methods are literature review, analysis of field data, selection and detailed study of the three cases, generation of thumb rule i.e. Mahoney table and Psychrometric chart and finally simulation of model in the energy analysis software "Ecotect".

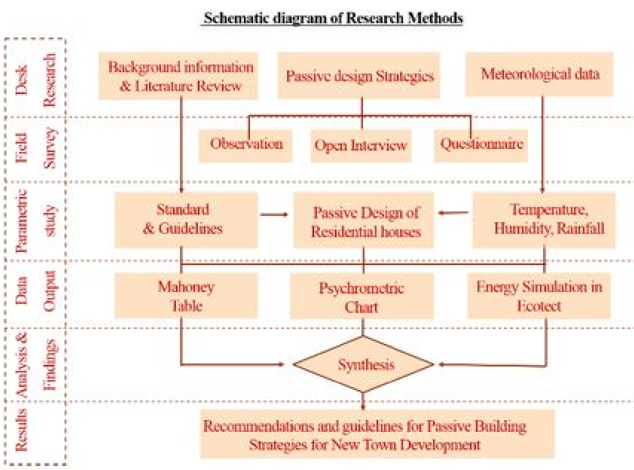

Figure 5: Schematic diagram of Research Methods

5. Data presentation and Analysis

5.1 Analysis of field data

Most of the buildings are oriented in the South direction i.e. 65.4%. Then about 25% of buildings are faced to the North and 9.6% to the East. According to the theory of passive design, in the colder areas, the buildings should be oriented towards south so as to gain the maximum solar radiation for warming the house. Similarly, for the summer areas, the building should be oriented towards the North, to cool the buildings. Thus, the orientations of the buildings are mostly to the south which is not favorable according to the climatic condition of the site area.

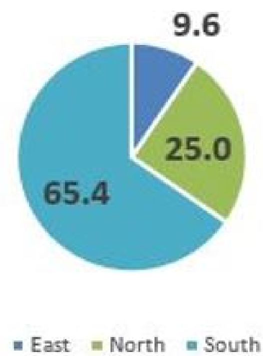

Figure 6: Building by main facade orientation

About 60% of building have window on only one side of the wall, only half of which have windows on the two sides which show that people have problems regarding cross ventilation.

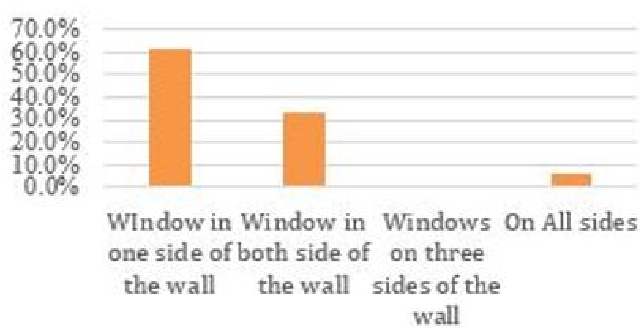

Figure 7: Cross ventilation

From the field survey, it is clear that maximum buildings use CGI sheet in their roof materials and it has been correlated with the energy consumption in the building. The maximum energy consumption is found in the CGI sheet which is shown in the figure 8.

