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Passive Solar Building Design Strategies in Lalitpur, Pokhara and Dharan cities of Nepal

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Abstract

Passive solar design is the first step toward achieving climate responsive and sustainable building design. With the introduction of modern construction technologies in the country, the building sector has adopted uniform design and building techniques which is neglecting local climate. In this research climatic data of Lalitpur, Pokhara and Dharan cities has been collected and analyzed with the help of Bioclimatic chart and Mahoney table. A bioclimatic approach has been adopted using the psychometric chart in order to identify passive design strategies. Whereas Mahoney table has been used to identify design guidelines from humidity and temperature data. From Mahoney table general design guidelines for each city has been found. This research is focused on reduction of energy use in a building with appropriate design strategies like site planning, building orientation, opening size, construction technique and building materials. After finding appropriate passive solar building design strategies, model design of two and half storey residential building has been proposed for each city. This research also provides checklists for building design. This will support the concerned municipality to sanction the design drawing as per energy conscious and climatic responsive building design.

Keywords

Passive Solar heating – Bioclimatic chart – Mahoney table – Building Design Strategies

1. Introduction

Climate-responsive design is considered to be one of the major requirements to drive the building sector towards sustainable development [1]. Passive solar design never neglects the impact of climate, but can only minimize the climatic effect on built up environment. It is essential to have climatic responsive architecture design based on different climatic zone and its topography.Traditional buildings of ancient Lichchhavi and Malla period of Nepal are good example of passive solar design. In a research it is found that, traditional residential buildings are minimum one to two degree cooler in summer and warmer in winter compared to contemporary residential buildings of Kathmandu valley [2]. As this research project was initiated by UN-Habitat, the research area are Lalitpur, Pokhara and Dharan.

Passive solar design refers to the use of the sun's energy for the heating, cooling, lighting and ventilation of living spaces. Passive solar design integrates a combination of building features to reduce or even eliminate the need for mechanical cooling and heating and daytime artificial lighting, heat in the summer, it does not involve the use of mechanical and electrical devices [3]. The key to design a passive solar building is to take advantage of the local climate performing an accurate site analysis [4]. A passive solar building makes the greatest use possible of solar gains to reduce energy use for heating and cooling. By using natural energy flows through air and materials radiation, conduction, absorption and natural convection.

The Bioclimatic chart, Building Bioclimatic chart and Mahoney tables can be use to analyze climatic parameters. In a bioclimatic chart the climatic elements can be assembled into the single chart. Chart shows the comfort zone in the centre. The bioclimatic approach explores the opportunities to design according to the local climate conditions. Givoni developed a bioclimatic chart based on indoor conditions using the standard psychometric chart. The Mahoney tables provide results of thermal comfort analysis using primarily temperature and humidity data, and recommendations of design guidelines. there are four tables in tota in mahoney tablel [5]. The control potential zone is another graphical method based on the psychometric chart [6], Which has been adopted for making bioclimatic chart in this research. It applies Auliciems' approach of the adaptive thermal comfort and it depends on the location.

Not any strategy for passive building design is available for these three cities. Few authors has identified the climate-responsive design strategies for Kathmandu valley using bioclimatic chart, Mahoney tables and a consideration of the traditional architecture.[7]. Bodach has identified four different bioclimatic zones (warm temperate, Temperate, Cool temperate and cold) using bioclimatic chart [1].

2. Methodology

This study was integrated type with both quantitative and qualitative research. The literature study was done through research reports, journals. After collecting the quantitative data (Temperature, Humidity, Rainfall) from meteorological department the data has been analyzed through the bioclimatic chart and Mahoney table. Based on analysis, model design of residential building is developed referring building orientation, building form, size of openings, sun shading device, building materials etc..

Mahoney tables provide results of thermal comfort analysis using primarily temperature and humidity data, and recommendations of design guidelines. there are four tables in total [5]. In Mahoney table, The monthly mean maximum and minimum temperature data along with corresponding afternoon (PM) and morning(AM) humidity can be tabulated. The Mahoney tables involve six indicators(i.e. , three humidity indicators, H1-H3 and three arid indicators, A1-A3). These indicators are determined by the thermal stress(day and night), rainfall, humidity group and the monthly mean range of temperatures. These indicators for each month of the year are tabulated and used to obtain data which indicate design recommendations.

