Regional differences of wintry indoor thermal environment of traditional houses in Nepal

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Abstract. Nepal has sub-tropical to cold regions due to large altitude difference. The traditional houses are well adapted to the local climate with the use of local building materials. However, traditional practice has been diminished by more introduction of the artificial building materials, modern design and new technology. Under this circumstance, some strong policies based on a field research to sustain the traditional architecture with some rational modern metamorphosis is necessary. For this reason, we investigated the wintry indoor thermal environment of traditional houses in three climatic regions of Nepal. We measured the indoor thermal environment all together nine houses in cold, temperate and sub-tropical regions during the winter in December 2016. The houses were found to be eighty percent of the time below 11°C, 16°C and 22°C in cold, temperate and sub-tropical regions, respectively. This result is well attributed to the regional climatic difference and the thermal characteristics of building materials used. The traditional houses surveyed are considered to be adapted to the climates because of the local availability of building materials.

1. Introduction

Nepal is a landlocked country with geographic variation ranging from 60m to 8848m. The variation in altitude has caused the diversity of people’s life style including the housing types. The types of housing have been reflected by the difference in geographic variation. The traditional construction skills, one of whose major objectives must have been to mitigate indoor thermal conditions. It has been handed over from one generation to another since old days with almost no modification. But they are being replaced by the contemporary ways of construction, modern design and technology including artificial materials [1, 2]. Every year new houses are being built in Nepal as a part of the process of urbanization and modernization. According to National Population and Housing Census [3]; more than 83% of population are living in traditional houses in rural area of Nepal. Under this...
circumstance, it is important to know the state of indoor thermal environment of the Nepalese traditional houses.

To sustain traditional constructing technology, we have to make policies that improves traditional technology using modern skills without deteriorating the cultural norm by keeping an eye on positive aspects of traditional houses that should be preserved and inherited into the future. All over the world, 40% of the energy supplied is used in buildings [4]. Most of the people in Nepal are living with passive means of heating and cooling; that is, without mechanical heating and cooling. Therefore, their indoor thermal environment depends much on natural climatic patterns.

The traditional construction skill of building housing system has been replaced with modern technologies and contemporary houses. We have to control such encroachment of modern housing technology on traditional houses. However, the question remains as how people were able to sustain thermal comfort in such houses in different climatic regions in Nepal. Therefore, it is worth knowing the quantitative relationship between indoor thermal environment and outdoor temperature in respective regions.

There are many field studies on so-called indoor thermal environment in various buildings around the world [5~9]. However, the climatic variation, living condition and house structures of Nepal are different from those focused in the previous studies. Although there are a few studies on indoor thermal environments which have been conducted in a specific place in Nepal [10~13], our study was conducted in traditional houses of three different regions as their wintry indoor thermal environment and adjustment would be totally different from one another. In this study, we examined the thermal environment of traditional houses in three climatic regions in Nepal. We compared the relationship between indoor and outdoor air temperature, distribution of indoor air temperature in three climatic regions in winter. The findings may be useful for the improvement of traditional houses in three climatic regions in the future.

2. Research areas and climates
Its climate varies from sub-tropical to cold due to large altitude difference. There are three climatic regions: Mustang in cold region (Himalayan, altitude 3000~8848m); Kavrepalanchok in temperate region (Hilly, 600~3000m); and Sarlahi in sub-tropical region (Terai, 60~600m). The field measurement was conducted during the winter of 2016 from December 3rd to January 2nd 2017. Figure 1 shows the study areas, the monthly mean outdoor air temperature and relative humidity. The mean outdoor air temperature and relative humidity are highest in sub-tropical, moderate in temperate and lowest in cold regions.

(a)   (b)   (c)

Figure 1 Three regions in Nepal for survey and their general climatic characteristics: (a) Map of Nepal [14],
(b) Monthly mean outdoor air temperature and (c) Relative humidity [15]
3. Investigated houses

Most of the traditional houses are designed and constructed by local people with the local materials. We have measured altogether 9 traditional houses. Figure 1 (a) shows the location of houses. Figure 2 shows three examples from the investigated 9 houses. Their shapes are rectangular. Table 1 shows the dimensions and the structure of these houses. Each house is two or three stories. Generally, the kitchen and living room are on the first floor, bed rooms are on the second floor and store rooms are on the top floor.

