Investigation on Wintry Thermal Comfort in Traditional Houses of Nepalese Three Climatic Regions

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Abstract:
The traditional houses are well adapted to the climate and socio-culture using local building materials and techniques. However, traditional practices are being replaced by the artificial materials, modern design and new technology. It requires strong policies to sustain the traditional architecture. The objectives of this study are to evaluate the thermal condition of traditional houses and to estimate the comfort temperature of residents. The thermal comfort survey was conducted during winter in the traditional houses. The thermal sensation votes were collected from 275 people in cold, temperate and sub-tropical climatic regions. This study was revealed that the mean indoor air temperature in cold climatic region is 12.3°C, which was 9.5K and 4.4K lower than sub-tropical and temperate climates. The comfort temperature of the residents in the cold climate was 13.9°C, which was 8.8K and 3.8K lower than sub-tropical and temperate climates. The mean clothing insulation in cold climate was 1.63 clo which was 0.48 clo and 0.31 clo higher than sub-tropical and temperate climates. It concludes that the people were well adapted to each climate with clothing adjustments and made themselves satisfied with the thermal condition of their houses.

Keywords: Regional Differences, Traditional Houses, Thermal Environment, Comfort Temperature, Clothing Insulation

1 Introduction

The traditional constructions of skills are delightful gift from our ancestors. It has been developed and handed over since many centuries without environmental, socio-cultural and health problems. The traditional houses are well matched and adjusted to the climates because they are made by using local building materials, technique and skill [1]. The different types of traditional houses, using a variety of way to mitigate indoor thermal conditions, can be found in courtyard, verandah, use of eaves or roofs cutting down sunshine, semi-open spaces and increasing thermal mass by applying local materials [2]. Traditional buildings are cool in summer and warm in winter than modern buildings [1, 3]. The traditional constructions are decreasing day by day, being replaced by artificial materials, modern design and new technology. It is necessary to preserve our ancestors’ gift and hand it over to the new generation [2]. Thus, we have to make strong policies to sustain the traditional idea of traditional architecture. However, the traditional architecture could be one of the key issues for sustainable building design for different climates.

Every year new houses are being built and it is necessary to be comfortable. The countries near Nepal have their own standard [4,5]. But in the context of Nepal, the government has not yet established any comfort standard. Nepal is in the process of federal system, urbanization and modernization, and it is essential to find out the comfort temperature experienced by Nepalese people in the present living condition separately in traditional houses.

Thermal comfort is one of the most important things for the people, which is related to energy utilization in buildings [6]. People have different thermal preferences and thus the comfort temperature is to vary according to seasons, climates, and regions [7]. There are many field studies related to comfort temperature in buildings that have been conducted around the world [8-12]. However, the climatic variation, living condition and houses structure of Nepal are different. The comfort temperature could be different in different climatic regions. But only few thermal comfort surveys have been conducted in Nepal [2, 13]. However, these results cannot be generalized in all places because they were found for a specific place. Thus, in order to clarify the thermal condition of Nepalese traditional houses in winter and estimation of comfort temperature of residents, a thermal comfort study was conducted.

2 Methodology

2.1 Research areas and investigated houses
large altitude difference. It has three climatic regions i.e. cold (Himalayan), temperate (Hilly) and sub-tropical (Terai), which were chosen as the research areas. Figure 1 shows the study areas. The field survey was conducted during the winter in three climates: cold (Mustang district), temperate (Kavrepalanchok district) and sub-tropical (Sarlahi district). The total number of the studied houses are 108 (cold: 30, temperate: 31 and sub-tropical: 47). Figure 2 shows the traditional houses constructed in three climatic regions. The most of the traditional houses are rectangular shape, which were designed by local people as can be seen in Figure 2. Each house is generally two or three stores in each climate. Generally, the kitchen and living room are in the ground floor and bedrooms are in the first floor of the houses.

2.2 Thermal measurement

The survey on indoor thermal environment was conducted in the month of December 3rd 2016 to January 2nd 2017 in the winter. During the survey time, the parameters such as indoor air temperature [°C], globe temperature [°C], outdoor air temperature [°C], were measured in the 12 traditional houses by using digital instruments as shown in Table 1. We installed the instruments in the first floors about 1.1m above the floor level. The thermal environment data was recorded by a data logger at the intervals of 10 munities.