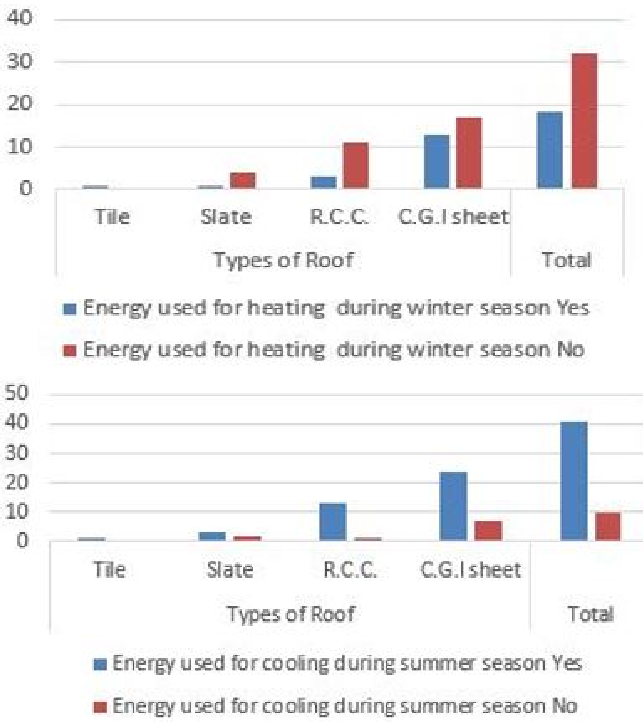

Figure 8: Correlation of roof with energy consumption during winter and summer

In the case of wall, it is seen that the cement bonded brick masonry has higher energy consumption than the mud bonded bricks and Hollow concrete block with cement mortar. Similar is in the case of internal wall in summer and in the winter as shown in the figure 9.

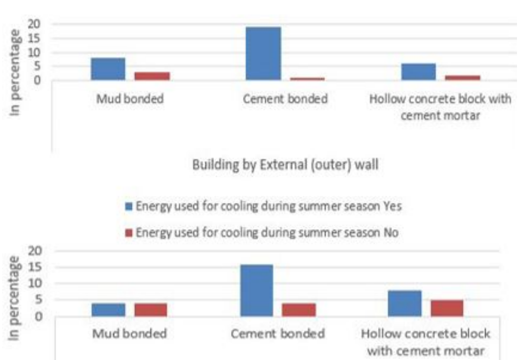

Figure 9: Correlation of wall with energy consumption during summer and winter

5.2 Development of Bioclimatic chart

The Bioclimatic chart was first proposed by Olgyay[6] and later derived by Givoni[7] that provides suggestions for building design considering local climatic conditions. Thus, psychrometric chart has been developed for the Baireni-galchhi for the longitude of 85°1'30" E, latitude of 27°49'40" at an altitude level of 441m. The comfort zone for the winter is found to be 19.5 - 24.5°C and for the summer is 24 - 29°C. In the chart different zones are plotted to indicate different strategies depending upon the monthly temperature humidity relationship. These zones are: ideal comfort zone, passive solar heating zone, air movement effect zone, evaporative cooling zone, mass effect/mass effect with night ventilation and internal gains and shading zone.

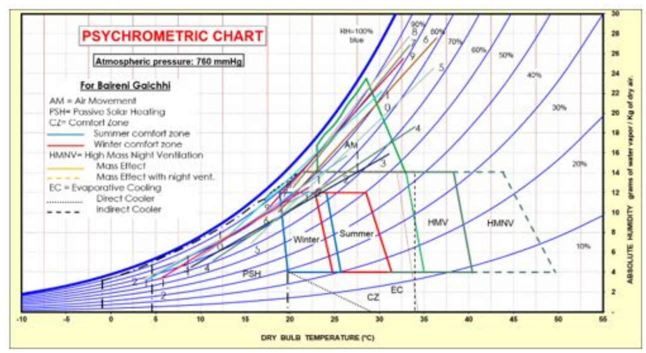

Figure 10: Psychrometric chart

5.3 Development of Mahoney Table

	Layout
1	Orientation north and south (long axis east-west)
2	Compact courtyard planning
	Spacing
3	Open space for breeze penetration
4	As 3, but protection from hot and cold winds
5	Compact layout of estates
	Air movement
6	Rooms single banked, permanent provision for air movement
7	Double banked rooms, temporary provision for air movement
8	No air movement requirement
	Openings
9	Large openings, 40 -80 %
10	Very small openings, 10-20 %
11	Medium openings, 20 -40 %
	Walls
12	Light walls, short time lag
13	Heavy external and internal walls
	Roofs
14	Light, insulated roof
15	Heavy roofs, over 8h time lag
	Outdoor sleeping
16	Space for outdoor sleeping required
	Rain protection
17	Protection from heavy rain necessary