3.1. Cold region

The houses in this region are very compact and harsh. They are often attached to each other creating small passage to protect from cold wind and snow storms. The houses stand closely together sharing one or more exterior walls. The houses are situated on the southern slope of hills or on flat valleys to enhance solar heat gains [15]. They are usually two or three stories. Animals are housed on the ground floor leading to increase indoor temperature due to their heat generation. The walls are built of local available stones and mud. The thickness of the walls up to 60 cm. Because of little rainfall, the roof of the houses in this region are generally flat. The roof is made of stone and mud laid on a timber columned and beamed structure.

3.2. Temperate region

The houses in temperate climatic region tend to be built in detached pattern. The houses have either rectangular floor plans or L-shape plan. Most of the houses are two or three stories. Semi-open spaces play an important role in this region [2]. The walls are made of locally available stone and mud with a thickness of up to 50 cm. The roofs are made of wooden pillar and beamed structure with thatch, tiles and zinc sheets.

3.3. Sub-tropical region

The traditional settlement pattern in sub-tropical region is dense. Different castes have made the traditional houses for their own respective culture in this region. The buildings have rectangular floor plans enclosed with low walls. The long side is usually oriented north-south. The houses in this reason have one to two stories with high ceilings for increasing the ventilation effect necessary especially in hot and humid climate. The walls of the houses are made of wood and bamboo. Their roofs are made of thatch and tiles.
(b) Temperate

(c) Sub-tropical

Figure 2 Three of the investigated houses and their second floor plan: (a) Cold, (b) Temperate and (c) Sub-tropical regions

Table 1 Description of the three houses surveyed shown in Figure 2

| Climates    | Dimension [m] | No. of floors | Walls Thickness [m] | Structure | Finishing                        | Window height and width [m] |
|-------------|---------------|---------------|---------------------|-----------|----------------------------------|------------------------------|
| Cold        | 8.0 x 4.5 x 7.0 | 3             | 0.60                | Mud and stone | Mud and cow dunk                | 1.2 x 1.2                   |
| Temperate   | 10.0 x 4.5 x 7.5 | 3             | 0.45                | Mud and stone | Outside cement, inside mud and cow dunk | 1.5 x 0.75                 |
| Sub-tropical | 7.5 x 4.0 x 5.0 | 2             | 0.025               | Wood       | None                             | 1.2 x 0.75                  |

4. Thermal measurement
We measured the indoor and outdoor air temperatures, indoor and outdoor relative humidity at 10-minute intervals with digital instruments as can be seen in Figure 3. The sensors were placed about 1.1 m above in the bedroom floor and 1.5 m above the ground outdoors. Outdoor sensors were placed under the shade of direct sunlight.
5. Result and Discussion

5.1. Variation of indoor and outdoor air temperature

Figure 4 shows the results of three days’ variation of indoor and outdoor air temperature in the houses in three climatic regions of Nepal. Outdoor air temperature has affected the indoor air temperature in all study areas. In the cold-climatic region, the average indoor and outdoor air temperatures tend to be lower than temperate and sub-tropical regions. The mean outdoor air temperature is 8.6°C in cold region, which is 4.4°C and 9.5°C lower than temperate and sub-tropical regions, respectively. The diurnal range of the indoor air temperature in the cold region is smaller than temperate and sub-tropical regions. The diurnal range is 3.9°C in cold region, 6.1°C in temperate region and 14.4°C in sub-tropical region. The cause of this difference in indoor air temperature may be due to the size of the windows, wall thickness and heat capacity of the materials used.

