Climate Responsive Building Design in the Kathmandu Valley

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Abstract

Traditional architecture in the Kathmandu Valley is the outcome of centuries of optimization of material use, construction techniques and climate consideration. However, contemporary buildings are being built with little consideration of the climate. This study aims to explore strategies for energy efficiency and climate consciousness in modern buildings in the Kathmandu Valley. The Bioclimatic chart, Building Bioclimatic chart and Mahoney tables are used to analyse climatic parameters, and design recommendations are given based on the results of the analysis. An overview of vernacular architecture helps to understand the climatic or technological limitations of the past in order to formulate design guidelines. These guidelines provide recommendations on the orientation and layout of buildings, the size and position of openings, and the characteristics of walls and roofs.

Keywords: climate; comfort; vernacular architecture; energy efficiency; design guidelines

1. Introduction

Climate and environmental conditions are highly important parameters in a building design. Buildings are designed to achieve or to create a suitable atmosphere for human comfort. Comfort may be defined as the sensation of complete physical and mental well-being of a person within a built environment (Givoni, 1976).

Traditional builders used limited resources to achieve maximum comfort and climate was the major determinant in the traditional building techniques. With the advancement in building technologies, heating and cooling in buildings have become easy and for modern buildings, there is less concern with climate and environment in maintaining comfortable indoor conditions. Modern buildings in the Kathmandu Valley, Nepal, also follow the standardized international style of building with very little response to the local climate.

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. The climate of the Kathmandu Valley is generally cool and solar energy can be used to heat buildings, but contemporary Nepalese designers rarely address this concept. The incorporation of solar energy in building design is one of the most important criteria for energy-efficient building design in a climate like that of the Kathmandu Valley.

2. Climate

The Kathmandu Valley is located between 27º36’ to 27º50’ north latitude and 85º7’ to 85º37’ east longitude at an altitude of about 1340 meters measured from sea level.

Air temperature in the Kathmandu Valley reaches a mean monthly maximum of 29.30ºC and a mean monthly minimum of 0.90ºC. The annual mean temperature of the Valley is around 16.50ºC. The average diurnal temperature range is 10.90ºC. Relative humidity is somewhat high but the value falls during the day and varies between 36% and 100% and is strongly dependent on ambient temperature, with the highest humidity values normally occurring around dawn (Showa Shell Seiku K.K., 1998).

The annual average rainfall is around 1300 mm. Severe downpours can be experienced during the months of March through September, primarily due to seasonal monsoon winds. The prevailing wind pattern in the Valley is westerly and the average wind speed is 0.6 m/s (Showa Shell Seiku K.K., 1998).

The average hours of sunshine is 6.3 hours, and varies between 3.3 hours and 8.4 hours (HMG, Department of Meteorology). The least hours of sunshine is recorded in the month of July, and is due to the monsoon rainfall. The Kathmandu Valley receives an average hours of sunshine of more than 6 hours per day from October to May, which is good for passive solar heating in the cooler months. The average annual global solar radiation in the Valley is at around 1510 kWh/m², i.e., the daily average of 4.13 kWh/m² (Showa Shell Seiku K.K., 1998).

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(Received October 7, 2005; accepted February 9, 2006)
3. Comfort analysis and strategies to achieve comfortable conditions

Evaluating the human-comfort condition is a complex process. There are various environmental and physiological factors that affect the comfort condition of an individual. The effect of climate is evaluated considering the physiological condition of an individual to be normal. Various climatic parameters are combined to form the thermal index to express their effect on man. In this study, we use the Bioclimatic chart (Olgyay, 1962) and Building Bioclimatic chart (Givoni, 1976) to evaluate the comfort condition and to formulate strategies to respond to it. Bioclimatic approaches to architecture are attempts to create comfortable conditions in buildings by understanding the microclimatic and resulting design strategies that include natural ventilation, daylight, and passive heating and cooling.