Figure 11: Mahoney Table

Mahoney tables are a set of reference tables used in architecture and used as a guide to climate-appropriate design. It is named after architect Carl Mahoney. It provides more detailed design recommendations based on the analysis of temperature, humidity, wind, precipitation and comfort condition for a given location. It comprises of four tables in total: Data input, Temperature and Humidity diagnosis, list of recommended specifications and list of detailed recommendations.[8]

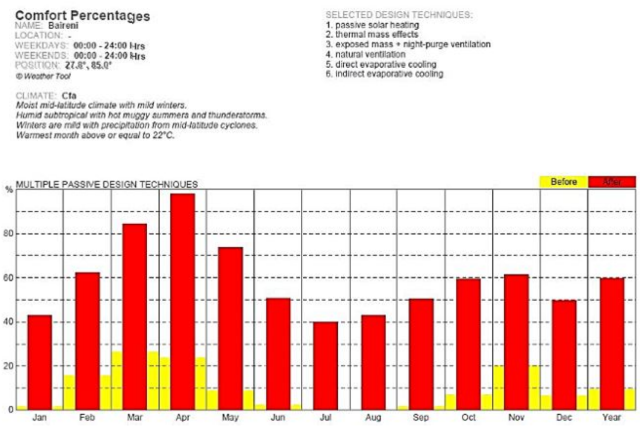

Figure 13: Multiple passive design techniques

5.4 Ecotect Analysis

The Ecotect analysis shows that the annual average orientation should be 150 degrees from the North in the clockwise direction. For the under-heated period, it shall be 170 degrees from the North in the clockwise direction as shown in the figure 12.

The Figure 14 shows that by using the multiple passive design techniques such as passive solar heating, thermal mass effects, exposed mass + night purge ventilation, natural ventilation, direct evaporative cooling and indirect evaporative cooling, we can save energy from (40 -95)%. But, if the passive design techniques are not applied then it can hardly save energy up to (20-25)%.

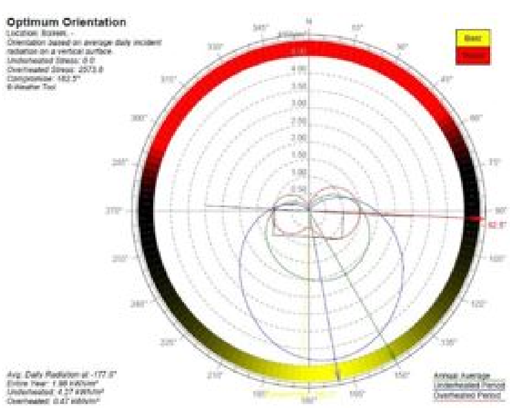

Figure 12: Orientation

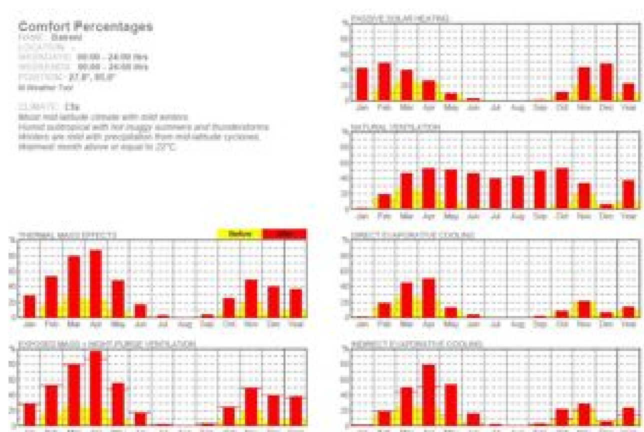

Figure 14: Passive design anlysis in each sector

The Figure 13 shows the individual passive design analysis in six different passive criteria. Among the six criteria, the natural ventilation, thermal mass effect and exposed mass with the night purge ventilation shows the best performance almost all the months. Therefore, these criteria should be considered the most.