The method to develop the bioclimatic chart has been adopted from [6]. First of all the psychometric chart has been made in excel. Initially, a range of dry-bulb temperature (T) values is chosen for the abscissa. This range is selected from minus 10 to about 55 degree centigrade. The ordinate of the plot is the absolute humidity (A.H), it is displayed from 0 to 30 (g/kg DA).Then the relative humidity curve(10 – 100 percent) has been plotted.

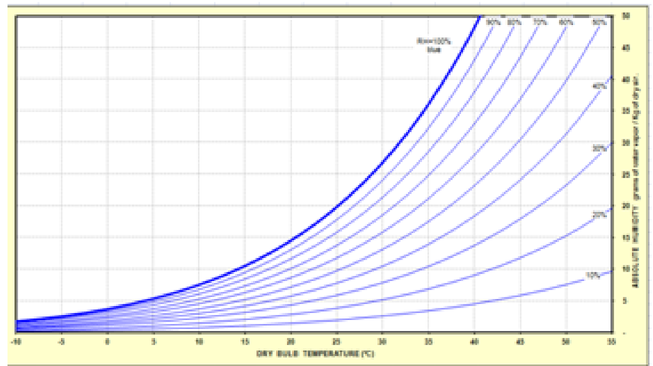

Figure 1: Psychometric chart with Relative Humidity curve

Bioclimatic charts are utilized by first identifying the average monthly condition. For each month, the average of the daily maximum temperature is calculated and matched. With the average of the minimum daily absolute humidity to form the point Likewise, the average of the daily minimum temperature is matched with that of the average daily maximum absolute humidity to form. The placement of the line segment connecting the two points will determine the proper passive strategy for that month. At high temperatures, mechanical air-conditioning is necessary to keep a habitable environment. On the left of the comfort zone (CZ), heating is needed to restore comfort using solar heating if the shift is slight but mechanical heating is necessary if the temperature is too low. The high thermal mass effect is provided by heavy construction that helps absorb heat that would be released overnight. If the weather is hot and dry, night ventilation will help releasing heat through windows, assisted by fans if necessary.

Passive Solar heating zone(PSH), Air movement zone (AM), Winter and summer comfort zone (CZ), High mass night ventilation zone(HMNV), Evaporative Cooling zone(EC) has been identified though the calculation for each city.

3. Analysis, Result and Discussion

Climatic parameters (Temperature and Humidity) of three cities has been analyzed through Bioclimatic chart and Mahoney table. Then the passive solar design strategies has been identified according to the analysis of climatic parameters in Lalitpur, Pokhara and Dharan cities of Nepal.

3.1 Bioclimatic chart for Lalitpur

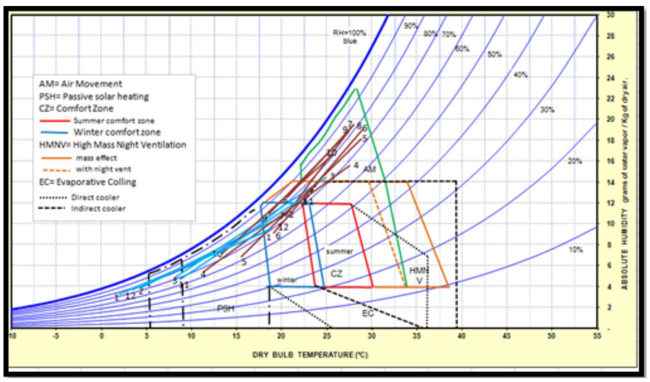

Figure 2: Bioclimatic chart of Lalitpur

By plotting climatic data (Temperature and Humidity) of 10 years [8] of Lalitpur city in the chart, It is confirmed that most of the months are relatively cool and passive solar heating strategies must be incorporated in the design. A short duration of day time temperature in March, April, May and October falls in the ideal comfort zone but night during these months are still cold. A short duration of morning time temperature in June and September falls in the ideal comfort zone. Five months (may to September) are hot, and building design strategies should make provision for air movement. The three months from December to February are the coldest months with the night temperature remaining below 5 degree centigrade. During this period, conventional heating is needed to maintain room temperature when the passive strategies cannot fulfill the heating demand.