2.3 Thermal comfort survey

The interview for thermal comfort survey was conducted as shown in Figure 3. The comfort survey was conducted in 108 traditional houses. The data were collected from 275 respondents, aging between 14 to 86 years during the day time from 7:00 to 18:00. We have measured the thermal environment by using digital instruments during the interview time as shown in Table 1. The sensors were placed about 1m far from the respondents about 1.1 m above the floor level for indoor and 1.5 m above the ground for outdoor away from direct sunlight and solar radiation. During the thermal measurement and comfort survey, people were asked individually about the thermal sensation vote [TSV], thermal preference [TP]. We used modified 7-point thermal sensation scale which is translated in Nepalese language as shown in Table 2 [2]. The checklist of the clothing insulation was used to record the clothing worn by the respondents during the voting time. The participants, clothing insulation value was determined in accordance with the values given by ISO 2003 [14].
Table 1: Description of the instrument

| Parameter measured                        | Name of instruments             | Sensors                                      | Range             | Accuracy                        |
|-------------------------------------------|---------------------------------|----------------------------------------------|-------------------|---------------------------------|
| Air temperature and relative humidity     | TR-74Ui                         | Thermistor and polymer membrane              | 0.55°C, 10-95%    | ± 0.5°C, ± 0.5% RH              |
| Globe temperature                         | Tr-52i, SIBATA, 080340-75        | Black painted, 75mm diameter globe           | -60 to 155°C      | ± 0.3°C                         |
| Air velocity                              | Trust Science Innovation (TSI) 9535 | Hot-wire anemometer                         | 0 to 30m/s        | ± 0.015m/s                      |

Table 2: Questionnaires used in the thermal comfort survey

| English                                | Nepalese                        |
|----------------------------------------|---------------------------------|
| Modify thermal sensation vote (mTSV)  | तापमात्साप्लालिता सन्धि (मित्र)    |
| 1. Very cold                           | युक्त                               |
| 2. Cold                                | काली                                |
| 3. Slightly cold                       | सीधे मलिका                          |
| 4. Neutral (Neither cold nor hot)      | जीते तापमात्साप्लालिता नहीं            |
| 5. Slightly hot                        | युक्तीली मलिका                        |
| 6. Hot                                 | दानी                                |
| 7. Very hot                            | युक्तीली दानी                         |

| Thermal preference                     | तापमात्साप्लालिता बोधन                          |
|----------------------------------------|---------------------------------|
| 1. Much warmer                         | वास्तविक मलिका                        |
| 2. A bit warmer                        | तापमात्साप्लालिता मलिका सीधे           |
| 3. No change                           | तापमात्साप्लालिता सीधे काली              |
| 4. A bit cooler                        | तापमात्साप्लालिता सीधे युक्तीली मलिका     |
| 5. Much cooler                         | तापमात्साप्लालिता युक्तीली दानी           |

3 Results and discussion

3.1 Thermal environment

Table 3 shows the mean indoor and outdoor air temperature. The mean outdoor and indoor air temperature in cold climatic region is lower than temperate and sub-tropical climatic regions. The mean outdoor air temperature is 11.4°C in cold climatic region which is 12.8K and 5.4K lower than sub-tropical and temperate climatic regions. Similarly, the mean indoor air temperature in cold climate is 12.3°C which is 9.6K and 4.3K lower than sub-tropical and temperate climatic regions. By comparing with the previous studies, the indoor air temperature is lowest in high altitude and vice versa in low altitude as shown in Table 3. The results showed that the indoor air temperature is significantly lower in cold climatic region than the conventional standards.

3.2 Relationship between indoor and outdoor air temperature

Figure 4 shows the relationship between indoor and outdoor air temperature during the voting time in three climatic regions. When the outdoor air temperature is increased, the indoor air temperature is also increased.

The previous studies [2, 11, 12, 15] have found that the indoor air temperatures have regional differences. In the cold climate the mean indoor air temperature is 0.9K higher than outdoor air temperature. But in the sub-tropical climate, the indoor air temperature is 2.4K lower than outdoor air temperature. The following regression equations representing the measured indoor air temperature as a function of outdoor air temperature.