5.5 Heating and Cooling Load Analysis

The U-value of materials for the roof, wall and floor materials that are prevalently used for the construction in Baireni-galchhi have been selected and calculated. For the calculation, the conductivity values of the materials are taken from the various literature standards.

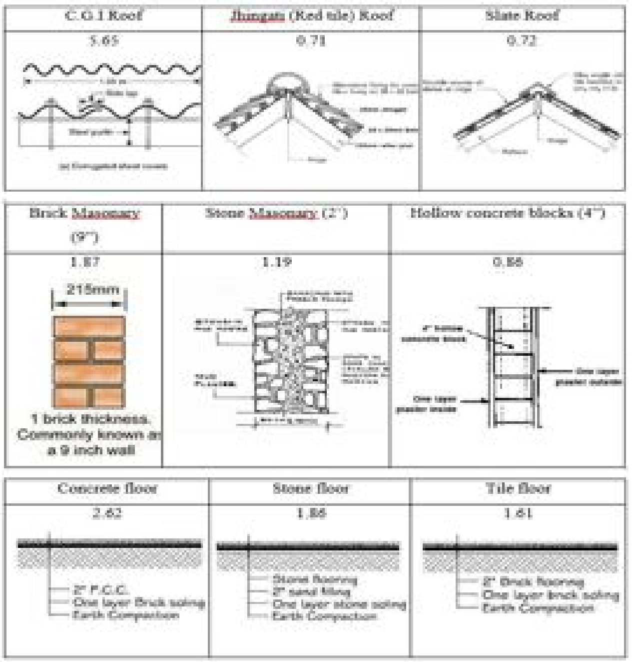

Figure 15: Calculation of U-value of materials

The calculated U-value is used for heating and cooling load calculation to maintain 20°C indoor temperature by creating the scenario I, II and III as shown in the figure 15.

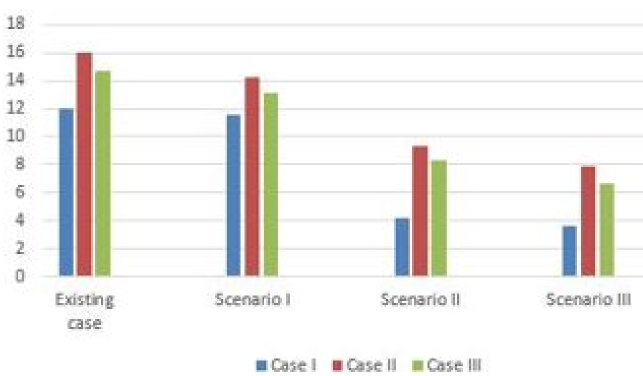

Figure 16: Existing and proposed case of heating load

From the graph 16, it is clear that the scenario I in case I building has 4.15% and scenario II 65.17% and scenario III 69.24% less heating load than the existing case. In the case II building scenario I has 11.2%, scenario II 41.71% and scenario III 50.87% less heating load than the existing case. Similarly, in the case III building, the scenario I has 11.2%, scenario II 43.23% and 54.45% less heating load than the existing case. Therefore, there is reduction in heating load by changing wall, roof and both materials than in the existing case.

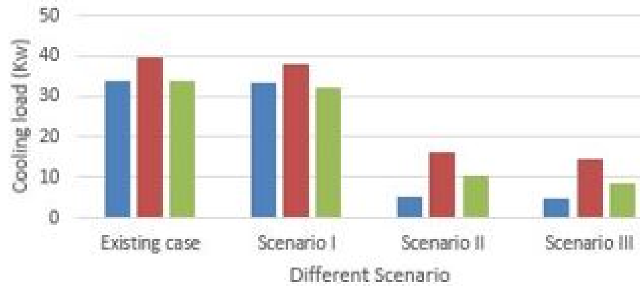

Figure 17: Existing and proposed case of cooling load

From the graph 17, it is clear that, the performance of scenario III is excellent as compared to scenario II, scenario I and existing case. In the case I, scenario I has 1.71%, scenario II 84.5% and scenario III 86.2% less cooling load in comparison to the existing case. In the case II building, the scenario I has 4.04%, scenario II 58.88% and scenario III 62.93% lesser cooling load in comparison to the existing case. Similarly, in the case III building, the scenario I has 4.87%, scenario II 69.02% and scenario III 73.92% less cooling load than the existing case.