3.2 Bioclimatic chart for Dharan

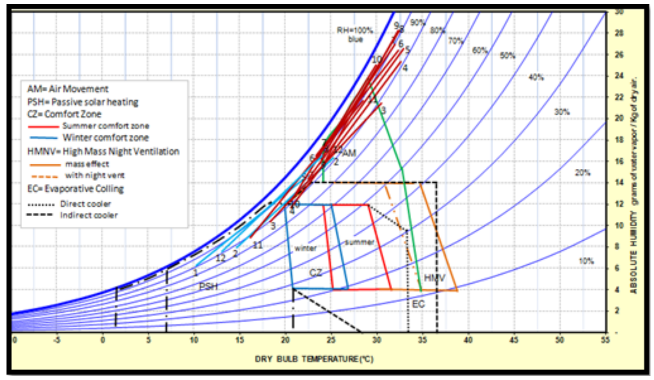

Figure 3: Bioclimatic chart of Dharan

By plotting climatic data (Temperature and Humidity) of 10 years [8] of Dharan district in the chart, It is confirmed that most of the months are hot and air movement must be incorporated in the design. A short duration of morning time temperature in December, January and February falls in the passive solar heating zone but night during these months are still hot. The six months from May to October are the hottest months with the day temperature exceeds more than 30 degree centigrade. During this period, active cooling is needed to maintain room temperature when the air movement cannot fulfill the cooling demand.

3.3 Bioclimatic chart for Pokhara

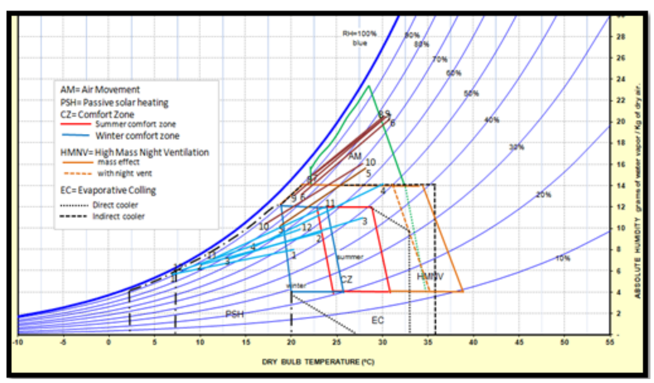

Figure 4: Bioclimatic chart of Pokhara

By plotting climatic data (Temperature and Humidity) of 10 years [8] of Pokhara city in the chart, It is confirmed that most of the months are relatively cool and passive solar heating strategies must be incorporated in the design. A short duration of day time temperature in February, March, April, May and November falls in the ideal comfort zone but night during these months are still cold. Four months (June to September) are hot, and building design strategies should make provision for air movement. The four months from November to February are the coldest months with the night temperature remaining below 10 degree centigrade.

3.4 Design Guidelines from Mahoney table for Lalitpur

- Layout: Orientation north and south (long axis east-West)
- Open spaces for breeze penetration, but protection from hot and cold wind
- Air movement: Rooms single blanked permanent provision of air movement
- Openings: Medium Openings, 20-40 %
- Position of Openings: In north and south walls at body height on windward side
- Protection of openings: Protection from rain
- Walls and floors: Light, Low thermal capacity
- Roofs: Light, well insulated
- External features: Adequate rainwater drainage

3.5 Design Guidelines from Mahoney table for Pokhara

- Layout: Orientation north and south (long axis east-west)
- Spacing: Open spaces for breeze penetration, but protection from hot and cold wind
- Air movement: Rooms single blanked permanent provision of air movement
- Openings: Medium Openings, 20-40 %
- Position of Openings: In north and south walls at body height on windward side
- Protection of openings: Protection from rain, Exclude direct sunlight
- Walls and floors: Heavy, over 8h time-lag
- Roofs: Light, well insulated
- External features: Adequate rainwater drainage