Cold:

$$T_i = 0.30T_o + 8.8$$

($n = 60, R^2 = 0.63, S.E. = 0.031, p < 0.001$)
Table 3: Comparison between mean indoor and outdoor air temperature with other studies in winter

| Country | Reference | Climate | Places        | Altitude [m] | Measurement period | $T_o$ [°C] | $T_i$ [°C] |
|---------|-----------|---------|---------------|--------------|-------------------|-----------|-----------|
| Nepal   | This study | Cold    | Mustang       | 2743         | Voting time       | 11.4      | 12.3      |
|         |           | Temperate| Kavrepalanchok| 1451         |                   | 16.8      | 16.7      |
|         |           | Sub-tropical| Sarlahi     | 157          |                   | 24.2      | 21.8      |
| Nepal   | Rijal et al. 2010 | Cold    | Solukhumbu    | 2410         | Daily mean        | 3.1       | 6.5       |
|         |           | Temperate| Dhading       | 1048         |                   | 10.1      | 11.5      |
|         |           | Sub-tropical| Banke        | 161          |                   | 11.3      | 13.3      |
| Pakistan| Nicol et al. 1996 | Cold    | Quetta        | 1672         | Voting time       | 6.0       | 19.3      |
|         |           | Temperate| Saidu         | 961          |                   | 8.0       | 12.7      |
|         |           | Sub-tropical| Maltun      | 122          |                   | 14.4      | 18.8      |
| India   | Thapa et al. 2018 | Cold    | Tiger Hill    | 2565         | Voting time       | 7.9       | 15.3      |
|         |           |         | Kurseong      | 1420         |                   | 14.2      | 16.6      |

Temperate:

\[ T_i = 0.51T_o + 8.1 \]

\[ (n = 85, R^2 = 0.72, S.E. = 0.035, p < 0.001) \] (2)

Sub-tropical:

\[ T_i = 0.52T_o + 9.3 \]

\[ (n = 130, R^2 = 0.27, S.E. = 0.074, p < 0.001) \] (3)

Where $T_i$ is indoor air temperature [°C], $T_o$ is outdoor air temperature [°C]; $n$ is number of respondents; $R^2$ is the coefficient of determination; S.E. is the standard error of the regression coefficient; and $p$ is the significance level of the regression coefficient.

Figure 4: Relationship between indoor and outdoor air temperature

The regression coefficient (the slope of the line) of cold climate is smaller than that of the temperate and sub-tropical climate. This difference might be due to wall thickness in the cold climate, where wall is thicker compared to temperate and sub-tropical climates. In the cold climate the houses are made up of stones and mud with thick wall (50cm) but in sub-tropical climate, the houses are made up of wooden with thin wall (2.5cm).

3.3 Thermal response

3.4 Thermal sensation

Thermal sensation has been analyzed to understand how the people respond to the thermal environment. Figure 5 shows the distribution of the thermal sensation votes of the respective climates. We have received the largest number of votes for ‘4 Neutral’ in all climatic zone. There are some votes for ‘5 slightly warm’ in temperate and sub-tropical climatic zones. If we group three of the seven-point thermal sensation scale 3, 4 and 5 for ‘comfort’ or ‘satisfied’ and the rest 1, 2, 6 and 7, ‘discomfort’ or ‘dissatisfied’, the 76.8% of the votes are in the ‘comfort’ in the cold climate which is 5.8% and 7.9% lower than temperate and sub-tropical climates. Likewise, in the cold climate, 23.4% of the votes are in ‘discomfort zone’ or
‘dissatisfied’ which is 5.7% and 8% higher than temperate and sub-tropical climates. The reason may be that the temperate and sub-tropical climate have slightly higher indoor air temperature compared to cold climate.

3.5 Thermal preference

Figure 6 shows the distribution of the thermal preference votes. We have received the largest number of the prefer votes for ‘2 a bit warmer’ in cold and temperate climatic zones which indicates that the occupants prefer to change the indoor environment. But in the sub-tropical climate we have received the largest number of prefer votes for ‘3 no change’, which indicates that the occupants satisfied to the indoor thermal environment. There are some votes for “1 much warmer” in cold climate and for “4 a bit cooler” in sub-tropical climatic zones. The reason for these votes may be that the occupants usually experience very cold environment in their everyday life during winter in cold climate and vice versa in sub-tropical climatic region.

![Figure 6: Distribution of thermal preference](image)

3.6 Comfort temperature

Estimation of comfort temperature by regression method

The regression analysis of thermal sensation and indoor air temperature was conducted to estimate the comfort temperature in three climatic regions as shown in figure 7.

![Figure 7: Relationship between thermal sensation vote and indoor air temperature](image)

![Figure 7: Relationship between thermal sensation vote and indoor air temperature](image)

The following regression equation is obtained for the thermal sensation (C) and indoor air temperature.

Temperate:

\[
C = 0.194T_i + 0.3 \\
(n = 85, R^2 = 0.241, S.E. = 0.040, p < 0.001)
\]  

(4)

When the comfort temperature was estimated by substituting “4 Neutral” in the equation 4, the comfort temperature would be 19.1°C in the temperate climate. However, the regression equations for the cold and sub-tropical climates are not statistically significant. This means that a reliable estimate of the comfort temperature is not possible using regression analysis as has been found in previous research [16, 17]. To avoid this problem, we have estimated the comfort temperature by Griffiths’ [18] method in next section.

