Proceedings of 12th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2022 Month: October Volume: 12

Climate Responsive Residential Architecture in Dhading

Jyoti Dhamala [a], Sushil Bahadur Bajracharya [b]

[a, b] *Department of Architecture, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] 076march006.jyoti@pcampus.edu.np, [b] sushil.bajracharya@puc.tu.edu.np

Abstract
Climate responsive design is considered to be one of the major requirements to drive the building sector towards sustainable development. Elements like air temperature, relative humidity, wind, irradiation, and rainfall these elements affect the climate responsive design of a certain region. Nepal has high varying topography which is leading to a variety of climatic conditions within short distance. With the introduction of modern construction technologies introduced in the country, the building sector has adopted uniform design and building techniques which is neglecting local climate and rely on energy intensive mechanical means to provide comfort within the building. For the study primary quantitative and qualitative field data and secondary quantitative climate data was collected from Department of Hydrology and Meteorology and developed bioclimatic chart and Mahoney table which gives the different design strategies for Dhading. This paper reviews examples of traditional and modern residential architecture and its building features in Dhading and analyses in a qualitative manner. Climatic data from Dhading shows that most of the month in a year are hot. From bioclimatic chart it was found that the summer temperature is high in day time hence passive cooling strategies are recommended. From Mahoney table also heavy walls and roof with permanent provision of air movement is recommended. From the study it was found that traditional building have less indoor air temperature but have high indoor humidity level. However traditional building materials and design features applied in Dhading are climate responsive than contemporary buildings.

Keywords
Climate responsive, residential building, climate, air temperature, humidity

1. Introduction

Climate responsive architecture is defined as architecture aimed at achieving occupant thermal and visual comfort with little or no recourse to nonrenewable energy sources by incorporating the elements of the local climate efficiently [1]. One of the essential requirements for guiding the construction sector toward sustainable development is climate-responsive design [2]. Climate responsive design uses climatic elements in formulating design approaches. The greatest use of climate elements like air temperature, relative humidity, wind, irradiation and rainfall can reduce the heating and cooling energy within buildings. Buildings are designed to achieve and produce an environment that is comfortable for people [3]. As a result, this refers to architecture that preserves the ecosystem of which it is a part while minimizing its adverse effects on the environment.

Buildings are now the world's biggest energy consumer and are crucial to attempts to combat climate change. Buildings consume an unexpectedly large 40 percentage of the world's energy, and the accompanying carbon footprint is much more than that of all forms of transportation combined [4]. This percentage will rise to more than 50 percentage if the energy used in the production of building materials like glass, cement, aluminum, and steel is taken into account. Energy demand in the building sector has increased by 2 percentage annually due to urbanization and wealth growth in developing nations and sub-urbanization in industrialized nations [5]. In Nepal, the residential sector alone consumes 89 percent of the total energy consumption, which is large attribute [3].

Buildings with high levels of energy efficiency improve the living conditions for occupants while minimizing their negative effects on the environment. On the other hand, the fundamental principle of climate responsive design is the assessment of climatic influence and the enhancement of building environmental performance [6]. In other words, trying to cooperate with the external climate to reduce resource consumption and negative environmental impact. So, without sacrificing contemporary living standards, climate responsive architecture can significantly contribute to lowering building energy use [6]. Truly, a building's ability to respond to climatic elements like wind and sun affects how comfortable its occupants feel within. Consequently, there is a relation between sustainability and climate responsive design, as both aim to reduce on active energy use while providing residents of the building with comfort [7]. Additionally, the usage of climate responsive design would be able to go further steps in sustainability and minimize energy consumption which is a nowadays discussion.

The climate of a given region plays a great role in building design. In order to design a building responding to environment all factors that effect on the external environment as well as all aspects of internal environment should be considered [8]. Potential saving of energy can be gained by activating specific, energy-efficient technologies but more so through careful design of urban environments and individual buildings: all naturally occurring resources should be integrated into planning and building and in such a way that their location, form and structure promote energy saving [9]. Many vernacular techniques of traditional architecture of Nepal are energy efficient and sustainable, though none of them is used in today's modern building design. Regrettably many traditional architectural values into designing with climate have been gradually lost in contemporary architecture [10].

The objective of the study is to study climate responsive design features and analyze climate responsive design strategies adopted in residential architecture in Dhading.