3.1 Bioclimatic chart:

The Bioclimatic chart proposed by Olgyay (1962) is very effective for analysing the comfort condition. The effect of climatic elements on the human physiology is graphically presented as a Bioclimatic chart. The use of this chart is not limited merely to identifying whether a particular temperature–humidity relationship falls into the comfortable zone, but also reveals strategies to achieve comfortable conditions. It provides recommendations on, for example, the quantity of radiation under a cold condition, and wind flow or humidification with wind flow under a hot condition.

To identify the comfort condition for the Kathmandu Valley, the climatic data of all the months are plotted in the Bioclimatic chart, as shown in Fig.1. Two points of each line represent mean minimum temperature with the AM (ante meridiem) relative humidity and the mean maximum temperature with the PM (post meridiem) relative humidity. This comfort chart clearly indicates that buildings in the Kathmandu Valley require heating for four months from November to February, as the lines fall below the comfort range. The daytime temperature-humidity relationship shows that March, April, May and October are in the comfortable range, but the nighttime temperature falls below the comfort limit. Similarly, June, July, August and September are hotter months but wind speeds up to 2 m/s can create a comfortable condition in the daytime and nights are usually pleasant. These data imply that buildings in the Kathmandu Valley require heating approximately eight months in a year, while comfort in summer can easily be achieved with a proper ventilation arrangement.

However, the Bioclimatic chart is limited in its applicability since the analysis of physiological requirements is based on the outdoor climate. Later, Givoni (1976) used the Psychrometric chart as the basis for defining the comfort zone and stretched out the probable extent of outdoor conditions under which certain passive control techniques could ensure indoor comfort.

3.2 Building Bioclimatic chart:

The Building Bioclimatic chart derived by Givoni (1976) provides suggestions for building design considering the local climatic conditions. Various control strategies, which ultimately lead to a climate-sensitive design, are suggested. In the Psychrometric chart, different zones are plotted to indicate different strategies depending upon the monthly temperature–humidity relationship. These zones are as follows:

(a) ideal comfort zone,
(b) passive solar heating zone,
(c) air movement effect zone,

![Fig.1. Bioclimatic Chart for the Kathmandu Valley](image-url)
(d) evaporative cooling zone,
(e) mass effect / mass effect with night ventilation zone,
(f) internal gains and shading zone.

By plotting climatic data of the Kathmandu Valley in this chart (Fig.2.), 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 daytime temperature in April, May and October falls in the ideal comfort zone but the nights during those months are still cold. Only four months (June to September) are hot, and building design strategies should make provisions for air movement, internal gains and shading for that period.

The three months from December to February are the coldest months with monthly maximum and minimum temperatures remaining below 18ºC and 2ºC, respectively. During this period, conventional heating is needed to maintain room temperature when the passive strategies cannot fulfill the heating demand.

3.3 Mahoney tables:

The Mahoney Tables (Koenigsberger, et al., 1973) provide results of thermal comfort analysis using primarily temperature and humidity data, and recommendations of predesign guidelines. There are four tables in total.

The monthly mean maximum and minimum temperature data along with corresponding afternoon (PM) and morning (AM) humidity are tabulated in Table 1. The humidity data is divided into four groups, as follows: (i) group 1, below 30%; (ii) group 2, 30 - 50%; (iii) group 3, 50 - 70%; (iv) group 4, above 70%. These humidity groupings are then used in conjunction with temperature variations to define thermal comfort limits which are also linked to annual mean temperature (AMT). There are three levels of annual mean temperatures (AMTs): AMT over 20ºC, AMT between 15 and 20ºC, and AMT below 15ºC. These are used with the four humidity groups to define thermal stress comfort limits. The mean temperature is graded into three categories of temperature indicators, i.e., O (Comfortable), H (Hot) and C (Cold) for mean temperatures within, above and below the thermal stress comfort limit, respectively. It indicates the indoor condition or the level of thermal stress, for both day and night, that is imparted to the occupants of the building.