Estimation of the comfort temperature by Griffiths’ method

In this study the comfort temperature is estimated by the Griffiths’ method [2, 6, 15, 19]. It is necessary to think carefully that what value of Griffiths’ constants is suitable for the 7-point thermal sensation scale.

\[
T_c = T_i + 4 - \frac{C}{a^*}
\]  

(5)

Where, \(T_c\) indicates comfort temperature to be estimated by Griffiths’ method [°C], 4 indicates neutral votes of the seven-point scale, \(C\) indicates the thermal sensation vote and \(a^*\) indicates regression coefficient assumed. In applying the Griffiths’ method, Nicol et al. [19, 20] investigated the effect of using various values for constants \(a^*\) (0.25, 0.33 and 0.50) to observe the change in comfort temperature.
Figure 8 shows the relationship between indoor air temperature when voting neutral and estimated indoor comfort temperature by Griffiths’ method. The mean neutral temperature calculated using 0.50 constant is nearest to the mean indoor air temperature when voting neutral. Therefore, the comfort temperature calculated with Griffiths constant of 0.50 is assumed for the further analysis similar to other studies [19].

Figure 8: Relation between mean indoor air temperature when voting ‘4 Neutral’ in thermal sensation vote and indoor comfort temperature by Griffiths’ method.

Regional difference in comfort temperature

Figure 9 shows the distribution of the estimated mean comfort temperature in each climatic region. The mean comfort temperature in cold climatic zone is 13.9°C which is 3.8K and 8.8K lower than temperate and sub-tropical climatic zones. The comfort temperature has regional difference which is similar to previous research [2,11,12]. Table 4 shows the comparison of comfort temperature with previous research. It can be said that since human beings have to keep the body core temperature within a narrow range, whether they are living in traditional houses or not. The regional difference of the winter comfort temperature may be affected by the difference of clothing insulation and activities of people. According to Nicol et al. [19], the seasonal difference of 0.50 clo corresponds to the difference of 3.5~4.0K in comfort temperature. The regional difference in comfort temperature by clothing insulation is about 1.3~3.9K. The rest of the difference [3.8K to 8.9K] could be due to other thermal adaptation.

Hence, the people are well adapted in lower indoor comfort temperature in cold climatic region than temperate and sub-tropical climatic regions.

3.7 Clothing adjustment

Figure 10: Distribution of the clothing insulation in three climatic regions

Clothing insulation directly affects the heat exchange between the occupants’ bodies, and their surrounding environment. It plays a key role in obtaining personal
Table 4: Comparison of comfort temperature in winter with different researches

| Countries  | Areas       | Altitude [m] | References          | House type   | Variables | Comfort temp. [ºC] |
|------------|-------------|--------------|---------------------|--------------|-----------|-------------------|
| Nepal      | Mustang     | 2743         | This study          | Traditional  | $T_i$     | 13.9             |
|            | Kavrepalanchok | 1451       |                     |              |           | 17.7             |
|            | Sarlahi     | 157          |                     |              |           | 22.7             |
|            | Solukhumbu  | 2410         | Rijal et al.        | Traditional  | $T_g$     | 13.4             |
|            | Dhading     | 1048         | 2010                |              |           | 24.2             |
|            | Banke       | 161          |                     |              |           | 16.2             |
| Pakistan   | Quetta      | 1672         | Nicol and Roaf 1996 | Naturally ventilated | $T_i$ | 20.2             |
|            | Saidu       | 961          |                     | buildings    |           | 19.8             |
|            | Maltun      | 122          |                     |              |           | 22.6             |
| India      | Tiger Hills | 2565         | Thapa et al.        | Residential  | $T_i$     | 15.6             |
|            | Kurseong    | 1420         | 2018                | buildings    |           | 18.1             |

The result shows that the clothing insulation is negatively correlated with the outdoor air temperature. It means that when the outdoor air temperature is increased, the people decreased the clothing insulation. The result also showed that people increase clothing as much as possible in the cold climate. According to equation 6, if outdoor air temperature is 14°C, the clothing insulation would be 1.5 clo.