2. Methodology

The study was done in traditional and modern buildings located in Dhading. In order to fulfill the objective, this paper has adopted quantitative and qualitative method. For primary data indoor and outdoor air temperature and humidity were recorded for 32 days in the month of May and June. As secondary quantitative data, climatic data (air temperature, relative humidity and rain fall) of 10 years (2012-2021) were collected from Department of Hydrology and Meteorology of Dhading. The collected data has been analyzed through the bio-climatic chart and Mahoney table. Monthly data of minimum and maximum relative humidity and temperature are plotted onto the chart for each month in bio-climatic chart. The Mahoney table methodology is a set of reference tables that use monthly climate data of temperature, relative humidity and precipitation to calculate indicators for heat and cold stress as well as humid and arid conditions for each month [11]. The recommendation from the Mahoney table and bio-climatic chart were critically examined and compared with the design features and limitations of studied residential buildings.

In next step both traditional and modern residential buildings were analyzed in respect to their design and construction to determine the applied climate-responsive design strategies. For the analysis of residential building the approach of [11, 12, 13] was adapted. All these study use a set of building features to analyze the design and construction techniques of buildings in regard to climate responsiveness. Also the recorded indoor and outdoor air temperature and humidity were compared within the studied buildings.

2.1 The study area

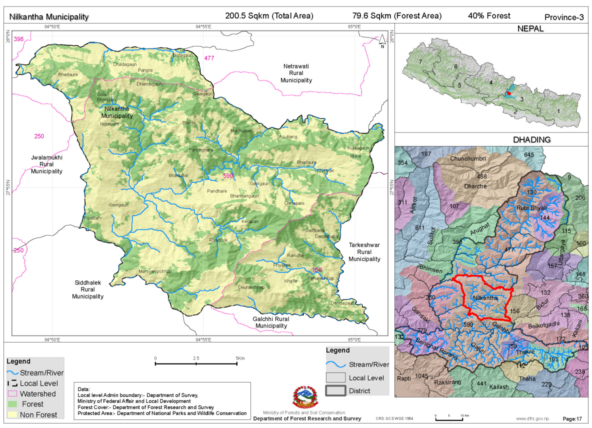

Figure 1: Location map of study area

source: https://nepalindata.com/resource/Local-Resource-Map—Nilkantha-Municipality/

In order to fulfil the defined objective, the study area has be chosen in such a place where there is ample numbers of traditional as well as modern residential buildings for investigation of climate responsiveness of buildings. The study area is in Pipley, ward number 7 of Neelkantha municipality, Dhading where most of the people are of Brahman. Most of the building within the study area used to be of timber and mud mortar- stone buildings before 2015 earthquake. But after earthquake the trend of cement mortar-brick and RCC type of building construction is rapid ("Ward Profile").

2.2 Measurement of air temperature and humidity

The measurement of air temperature and humidity has been recorded to access the climate responsiveness of residential building in Dhading. For the comparison both traditional and modern houses are taken for study. The study was conducted from May 5 to June 23, which is one of the hottest month throughout the year. Three different time readings were taken i.e. morning 7AM, day 2PM and evening 7PM. For temperature recording digital thermometer were used which also show the humidity level. The thermometer was place at 5ft. height from floor level. The thermometer was placed in such a place that it was not directly in front of openings or any kind of heat generating sources in the room.

2.3 Investigated buildings

In total nine houses were selected for case study. Out of nine, five of them are traditional houses where as four were recently built modern houses. As a house code 'T' is used for traditional and 'M' as modern building. All the traditional houses were built before 2050 B.S., whereas all modern houses were built after 2015 Gorkha earthquake.

2.4 Climate of Dhading

Ten years (2012-2021) data of temperature, humidity and rain fall was collected from Department of Hydrology and Meteorology. According to last ten years data, the climate is generally warm from March to October during day time. The summer months have a mean maximum outdoor air temperature 31.5°C during day and maximum at night is about 22.4°C. The cool season lasts from November to February. The mean minimum outdoor temperature is 6.9°C in winter month of December, with mean high with 18.9°C in daytime of same month. It has composite climate which changes from season to season, altering between longer hot periods to cool period and