In both graphs,
Existing case: Building as usual (without treatment)
Scenario I: By changing wall by H.C.B
Scenario II: By changing roof by slate roof
Scenario III: By changing both wall and roof by HCB and slate roof

5.6 Economic Analysis

The economic analysis has been done for all three building cases for existing and three different scenarios for heating and cooling load. The Baireni-galchhi has three hotter months (January, February and December), four comfortable months (March, April, October and November) and five winter months (May, June, July, August, September). From the survey, the average heating and cooling hours are calculated and for heating two hours per day and for cooling. The calculations are done to maintain indoor air temperature to be 20°C, which is the standard thermal comfort temperature as per the Ashrae[9]). In the calculation, other factors such as infiltration, presence of people, lighting, ventilation, miscellaneous etc. are kept constant. Also, the capital cost has not been considered in the calculation but only the energy cost is included with the increased tariff of electricity to be 3% per annum as obtained from the NEA report [10] and interest rate of 10%. As the building life is assumed to be 40 years, the calculation is done for 40 years and converted into the Net present value (NPV). The cost analysis is shown in the figure 18

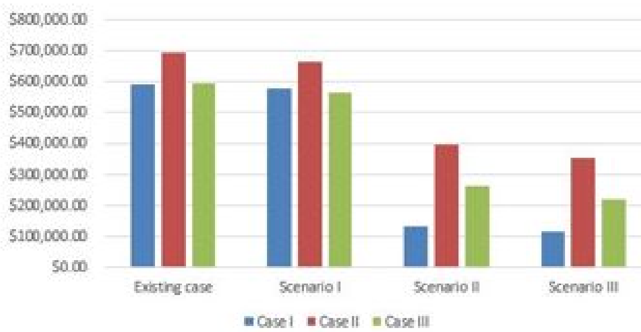

Figure 18: Economic analysis of three building cases

6. Findings and Discussion

The climatic analysis revealed that Baireni-Galchhi has predominantly warm and humid climatic conditions and Bioclimatic chart develops the comfort zone in that area and six different passive approaches that could help to maintain thermal comfortable environment in the building. Various thermal comfort guidelines for the settlement level, building design and building component level are developed which is obtained through the literature review, Field data, participant observation, Bio-climatic chart, Mahoney table and model analysis and simulation through Ecotect analysis. Ecotect analysis has been performed to check the recommendations provided by the Mahoney table and also to check whether the computable model is working or not. The Ecotect analysis is more detailed and specific than the Mahoney table but within the limits specified by the Mahoney table. The results obtained from the above analysis are further compared and finally general to specific recommendations are derived.

7. Recommendation

Recommendations have been made at three levels: settlement level, Building design and Building component.

7.1 Settlement Level

Settlement pattern/morphology
The semi-compact settlement should be preferred with reduced exposed external surfaces. The courtyard planning is preferred where possible.

Site selection
For the hill topography, North slope would be preferred as it would receive least direct radiation for the hill topography. The basin valleys are not recommended for the settlement as it hinders the cool air movement and consumes more energy for heating in the winter.

Street size and Orientation
Street layout should provide maximum shade in summer for pedestrian and minimum solar exposure of the buildings along the streets. Small street width to building height ratio ensures narrow streets and thereby shading. Streets running north-south have better light conditions in winter than east-west streets.

Building type, height and massing
The building height and width ratio (aspect ratio) should be maintained for the proper ventilation and day-lighting. The aspect ratio should be greater than or equal to 2.