4 Conclusions

We measured the indoor thermal environment in 108 traditional houses and conducted thermal comfort survey to 275 respondents in cold, temperate and sub-tropical climates. The results are summarized as follows:

1. The mean indoor air temperature is 12.3ºC in cold climate which is 4.4K and 9.5K lower than temperate and sub-tropical climates. The indoor air temperature in cold climate is significantly lower than the conventional standard.
2. The mean comfort temperature is 13.9ºC, 17.7ºC and 22.7ºC in cold, temperate and sub-tropical climates respectively. Thus, the regional difference of comfort temperature is very large 9.3K. It must be related to the adaptive behavior such as clothing insulations.

The mean clothing insulation in cold climate is 1.63 clo which is 0.31 clo and 0.48 clo higher than temperate and sub-tropical climates. However, the respondents do not wear less than 1 clo in cold climate and not more than 2 clo in the sub-tropical climates. The result showed that people increase the clothing as much as possible in the low temperature. Especially, people wear more clothing in cold climate to adapt in low indoor and outdoor air temperatures.

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References

[1] Rijal HB (2012), Thermal improvement of traditional houses in Nepal for the sustainable building design, *Journal of the Human-Environment System*, 15 (1): 1-11.

[2] Rijal HB, Yoshida H and Umemiya N (2010), Seasonal and regional differences in neutral temperatures in Nepalese traditional vernacular houses. *Building and Environment*, 45 (12): 2743-2753.

[3] Bajracharya S (2013), Investigation of thermal environment of the traditional houses of Kathmandu valley. *AIJ Kanto Chapter Architectural Research Meeting*, 141-144.

[4] BIS. National Building Code (2005), *Bureau of India Standard*.

[5] ENERCON, Building Energy Code of Pakistan (1990), *Government of Pakistan, Islamabad*.

[6] Nicol JF, Humphreys M and Roaf S (2012), Adaptive thermal comfort principles and practice.

[7] Rijal HB, Humphreys MA and Nicol JF (2017), Towards an adaptive model for thermal comfort in Japanese offices. *Building Research and Information*.

[8] de Dear RJ, and Brager GS (2002), Thermal comfort in naturally ventilated buildings. *Revisions to ASHRAE Standard 55. Energy and Buildings*, 34: 549-561.

[9] Indraghanti M (2010), Using the adaptive model of thermal comfort for obtaining indoor neutral temperature: Findings from a field study in Hyderabad, India, *Building and Environment*, 45: 519-536.

[10] Nicol JF and Roaf S (1996), Pioneering new indoor temperature standards: The Pakistan project. *Energy and Buildings*, 23: 169 -174.

[11] Thapa S, Bansal AK and Panda GK (2018), Adaptive thermal comfort in the residential buildings of north east India-An effect of difference in elevation. *Build Simul*, 11: 245-267.

[12] Wang Z (2006), A field study of thermal comfort in residential building in Harbin. *Building and Environment*, 41: 1034-1039.

[13] Thapa R, Rijal HB and Shukuya M (2018), Field study on acceptable indoor temperature in temporary shelters built in Nepal after massive earthquake 2015. *Building and Environment*, 135: 330-343.

[14] Havenith G (2003), Ergonomics of the thermal environment estimation of the thermal insulation and evaporative resistance of a clothing ensemble. ISO 9920.

[15] Kubota T, Rijal HB and Takaguchi H. (Eds.) (2018), Sustainable houses and living in the hot-humid climates of Asia. *Springer, July*.

[16] Rijal HB (2013), Field investigation of comfort temperature and adaptive model in Japanese houses. 29th *PLEA conference, Sustainable Architecture for a Renewable Future*, Munich, Germany 10-12 September.

[17] Nicol JF, Iftikhar AR, Alluidin A and Jamy GN (1999), Climate variations in comfort temperatures: The Pakistan projects. *Energy and Buildings*, 30: 261-279.

[18] Griffiths ID (1990), Thermal comfort in buildings with passive solar features: Field Studies. *Report to the commission of the European communities*, EN3S-090, UK: University Survey Guildford.

[19] Humphreys MA, Rijal HB and Nicol JF (2013), Updating the adaptive relation between climate and comfort indoors: new insights and an extended database. *Building and Environment*, 63(5): 40-55.

[20] Nicol JF, Jamy GN, Syker O, Humphreys M, Roaf S and Hancock M (1994), A survey of thermal comfort in Pakistan toward new indoor temperature standards. *Oxford Brookes University, Oxford England*.

[21] Watanabe K, Rijal HB and Nakaya T (2013), Investigation of clothing insulation and thermal comfort in Japanese houses. 29th *PLEA conference, Sustainable Architecture for a Renewable Future*, Munich, Germany 10-12 September.