Table 1: Summary of investigated houses

Design features	Houses	
	Traditional	Modern
Settlement pattern	Scattered	Scattered
Building form	Rectangular floor plan	Rectangular floor plan
Building orientation	West	West
Building stories	Two- two and attic floor	Two-two and half floor
Internal space arrangement	Ground floor: Kitchen, sleeping First floor: Sleeping, storage Attic floor: Storage	Ground floor: Rental, sleeping First floor: Sleeping, living Top floor: Kitchen
Semi-open space	Shaded veranda	Veranda and balcony in upper floor
Wall material	Stone and mud with mud plaster in front facade	Brick and cement wall with cement plaster
Wall thickness	0.45	0.127
Roof material	Pitched roof of slate	RCC flat roof
Floor and ceiling	Wooden structure with lathwork and mud covering	RCC
Average opening percent	6.36	16.23

Figure 2: Sample of investigated traditional and modern residential buildings

concentrated rainfall. The total rainfall is more than 1451 mm in a year. But mostly rainfall occurs during

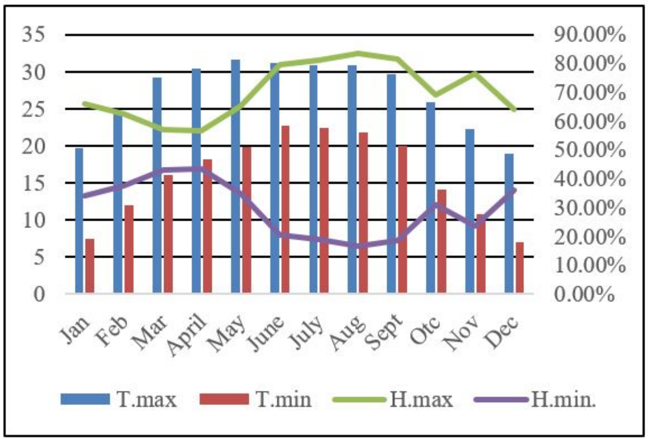

Figure 3: Mean temperature and relative humidity of Dhading

only monsoon season. The yearly average maximum relative humidity is more than 70 percentage during monsoon period (June, July, August and September) in the last ten years (2012-2021) according to Meteorological Department of Government of Nepal.

3. Data Presentation and Analysis

3.1 Air temperature and humidity in traditional houses

In the figure below indoor temperature and humidity of the investigated traditional houses are presented. During investigation it was found that T3 house has highest 26.41°C indoor temperature, whereas T2 house has lowest 25.39°C temperature. But T2 house has highest humidity level with 87 percent, whereas T1 has minimum level of humidity with 84 percentage. The average indoor temperature difference of investigated houses is 1.02°C and humidity differences is 3percentage which is between house T3 and T2 and T2 and T1 respectively. The average outdoor temperature of the day was 28.05°C. In an average the indoor and outdoor temperature differences was 2.05°C. The average indoor humidity level is high with 3 percentage.

3.2 Air temperature and humidity in modern houses

In investigated modern houses the temperature and humidity level of 32 days are plotted in graph above. During the investigation it was found that M1 house

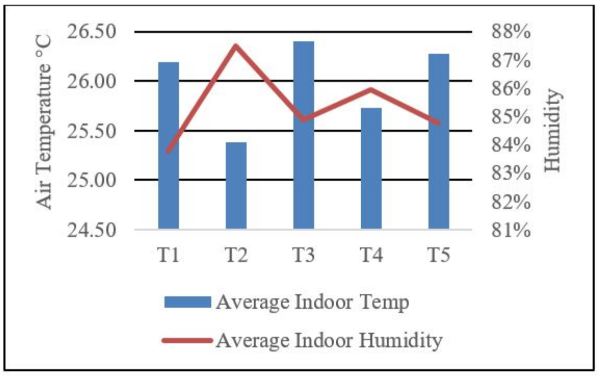

Figure 4: Average indoor temperature and humidity of traditional houses

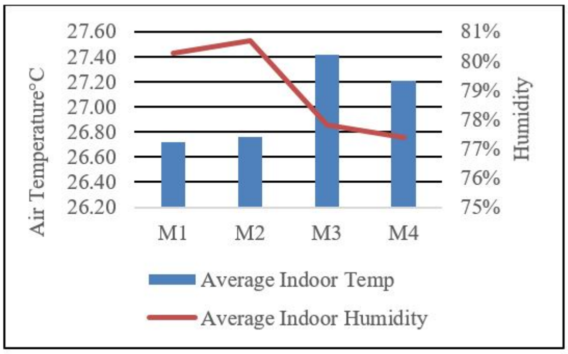

Figure 5: Average indoor temperature and humidity of modern houses

has lowest average indoor temperature with 26.72°C and maximum of house M3 with 27.41°C. The average indoor humidity level was high in M2 house with reading 81 percent and low of house M4. The differences of highest and lowest average temperature and humidity level was between house M1 and M3 with reading 0.69°C and M2 and M4 with 4 percent respectively. In an average outdoor and indoor temperature difference in modern building was 1.12°C. The average indoor humidity level was high with 2 percent than outdoor humidity level in modern building.