Once the local climatic conditions have been analysed and the indoor comfort limits classified, certain groups of conditions (nature of thermal stress, some climate characteristics and the durations of both) provide indications of the remedial action that the physical climate designer could take in order to arrive at the acceptable predesign conditions for better 'indoor' climate. These predesign conditions are classified under certain climatic groups or indicators. The Mahoney tables involve six indicators (i.e., three 'humidity indicators', H1- H3, and three 'arid indicators', A1 –A3), as shown in Table 2.

The Mahoney tables indicate remedial action involving air movements for humid conditions in H1 and H2. Excess downpours may affect the building structure, so adequate rain protection is advised in H3. Similarly, for hot and arid conditions, thermal capacity (A1) is one of the options for making the indoor space comfortable. Climatic zones with nighttime temperature above the comfort limit are advised to make a provision for outdoor sleeping (A2). An arid climate with lower temperature needs protection of the building from cold wind (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
### Mahoney Tables - Table 1. Data Input

| LOCATION         | SUNDARIGEHAT, KATHMANDU |
|------------------|--------------------------|
| LONGITUDE        | 85° 22′ E               |
| LATITUDE         | 27° 42′ N               |
| ALTITUDE         | 1336 m.                 |

### Air Temperature °C

|                | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Monthly mean max. | 15.2| 16.8| 22.4| 24.4| 24.4| 27.0| 25.6| 25.5| 25.6| 25.0| 23.8| 20.6|
| Monthly mean min.  | 0.9 | 1.9 | 6.6 | 8.4 | 14.7| 18.7| 19.9| 19.4| 18.1| 11.2| 5.3 | 1.5 |
| Monthly mean range | 14.3| 14.9| 15.8| 18.6| 10.9| 6.8 | 5.7 | 6.2 | 6.9 | 12.6| 15.3| 15.9|

### Relative Humidity %

| Monthly mean max. (AM) | 100 | 100 | 99  | 98  | 99  | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Monthly mean min. (PM) | 51  | 46  | 44  | 37  | 45  | 76  | 80  | 79  | 76  | 62  | 51  | 46  |
| Average             | 76  | 73  | 72  | 68  | 72  | 88  | 90  | 90  | 88  | 81  | 76  | 73  |
| Humidity Group      | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   | 4   |

- **Humidity Group:**
  1. If average RH: Below 30%
  2. 30 - 50%
  3. 50 - 70%
  4. Above 70%

### Other Climatic elements

| Rainfall, mm | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Wind speed (m/s) (max.) | 2.5 | 2.9 | 2.9 | 2.4 | 2.4 | 2.1 | 2.1 | 1.6 | 1.7 | 1.8 | 2.4 | 2.7 |
| Wind direction (prevailing) | SW | SW | W | SW | W | SW | SW | SW | W | SW | SW | W |
| Sunshine hours (hr.) | 58  | 6.7 | 7  | 8.4 | 7.4 | 5.7 | 3.3 | 4.5 | 4.8 | 7.9 | 7.4 | 6.2 |
| Solar radiation (W/m²day) | 167 | 190 | 216 | 212 | 203 | 166 | 162 | 172 | 178 | 223 | 203 | 183 |

### Comfort Limits

| Humidity Group | AMT over 20 °C | AMT 15 - 20 °C | AMT below 15 °C |
|----------------|---------------|---------------|---------------|
| Day            | Night         | Day           | Night         |
| 1              | 27-34         | 23-32         | 14-23         |
| 2              | 25-31         | 22-30         | 14-22         |
| 3              | 23-29         | 21-28         | 14-21         |
| 4              | 22-27         | 20-25         | 14-20         |