3.6 Design Guidelines from Mahoney table for Dharan

- Layout: Orientation north and south (long axis east-west)
- Spacing: Open spaces for breeze penetration, but protection from hot and cold wind
- Air movement: Rooms single blanked permanent provision of air movement
- Openings: Large openings, 40–80 %
- Position of Openings: In north and south walls at body height on windward side
- Protection of openings: Protection from rain, Exclude direct sunlight
- Walls and floors: Light, Low thermal capacity
- Roofs: Light, well insulated
- External features: Adequate rainwater drainage

3.7 Passive Solar Building Design strategies for Lalitpur and Pokhara

After analyzing the climatic parameters through Bioclimatic chart and Mahoney table, following strategies has been proposed for Lalitpur and Pokhara city.

- Site Planning: compact planning with deciduous trees in East and west direction.
- Building Orientation: Building should have E-W elongated plan.

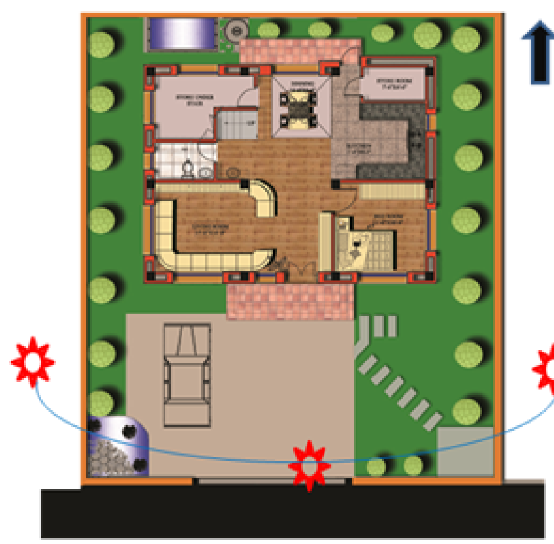

Figure 5: Example of Site plan in Lalitpur and Pokhara

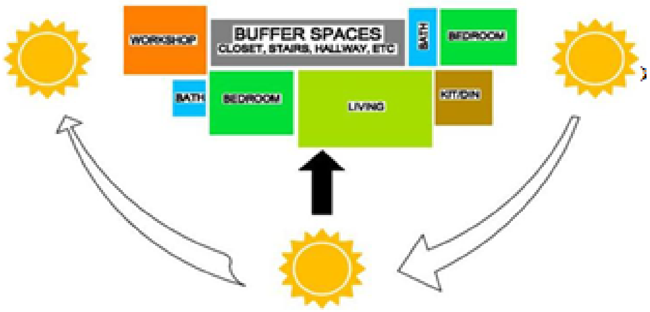

Figure 6: Living spaces, bed room, and kitchen, for sunlight in southern side and passage, stair, buffer spaces in northern side

- Building form: Open elongated rectangular plan with rooms having diagonal cross-ventilation.
- Opening: Opening should be located in such a way that, the circulation of air in a building is increased by natural means. Opening size should be 20-40 % of floor area.
- Material and Technology: Materials and technology of wall, roof, floor and partition should have maximum time lag with low U value. Heavy walls with high thermal capacity and large time lag is recommended.
- Shading devices: should exclude the direct sunlight. So it is necessary to design shading devices in a building to protect the summer Sun. There should be minimum of 2’9” inch of projection to avoid direct sunlight.

Figure 7: Perspective view of proposed building in Lalitpur

Figure 8: Perspective view of proposed building in Pokhara

3.8 Passive Solar Building Design strategies for Dharan

Analysis of climatic parameters Through Bioclimatic chart and Mahoney table, following strategies has been proposed.

- Site Planning: compact planning with deciduous trees in East and west direction.