3.3 Comparison of indoor air temperature and humidity in traditional and modern house

The collected data of temperature and humidity was compared between traditional and modern house. In the chart below all traditional houses have less indoor average temperature than modern house. The minimum indoor temperature was in morning time which is recorded at 7AM and the highest is during day time which is recorded at 2PM. In morning time there is 0.08°C indoor temperature differences between modern and traditional houses which is negligible. In day time the indoor temperature differences was 1.05°C. Likewise in the evening time the indoor temperature differences is 0.9°C. In an average indoor air temperature of traditional building was 26°C and average indoor air temperature of modern buildings was 27.03°C. The average air temperature difference between modern and traditional house is 1.03°C. This show that traditional houses are cooler than modern houses. During the

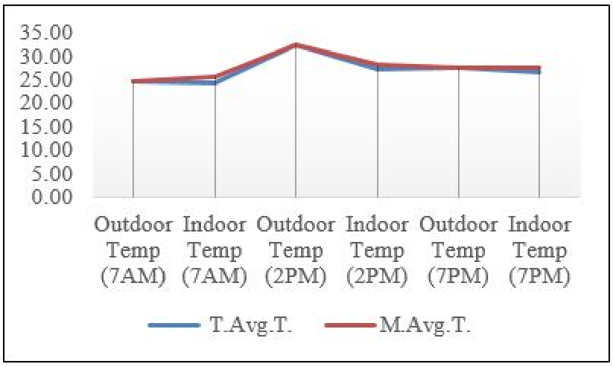

Figure 6: Average temperature of traditional and modern houses

investigation it was found that the average indoor humidity level was high in traditional buildings than modern houses by 2 percentage. The average indoor humidity level in traditional building was 81 percentage and 79 percentage in modern building. In morning and evening time the humidity level was high in both indoor and outdoor. The differences in humidity level in modern and traditional houses was up to 7 percentage in morning and evening time.

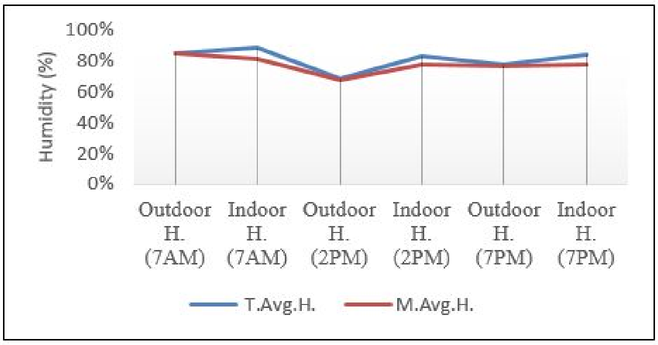

Figure 7: Average humidity of traditional and modern houses

3.4 Mahoney table for Dhading

The recommendations from Mahoney table provide preliminary design recommendations. From the data available from Department of Hydrology and Meteorology of ten years, Mahoney table was developed for Dhading. The Mahoney table suggest that the orientation of building should be north and south (long axis east-west) direction. Single blanked room with permanent provision of air movement is essential. Medium opening with 20-40 percentage is recommended in north and south wall at body height on windward direction. The opening should be protected and adequate rainwater drainage features should be applied for heavy rain.

3.5 Bioclimatic Chart for Dhading

By plotting climatic data of Dhading in the chart, it shows that most of the months are relatively hot and passive cooling strategies must be incorporated in the design. Day time temperature in October and February falls in the ideal comfort zone but night during these months are still cold. A short duration of night time temperature in May to September falls in the ideal comfort zone. Six months (April to September) are hot and humid, and building design strategies should make provision for air movement. For the month of January and December solar passive heating is required. In this month night temperature remaining below 12°C, where month of January and December temperature come close to 8°C. To maintain room temperature in this period the passive heating strategies should be applied.