![Figure 4 Three days’ variation of indoor and outdoor air temperature](image)

5.2. Distribution of indoor air temperature

Figure 5 shows cumulative frequency of indoor air temperature in the measured houses. Among the three regions, the most of the time was lower indoor air temperature in the cold region, middle in the temperate region and highest in sub-tropical region. The 80% of the data are below 11°C in house C2 and C3 but house C1 data are below 11.5°C in the cold region. The indoor air temperature is not so different in these houses. The 80% of the data are below the 16°C in temperate region. Likewise, 80% of the data are below about 22°C in houses S1 and S2 but house S3, the 80% of the data are below the 20°C in sub-tropical region. It is due to the difference in house materials used, heat generation and wall thickness.
5.3. Relationship between indoor and outdoor air temperature

Figure 6 shows the relationship between the indoor air and outdoor air temperature. When the outdoor air temperature increased the indoor air temperature also increased. We have found the following regression equations for temperate and sub-tropical climatic regions,

\[
\begin{align*}
\text{Temperate} & \quad T_i = 0.150T_o + 13.5 \quad (n = 1296, R^2 = 0.406, \text{S.E.} = 0.005, p < 0.001) \quad (1) \\
\text{Sub-tropical} & \quad T_i = 0.538T_o + 8.6 \quad (n = 1296, R^2 = 0.572, \text{S.E.} = 0.013, p < 0.001) \quad (2)
\end{align*}
\]

where, \(T_i\) is the indoor air temperature, \(T_o\) is the outdoor air temperature, \(n\) is the number of data, S.E. is the standard error of the regression coefficient and \(p\) is the significance level of the regression coefficient. Since the regression coefficient for cold region was found very small. The regression equation was not presented here.

The regression coefficient (the slope of the line) of temperate region is smaller than that of the sub-tropical regions. This difference must be due to the effect of thermal mass of materials used. In the temperate climatic region, the houses are made of stones and mud with thick wall (45cm) but in sub-tropical climatic region, the houses are made up of wooden with thin wall (2.5cm). For both temperate region and sub-tropical region, there are data plots between 10°C and 22°C. According to the regression lines shown above, indoor air temperature, \(T_i = 16.6°C\) for temperate region and \(T_i = 19.9°C\) for sub-tropical region, with assumption of outdoor air temperature being 21.0°C. The regional difference of indoor air temperature \(\Delta T_i = 3.3°C\). These tendencies are similar to previous studies [1, 9, 11, 16].

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**Figure 5 Distribution of indoor air temperature in three climatic regions**

**Figure 6 Relationship between indoor and outdoor air temperature**
6. Discussion
The results of this study indicate that in the cold region, the average indoor and outdoor air temperatures tend to be lower than those in temperate and sub-tropical regions. The mean outdoor air temperature of cold region is 8.6°C, which is 4.4°C and 9.5°C lower than temperate and sub-tropical regions. Likewise, the men indoor air temperature also is lower (10.9°C) in cold climatic region, which is 4.5°C and 7.5°C lower than temperate and sub-tropical regions. The regional differences of indoor air temperature are around $\Delta T_i = 3.3°C\sim 5.0°C$. This result is similar to previous study [9]. In cold climatic region, the indoor air temperature was found to be 80% of the time below the 11°C. It can be said that if indoor environment is extremely low it directly affects to human health. The mortality rate rise evidently with increasing cold stress [17]. The elderly and infants are more vulnerable from exposure to low temperature [18]. The body’s reaction to low temperature includes thickening of the blood and hypertension [19].

7. Summary
We measured the indoor thermal environment in nine traditional houses in cold, temperate and sub-tropical regions in winter. We have found the following:

1. The mean indoor air temperature is 10.9°C in cold region, 15.4°C in temperate region and 18.4°C in sub-tropical region.
2. The variation of indoor air temperature in cold region was narrower than those in temperate and sub-tropical regions.
3. The 80% of occurrence indoor air temperature was below 11°C, 16°C and 22°C in the cold, temperate and sub-tropical regions, respectively. These differences are considered to be due to the difference in buildings materials used.
4. The regression coefficient (the slope of the line) of temperate region was smaller than that of the sub-tropical region.

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