### Table 2. Temperature and Humidity Diagnosis

| Diagnosis: °C | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Monthly mean max. | 15.2| 16.8| 22.4| 24.4| 24.4| 27.0| 25.6| 25.5| 25.6| 25.0| 23.8| 20.6|
| Day comfort: upper | 24  | 24  | 24  | 26  | 24  | 24  | 24  | 24  | 24  | 24  | 24  | 24  |
| lower          | 18  | 18  | 18  | 18  | 18  | 18  | 18  | 18  | 18  | 18  | 18  | 18  |
| Monthly mean min. | 0.9 | 1.9 | 6.6 | 8.4 | 14.7| 18.7| 19.9| 19.4| 18.1| 11.2| 5.3 | 1.5 |
| Night comfort: upper | 18  | 18  | 18  | 18  | 18  | 18  | 18  | 18  | 18  | 18  | 18  | 18  |
| lower          | 12  | 12  | 12  | 12  | 12  | 12  | 12  | 12  | 12  | 12  | 12  | 12  |
| Thermal stress: day | C   | C   | O   | O   | H   | H   | H   | O   | O   | C   | C   | C   |
| night          | C   | C   | C   | O   | O   | H   | H   | H   | C   | C   | C   | C   |

### Indicators

| Humid: | H1 | H2 | H3 |
|--------|----|----|----|
|        | ✓  | ✓  | ✓  |
| Arid:  | A1 | A2 | A3 |
|        | ✓  | ✓  | ✓  |

### Applicable when:

| Meaning                          | Indicator | Thermal stress | Rainfall | Humidity group | Monthly mean range °C |
|----------------------------------|-----------|----------------|----------|----------------|------------------------|
| Air movement essential           | H1        | H              | 4        |                |                        |
| Air movement desirable           | H2        | O              | 2, 3     | Less than 10   |                        |
| Rain protection necessary        | H3        | Over 200 mm    |          |                |                        |
| Thermal capacity necessary       | A1        |                | 1, 2, 3  | More than 10   |                        |
| Outdoor sleeping desirable       | A2        | H              | 1, 2     |                |                        |
| Protection from cold             | A3        | C              |          |                |                        |

- **H (Hot):** If mean is above limit
- **O (Comfort):** If mean is within limit
- **C (Cold):** If mean is below limit
Table 3. List of Recommended Specifications

| Indicator from Table 2 | H1 | H2 | H3 | A1 | A2 | A3 |
|------------------------|----|----|----|----|----|----|
| LAYOUT                 |    |    |    |    |    |    |
| 0 - 10                 |    |    |    |    |    | ✓  |
| 11, 12                 |    |    |    |    |    | ✓  |
| 0 - 4                  |    |    |    |    |    | ✓  |
| 1                      | Orientation north and south (long axis east - west) |
| 2                      | Compact courtyard planning |
| SPACING                |    |    |    |    |    |    |
| 11,12                  |    |    |    |    |    | ✓  |
| 2 - 10                 |    |    |    |    |    | ✓  |
| 0, 1                   |    |    |    |    |    | ✓  |
| 3                      | Open space for breeze penetration |
| 4                      | As 3, but protection from hot and cold winds |
| 5                      | Compact layout of estates |
| AIR MOVEMENT           |    |    |    |    |    |    |
| 3 - 12                 |    |    |    |    |    | ✓  |
| 1, 2                   |    |    |    |    |    | ✓  |
| 0 - 5                  |    |    |    |    |    | ✓  |
| 6 - 12                 |    |    |    |    |    | ✓  |
| 0                      |    |    |    |    |    | ✓  |
| 2 - 10                 |    |    |    |    |    | ✓  |
| 0, 1                   |    |    |    |    |    | ✓  |
| 6                      | Rooms single banked, permanent provision for air movement |
| 7                      | Double banked rooms, temporary provision for air movement |
| 8                      | No air movement requirement |
| OPENINGS               |    |    |    |    |    |    |
| 0, 0                   |    |    |    |    |    | ✓  |
| 11,12                  |    |    |    |    |    | ✓  |
| 0, 1                   |    |    |    |    |    | ✓  |
| Any other conditions   |    |    |    |    |    | ✓  |
| 11                     | Medium openings, 20 - 40 % |
| WALLS                  |    |    |    |    |    |    |
| 0 - 2                  |    |    |    |    |    | ✓  |
| 3 - 12                 |    |    |    |    |    | ✓  |
| 0 - 5                  |    |    |    |    |    | ✓  |
| 6 - 12                 |    |    |    |    |    | ✓  |
| 12                     | Light walls, short time lag |
| 13                     | Heavy external and internal walls |
| ROOFS                  |    |    |    |    |    |    |
| 0 - 5                  |    |    |    |    |    | ✓  |
| 6 - 12                 |    |    |    |    |    | ✓  |
| 14                     | Light, insulated roof |
| 15                     | Heavy roofs, over 8 h time lag |
| OUTDOOR SLEEPING       |    |    |    |    |    |    |
| 3 - 12                 |    |    |    |    |    | ✓  |
| 16                     | Space for outdoor sleeping required |
| RAIN PROTECTION        |    |    |    |    |    |    |
| 3 - 12                 |    |    |    |    |    | ✓  |
| 17                     | Protection from heavy rain necessary |