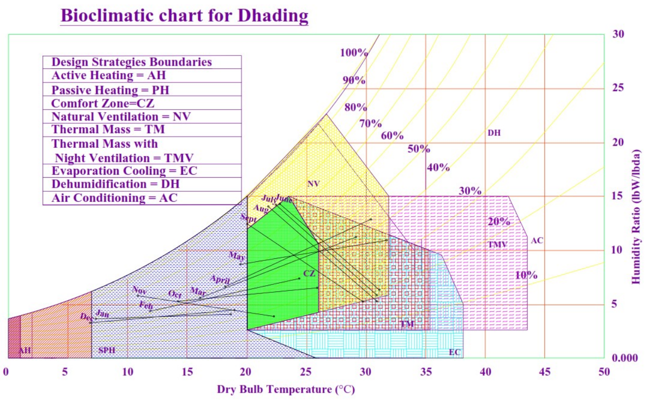

Figure 8: Givoni's Bioclimatic chart for Dhading

3.6 Climate-responsive design strategies applied on investigated houses

Residential buildings both modern and traditional were studied as a part of climate responsive architecture in Dhading. In table below climate-responsive or solar passive design strategies parameters which were identified from literature reviews were checked in individual buildings. After studying the result are shown in following table. '+' applied, '±' partially applied, '-' not applied

Table 2: Climate responsive design strategy applied in investigated houses

Climate responsive design strategy	Recommendation	Traditional houses	Modern houses
Layout	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	±	-
Opening	Medium openings,20-40 percentage	-	-
Walls and floors	Heavy external and internal walls	+	-
Rain protection	Protection from heavy rain necessary	±	-
Position of opening	In north and south walls at body height on windward side	-	±
External features	Adequate rainwater drainage	±	±

4. Discussion

Climate data of 10 years (2012-2021) available from Department of Hydrology and Meteorology shows that seven month from March to September, the maximum average temperature remains above 29°C. The primary data was collected in month of March and June for 32 days. The average maximum and minimum outdoor temperature measured during field study was 32.6°C and 24.52°C. The average maximum and minimum outdoor temperature was 31.36°C and 21.29°C for the month of May and June as per Department of Hydrology and Meteorology. The average maximum humidity for the month was 72 percentage as per data available from Department of Hydrology and Meteorology and as per field recorded data, the average humidity was 77 percentage.

Investigation done in traditional houses shows that average indoor temperature was 26°C. During day time when the average outdoor temperature was 32.33°C, indoor temperature was 5.25°C cooler than outdoor temperature. In an average inside of traditional houses are 1.05°C cooler than outdoor. According to Rijal, Yoshida [14] the study done including Dhading, the comfort temperature is 15.2°C to 25.6°C for winter and summer in temperate region. However a study done by Lamsal, Bajracharya [3] shows that comfort temperature in temperate climate rage between 22.8-27.8°C and 18.5-23.5°C for summer and winter respectively. The average indoor temperature is very close to upper limit of comfort temperature. However the average indoor humidity is 81 percentage which makes indoor environment not comfortable. This result shows that in traditional houses natural ventilation is very essential during summer season. Likewise, in modern houses the average indoor average temperature was 27.03°C. In day time the average indoor temperature was 28.13°C, which is less than 4.25°C than outdoor air temperature. The average outdoor humidity was 77 percentage and which is less than 3 percentage indoor humidity level. In modern buildings the indoor temperature and humidity level is above the comfort level.

The indoor temperature in traditional building is less by 1.03°C but humidity level is high by 2 percentage. This shows more than 10 percentage energy can be saved for cooling in traditional houses [14]. The investigation done in Dhading shows that, both types of houses are not comfortable in summer season. This shows that in both types of building design intervention is needed to achieve comfort within the buildings. The bioclimatic chart for Dhading shows that natural ventilation is very essential for five month i.e. May, June, July, August and September. These are the hottest month of the year in Dhading according to climatic data also. The humidity is high in these months. Also short period of day, natural ventilation is essential in the month of March and April. For the month of December and January, solar passive heating is essential. Also in October and November, majority time are cold hence passive heating is needed. Mahoney table also suggest that from June to September, air movement is essential. Protection from cold is essential for the month of November, December and January. According to Mahoney table rain protection is needed for the month of June, July and August which is peak monsoon time as per climatic data of Dhading.

During the investigation it was found that, climate responsive design strategies were fully or partially followed by traditional houses more than modern houses. All the building has rectangular floor plan facing west as per nature of the land terrace. To orient longer axis east-west direction as suggested by Mahoney table, site intervention is required.