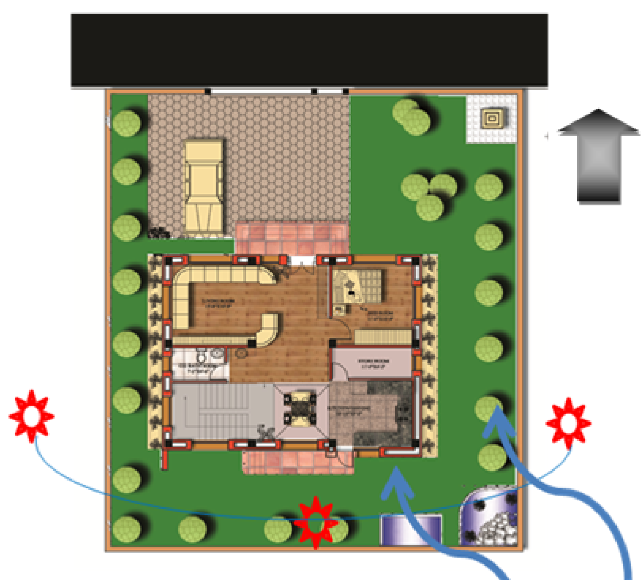

Figure 9: Example of site plan in Dharan

- Building Orientation: Building should have E-W elongated plan. Orientation of building should be away from Sun for cooling purpose during long hot season in Dharan. It is better to maximize building face towards north, north east and northwest for living spaces. Living spaces like bed, living, kitchen, dining, etc. must be located towards north direction. Main living spaces and openings locate away from Sun light. It is better to locate buffer spaces like stair, bath, passage, balcony in south and south west. Maximum intensity of sun light focuses from south and south west direction during 12 noon to 6 evening. So the bad orientation is south west for living spaces.

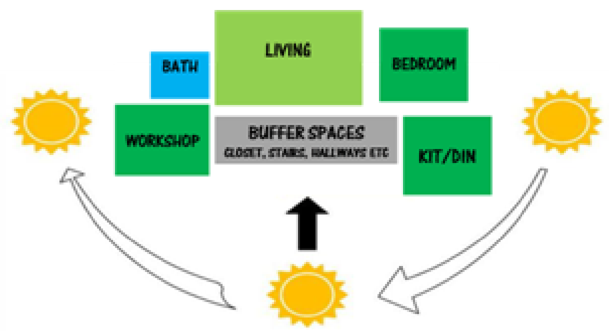

Figure 10: Living spaces, bed room, and kitchen, to avoid sunlight in Northen side and passage, stair, buffer spaces in southern side

- Opening: Opening should be located in such a way that, the circulation of air in a building is increased by natural means. Opening size should be 40-80 % of floor area. It is recommended to provide 8' lintel height with ventilation to ventilate hot air from the room. Stack ventilation effect is recommended in Dharan city.
- Building form: Building form is better to have open elongated rectangular plan with rooms having diagonal cross-ventilation. Building long wall with openings should face towards windward direction. Floor height should be as high, more than 10 feet as to escape hot air.
- Material and Technology: Materials and technology of wall, roof, floor and partition should be constructed in such a way that it should have maximum time lag with low U value. Building materials for wall recommended for the Dharan city is Cavity wall construction with 4" exterior and interior Brick wall with 8" air cavity which has 1.61 U-value and large time lag. Concrete hollow block or soil cement block also can be used.
- Shading devices: Shading devices should exclude the direct sunlight. So it is necessary to design shading devices in a building to protect from direct sunlight. There should be minimum of 2'9" inch of projection to avoid direct sunlight.

Figure 11: Perspective view of proposed building in Dharan

3.9 Summary

Checklist for passive solar building design strategies for Lalitpur, Pokhara and Dharan cities has been summarized in a single table and the comparison of U-value and cost of different building materials has also been done.