Table 4. List of Detailed Recommendations

| Indicator from Table 2 | H1 | H2 | H3 | A1 | A2 | A3 |
|------------------------|----|----|----|----|----|----|
| SIZE OF OPENING        |    |    |    |    |    |    |
| 0, 0                   |    |    |    |    |    | ✓  |
| 1 - 12                 |    |    |    |    |    | ✓  |
| 2 - 5                  |    |    |    |    |    | ✓  |
| 6 - 10                 |    |    |    |    |    | ✓  |
| 11,12                  |    |    |    |    |    | ✓  |
| 0 - 3                  |    |    |    |    |    | ✓  |
| 4 - 12                 |    |    |    |    |    | ✓  |
| 1                      | Large: 40 - 80 % |
| 2                      | Medium: 25 - 40 % |
| 3                      | Small: 15 - 25 % |
| 4                      | Very Small: 10 - 20 % |
| 5                      | Medium: 25 - 40 % |
| PROTECTION OF OPENING  |    |    |    |    |    |    |
| 3 - 12                 |    |    |    |    |    | ✓  |
| 0 - 5                  |    |    |    |    |    | ✓  |
| 1 - 2                  |    |    |    |    |    | ✓  |
| 6 - 12                 |    |    |    |    |    | ✓  |
| 0                      | In north and south walls at body height on windward side |
| 1                      | As above, opening also in internal walls |
| 2 - 12                 |    |    |    |    |    | ✓  |
| 8                      | Exclude direct sunlight |
| 9                      | Provide protection from rain |
| WALLS AND FLOORS       |    |    |    |    |    |    |
| 0 - 2                  |    |    |    |    |    | ✓  |
| 3 - 12                 |    |    |    |    |    | ✓  |
| 10                     | Light, low thermal capacity |
| 11                     | Heavy, over 8 h time lag |
| ROOFS                  |    |    |    |    |    |    |
| 0 - 2                  |    |    |    |    |    | ✓  |
| 3 - 12                 |    |    |    |    |    | ✓  |
| 0 - 5                  |    |    |    |    |    | ✓  |
| 6 - 12                 |    |    |    |    |    | ✓  |
| 12                     | Light, reflecting surface, cavity |
| 13                     | Light, well insulated |
| 14                     | Heavy, over 8 h time lag |
| EXTERNAL FEATURES      |    |    |    |    |    |    |
| 1 - 12                 |    |    |    |    |    | ✓  |
| 16                     | Adequate rainwater drainage |
obtain data in Tables 3 and 4 which indicate design recommendations.

4. Design recommendations

Once the climatic data has been analysed using comfort indices, some design recommendations are formulated to narrow down the design strategies. The climatic data has been incorporated in the Mahoney Tables (Koenigsberger, et al., 1973), as shown in Tables 1, 2, 3 and 4, which provide preliminary design recommendations. The design specifications are grouped under eight headings: layout, spacing, air movement, openings, walls, roofs, outdoor sleeping and rain protection requirements. These recommendations are useful for architects and planners in the initial building design stages.

The following is a summary of the recommendations for the Kathmandu Valley.