In traditional buildings the semi open veranda in ground and first floor level helps to shade the front (west) façade from direct heat gain in the building. Generally, houses in this climate are of high thermal mass using locally available materials like stone, mud, timber and bamboo. Particularly, during sunny winter days the thermal mass is favorable to store solar heat gains of the day for cooler nights [11].

The material used in contemporary buildings are kiln burnt bricks, cement, sand, reinforcement bars etc which are very energy intensive and not environmental friendly [15]. The external wall in most of houses are very thin (five inches), from which heat loss and gain in winter and summer is very high. In contemporary building there are open veranda which shade the lower portion of the wall/ floor but during summer season these area gain so much heat that it is inhabitable during day time. The opening size of traditional houses are small and are only on longer façade. But in modern buildings the size of openings are huge and can be observed in most of the direction. From the study it can be said that the percentage of opening (area wise) in modern buildings seems close enough as suggested from Mahoney table. But still there is lack of cross ventilation system in modern building.

5. Conclusion

Climate responsive building design has become the growing issue for researcher all over the world for achieving indoor comfort and saving active use of energy. Climate-responsive design is considered to be one of the major requirements to drive the building sector towards sustainable development. Elements like air temperature, relative humidity, wind and rainfall these elements affect the climate responsive design for that region. The research has presented the result and findings of air temperature and humidity in the field regarding the indoor and outdoor environment of the traditional and modern houses in Dhading. The research from the field study shows that traditional houses are 1.03°C cooler than modern houses. Traditional architecture considers local climate and is in consonance with climate responsive design strategies recommended by Mahoney's table and bioclimatic chart such as high thermal mass, open spaces for breeze penetration, single blanked, heavy walls and roofs etc. in Dhading.

6. Recommendations and Further Works

It is recommended to researchers to incorporate air temperature and humidity of all four season to validate research more accurately. Further work can be carried out by incorporating macro and micro climatic factors like radiations, local wind directions etc. During the field visit it was found that most of the traditional building lack maintenance, hence those who inhabit are recommended to carry out regular maintenance work. For designer it is recommended to use locally available materials. Also the position, area of opening and air tightness in traditional buildings are highly recommended.

References

[1] Simos Yannas. Towards environmentally-responsive architecture. In *Proc. PLEA*, 2003.

[2] Steven Szokolay. *Introduction to architectural science*. Routledge, 2012.

[3] Prativa Lamsal, Sushil B Bajracharya, and Hom B Rijal. Guidelines for climate responsive building design in three regions of nepal. *Journal of Building and Environmental Engineering*, 2(1):63–74, 2021.

[4] WBC WBCSD. Energy efficiency in buildings: Transforming the market, 2009.

[5] Trevor Houser. The economics of energy efficiency in buildings. *Transport*, 1(5):6, 2009.

[6] Richard Hyde. *Climate responsive design: A study of buildings in moderate and hot humid climates*. Taylor & Francis, 2013.

[7] Parinaz Motealleh, Maryam Zolfaghari, and Mojtaba Parsaee. Investigating climate responsive solutions in vernacular architecture of bushehr city. *HBRC journal*, 14(2):215–223, 2018.

[8] Y Lavaf Pour and M Surat. Towards new approaches for converting principles of vernacular architecture into energy efficient buildings in hot and dry climates. *Journal of Building Performance*, 2012.

[9] Holger Koch-Nielsen. *Stay cool: a design guide for the built environment in hot climates*. Routledge, 2013.

[10] Hom Bahadur Rijal. *Nepal: Traditional Houses*, pages 59–66. Springer Singapore, Singapore, 2018.

[11] Susanne Bodach, Werner Lang, and Johannes Hamhaber. Climate responsive building design strategies of vernacular architecture in nepal. *Energy and Buildings*, 81:227–242, 2014.

[12] Zhiqiang John Zhai and Jonathan M Previtali. Ancient vernacular architecture: characteristics categorization and energy performance evaluation. *Energy and buildings*, 42(3):357–365, 2010.

[13] Manoj Kumar Singh, Sadhan Mahapatra, and SK Atreya. Solar passive features in vernacular architecture of north-east india. *Solar Energy*, 85(9), 2011.

[14] Sushil B Bajracharya. The thermal performance of traditional residential buildings in kathmandu valley. *Journal of the Institute of Engineering*, 10(1):172–183, 2014.

[15] Vesa Penttala. Concrete and sustainable development. *ACI materials journal*, 94(5):409–416, 1997.