Landscape
Tree canopies should be located on the east and west sides of the structure in order to block direct sunlight and permit air movement. Dense low canopy trees should be avoided as they can block breezes and trap humidity.

Building spacing
Spacing of buildings should be at least 5 times their height and sizes of openings should be between 40 – 80% of north and south walls for effective ventilation in warm humid climate.

7.2 Building Design Level

Building orientation and platform
In general, building should be oriented along the East-West axis. i.e. facing north and south. For the specific angle, it should be oriented at 150 degrees from the North in the clock-wise direction.

Outdoor spaces (semi-covered spaces)
Outdoor spaces are must for the warm-humid climate for various purposes like social gathering, outdoor sleeping, household activities etc.

Plan configuration
Square and rectangular planned buildings saves energy in comparison with the other building plans.

Courtyard house
Courtyard houses should be preferred for easy solar access during the winter and enough cross ventilation during the summer.

7.3 Building Component Level

Walls
The material with either low thermal capacity or heavy exterior walls over 8h time lag are preferred. For this, the locally produced materials such as hollow concrete blocks are recommended.

Roofs
The light weight insulated roof having lower U-value is recommended. For the flat roof, the insulation layer should be provided beneath the roof. For the slope roof, either insulation or the attic space should be provided. Cool roof is also preferred that reflects the solar radiation.

Windows size and location
It is recommended to locate the windows at windward side i.e. at the Northern façade of the building and opening height should be at the body height on the windward side. Window sizes should be minimum 15 – 20% of the floor area or 40 – 80% of the main façade area.

Shading device
It is recommended to calculate the shading device to prevent the direct solar radiation from entering the room especially at the South and East direction.

Air movement/ventilation
Buildings should be located on a hill or should be raised above the ground at a 20-40°angle to the prevailing breezes. Rooms should be single banked and there should be permanent provision for the air movement.

Color of External surfaces
Light color have reflective properties with high solar reflectance index (SRI) and helps to decrease the cooling load in the extensive summer. Therefore in hot and humid area, light color especially white is preferred.

8. Conclusion

Energy is the crucial aspect that should be considered for the sustainable development of the nation as buildings consume about 40% of the world's energy use. In this study, the heating and cooling load due to building envelope are considered and recommendations are provided for the minimal modification and general climatic design guidelines for the proposed Baireni-Galchhi were developed which is utmost essential for sustainable social development of new towns. Thus, these guidelines could be used by the architects, designers, planners, contractors and home-owners for the construction of new buildings.

References

[1] Nastaran Shishegar. Residential block configurations and passive solar strategies: Analyzing the impacts of design parameters on outdoor and indoor solar access. *Journal of Buildings and Sustainability*, 2016.

[2] Anir Kumar Upadhyay, Harunori Yoshida, and Hom Bahadur Rijal. Climate responsive building design in the kathmandu valley. *Journal of Asian Architecture and Building Engineering*, 5(1):169–176, 2006.

[3] DUDBC. Planning norms and standard 2013. Technical report, Ministry of Urban Development, 2013.

[4] Nest Pvt. Ltd. Preparation of integrated development plan of khurkot and baireni galchhi new town. Technical report, New Town Project Coordination Office.

[5] Martyn Denscombe. *The good research guide: for small-scale social research projects*. McGraw-Hill Education (UK), 2014.

[6] Victor Olgyay. *Design with climate: bioclimatic approach to architectural regionalism*. Princeton University Press, 2015.

[7] Baruch Givoni. Man, climate and architecture. 1976.

[8] Otto H Koenigsberger et al. *Manual of tropical housing & building*. Orient Blackswan, 1975.

[9] ASHRAE Handbook. Product directory: 1978 applications. *American Society of Heating, Refrigerating and Air Conditioning Engrs., Inc., New York, NY*, pages 58–4, 1978.

[10] NEA. Nepal electricity authority - fiscal year 2016/17. Technical report, Nepal Electricity Authority (NEA), 2017.