(a) Layout: Orientation north and south (long axis east-west)
(b) Spacing: Open spaces for breeze penetration, but protection from hot and cold winds
(c) Air movement: Rooms should be single banked with permanent provision for air movement
(d) Openings: Medium level of openings, 25-40%
(e) Position of openings: In windward side walls at body height
(f) Protection of openings: Protection from rain
(g) Walls: Light walls, low thermal capacity, short time lag
(h) Roofs: Light, insulated roofs
(i) Rain protection: Protection from heavy rain necessary

5. Vernacular architecture of the Kathmandu Valley

The vernacular architecture often represents the result of many years or even centuries of optimization in the use of resources, the activities carried out within and around the dwelling, the social organization of the household and the climate consideration (Wagner, 1980).

A traditional house in the Kathmandu Valley is a simple building with a rectangular plan and a tiled sloped roof. Dwellings are built in continuous rows facing the street with internal houses arranged around interconnected courtyards (Korn, 1976). Courtyard planning is the ideal form; it provides a source of light, air, and a space for social interaction in the Kathmandu Valley. Land value in the past was at a premium due to agricultural demand, so the houses are planned vertically. However, seismic conditions limited the height of the buildings, and three and a half storeyed buildings are common. The ground floor is used for the storage of farm implements, cattle, poultry, manure etc. and is usually not inhabited. The first floor is used as bedrooms, while the second floor is usually used as the main living area. Large windows face the street and provide natural light as well as a view of the activities on the street. Attic space is utilized as the kitchen and prayer room. Most houses consist of three parallel load-bearing walls, and thus rooms are double banked (Gutschow, et al., 1987).

6. Building materials

Basically, wood and clay products were used as building materials. Tiles were widely used for roofing. A few houses also had straw-thatched roofing. Almost all structures were built with bricks in mud mortar while wood was used for openings and flooring.

(a) Openings
People in the past spent most of the daytime outdoors, so large openings were not needed to keep the house well lit during the day. The area of the opening was approximately 10 percent of the total floor area. The roof overhang was sufficient to shade the south façade in summer while admitting the winter sun, and to protect the wall from rain.

(b) Walls
Thick walls made of a combination of burnt and sun-dried bricks formed the most common external walls. The wall section had a thickness of almost one meter and a low U-value; hence, it served as a good insulator. The time lag of these walls was high; they stored heat during the daytime and radiated it into the room at night when the outside temperature was below the comfort range. Unburnt clay bricks were used on the inside, which absorbed 10 to 20 times more moisture than burnt bricks and helped to maintain a comfortable interior environment.

(c) Roofs
Roofs were light but were well insulated and had a higher U-value than the walls. The higher the U-value, the lower the insulating property and the quicker the
transmission of heat through the roof, making the attic space warm throughout the day. However, the attic was used primarily as the kitchen and was not uncomfortable for the users as the space was mainly used in the morning and the evening.

7. Design guidelines

Designing a building considering the local climate has many benefits, as it will be able to use natural energy and the benefits of climate to maintain its operational energy demand. The following design guidelines are formulated on the basis of the results of climate analysis and the study of traditional architecture of the Kathmandu Valley.

(a) The climatic analysis revealed that the Kathmandu Valley has predominantly cold climatic conditions and the Building Bioclimatic chart suggests that there is an opportunity for passive solar heating in the winter months. The Mahoney tables also recommend orienting buildings towards the south to receive the low-angle winter sun. More precisely, Upadhyay (2000) suggests orienting buildings 10 degrees west of south to receive the maximum solar radiation in winter; this is a suitable option for passive solar heating. The Kathmandu Valley is often cloudy in the morning in winter, and also, considering the westerly wind, slightly rotating the building towards the west gives an optimum orientation angle.

(b) Since we are planning to use solar energy for space heating, an unobstructed sun’s movement to the site must be assured in winter months. For this purpose, a solar envelope (Knowles, 1981) should be prepared for the site, which will ensure solar exposure on the building during the specified time. It will stipulate building volume with respect to the size of the plot so that each plot can enjoy solar exposure.