Table 1: Comparison of U-value and cost of different Building materials (Source: [9, 10, 11] and Author's calculation)

Wall material	Heat transfer coefficient ,U-value (W/m².C)	Cost Rs. (per sq.m)	Remarks
Brickwork			
9" Brick	1.96	3000	-
Cavity wall (4"brick+8"cavity+4"brick)	1.61	3300	Recommended in Lalitpur city as brick is easily available
Rat trap bond	N.A.	1800	-
Concrete hollow block(8")	2.89	1545	Recommended in Dharan city
Soil cement Stabilized block	1.61	2500	Recommended in all city as it has lower U-value and lower cost

Table 2: Checklist and Toolkit for passive Building Design Model for Dharan, Lalitpur and Pokhara

Features	Dharan	Lalitpur	Pokhara
Site planning	Water bodies at S-W corner, Deciduous trees at East & west	Deciduous trees at East & west	Deciduous trees at East & west
Building orientation	E-W direction	E-W direction	E-W direction
Opening size and location	(40-80)% of floor area, maximum at north with cross ventilation	(20-40)% of floor area, maximum at South with cross ventilation	(20-40)% of floor area, maximum at South with cross ventilation
Lintel height	8' with ventilation	7' without ventilation	7' without ventilation
Building form	E-W elongated	E-W elongated	E-W elongated
Material & technology	CHB or soil cement stabilized block or Brick wall with 8" cavity or Slope roof or flat roof with insulation	Brick wall with 8" cavity or CHB or soil cement stabilized block Slope roof or flat roof	Stone wall with 6" cavity or CHB or soil cement stabilized block Slope roof or flat roof
Shading device projection	2'9"	2'9"	2'9"
Building envelope, texture and color	Light, wall texture , smooth finishing	Light, smooth finishing	Light, smooth finishing
Flooring	Marble, tile	wooden	wooden
Floor height	10'	9' 5"	9' 5"
Terrace garden	Most	Recommended	Recommended

4. Conclusion

The following conclusions have been drawn from this research:

- Bioclimatic chart of Lalitpur (Figure 2) shows that most of the months are relatively cool and passive solar heating strategies is must. Five months (May to September) are hot, and building design strategies should make provision for air movement. Mahoney table of Lalitpur also suggests for single blanked rooms with permanent provision of air movement. Three months from December to February are the coldest months, During this period conventional heating is needed to maintain room temperature when the passive strategies cannot fulfill the heating demand. Other design guidelines from Mahoney table are East-West elongated plan, Open spaces for breeze penetration but protection from hot and cold wind, medium opening size(20-40 percent) etc...
- Bioclimatic chart of Dharan (Figure3) shows that most of the months are hot and air movement is must. The six months from May to October are the hottest months, during this period active cooling is needed to maintain room temperature when the air movement cannot fulfill the cooling demand. Design guidelines from Mahoney table are East-West elongated plan, Open spaces for breeze penetration but protection from hot and cold wind, large opening size(40-80 percent) etc...
- Bioclimatic chart of Pokhara (Figure4) shows that most of the months are relatively cool and passive solar heating strategies is must. Four months (June to September) are hot, and building design strategies should make provision for air movement. The four months from November to February are the coldest months with the night temperature remaining below 10 degree Centigrate. Design guidelines from Mahoney table are East-West elongated plan, Open spaces for breeze penetration but protection from hot and cold wind, medium opening size(20-40 percent) .
- By combining results from both bioclimatic chart and Mahoney table, passive building design strategies has been proposed and then two and half storey residential model has been proposed for each city.
- In a bioclimatic chart of Lalitpur, Only a short duration of few month lies in comfort zone if we don't do anything to achieve comfort. While in case of Dharan there is no comfort level inside the building unless we apply passive solar building design strategies. And in Pokhara, Only a short duration of few month lies in comfort zone. So, to get the comfort level inside the building we should follow passive solar building design strategies. Then, ultimately this comfort level inside the building reduces the electric bill as we don't need fan, room heater. So, It is recommended to all the owners to follow the Passive solar building design strategies while constructing the buildings. Passive building though have slightly higher initial cost(5-10 percent) than contemporary building as it adds the cost for materials and technology but in the long run passive building are less costlier than contemporary modern building.

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