(c) June to September are hot and humid months with high temperature, humidity and rainfall. The Kathmandu Valley receives approximately 82% of the total yearly rainfall in these months. A permanent provision for ventilation and rain protection is necessary for this period. To secure cross ventilation, single-banked construction is suggested in the Mahoney tables. Contrary to this climatic recommendation, the vernacular architecture of the Kathmandu Valley generally does not have good provision for cross ventilation as most of the houses are double banked with small windows in one wall. The minimum openings are usually due to the structural limitations.

(d) The Building Bioclimatic chart suggests adopting the passive solar heating option for eight months. Mahoney tables also suggest a medium level of openings in the range of 25-40% of the floor area, which is suitable for the direct gain system if the south façade can be exploited for this purpose. The vernacular architecture of the Kathmandu Valley has very few openings in the lower storeys, but on the upper floors, the opening area is almost 20-25%. However, the traditional windows are not purposefully designed as solar collectors. They have timber shutters, so are unable to retain heat inside the room. The window design has changed greatly and people are now using glass in the shutters. Hence, there is an opportunity to use normal windows as solar windows.

(e) Openings on the south façade are effective for sun tempering as well as letting in daylight. Large French windows in the south façade are always beneficial as the solar collection area is large which enables the heating of a large floor area. As far as possible, openings on the north façade are to be avoided as the north side does not receive solar radiation in winter months and openings will contribute to heat loss.

(f) The Kathmandu Valley is subjected to monsoon rain for four months of the year, so rain protection is necessary. Windows are protected by projections. Traditional buildings are protected by roof projections, which also help in shading openings from unwanted solar radiation in summer months.

(g) The Mahoney tables suggest light outer walls with low thermal capacity and short time lag; contemporary buildings in the Kathmandu Valley are constructed in this fashion. Contrary to this suggestion, traditional buildings are constructed with heavy walls of high thermal capacity and large time lag. People who had lived in traditional buildings but have recently moved into new

![Fig.4. A Typical Wall Section of a Traditional Building](image)

![Fig.5. A Typical Roof Section of a Traditional Building](image)
buildings often complain that the new buildings are not as comfortable as the traditional ones. They feel cold in winter and hot in summer in the new buildings, which was not a problem in the traditional buildings. Although aridity is not a problem in the Kathmandu Valley, the eight months of winter can be better coped with by having heavy walls with high thermal capacity and large time lag.

(h) The roof receives as much as 40 percent of the total solar radiation throughout the year. In winter months, the sun has a lower altitude angle, so the roof receives less solar radiation than in summer. In the Kathmandu Valley, the roof should be perfectly insulated or would otherwise contribute to rapid heat loss at nighttime. The problem with the roof is conduction. In winter, warm air inside the building tends to rise and if it encounters a cold ceiling or a badly insulated roof, it will cool quickly and descend again as cold air. Thus, a heat loss cycle is set up. In summer, the roof surface receives a higher amount of radiation, so the situation is worse. The traditional buildings were constructed with a slope roof and a false ceiling creating a buffer space between the living space and the roof. A roof with a 10-hour time lag is recommended for residential buildings. It prevents the flow of unnecessary heat flux when heat is not needed and allows the flow of heat at night when the room temperature falls below the comfort range. Proper insulation measures must be taken into account to achieve a desirable time lag. In modern buildings, roof insulation is rarely provided; hence, the indoor comfort condition is poor.

(i) Considering the four months of monsoon rain, a building should have a raised plinth and surface drainage should be maintained properly so that a heavy downpour does not affect the building.

8. Conclusion

In this study, the general climatic design guidelines for the Kathmandu Valley were developed using the Bioclimatic chart, Building Bioclimatic chart, Mahoney Tables and a consideration of the traditional architecture. The building design recommendations are not meant to be prescriptive, but they are aimed at providing a set of targets to encourage innovative and individual design solutions. Furthermore, these design guidelines will provide appropriate information at strategic decision stages to help make better use of energy in building design and development in order to incorporate passive solar energy considerations in design.

Acknowledgement

We would like to thank the "Japan Society for the Promotion of Science" for their financial support.

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