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.

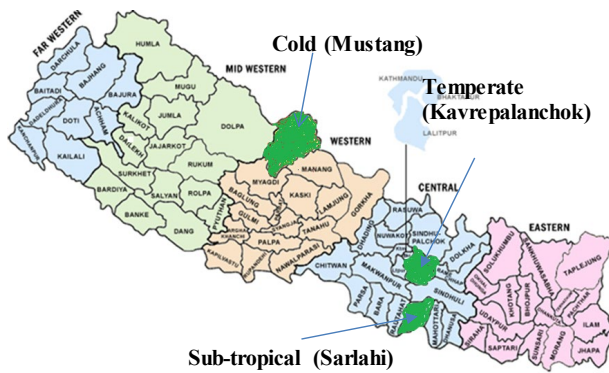## 2 Methodology

2.1 Research areas and investigated houses

Figure 1: Research areas

a)   **Cold climate**

b)   **Temperate climate**

c)   **Sub-tropical climate**

Figure 2: Investigated houses in each climate

Nepal has geographical variation ranging from 60m to 8848m. Its climate varies from sub-tropical to cold due to

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

(a) **Cold climate**   (b) **Temperate climate**   (c) **Sub-tropical climate**

Figure 3: Thermal measurement and thermal comfort survey

Table 2: Questionnaires used in the thermal comfort survey

English	Nepalese
Modify thermal sensation vote (mTSV)	चिसो तातोको अनुभव:
1. Very cold	१. जाडो
2. Cold	२. चिसो
3. Slightly cold	३. अलिकति चिसो
4. Neutral (Neither cold nor hot)	४. ठिक्क (चिसो पनि तातो पनि छैन।)
5. Slightly hot	५. अलिकति तातो
6. Hot	६. तातो
7. Very hot	७. गर्मी
Thermal preference	तापक्रमको चाहना:
1. Much warmer	१. धेरै न्यानो चाहिन्छ
2. A bit warmer	२. अलिकति न्यानो चाहिन्छ ।
3. No change	३. एतिकै ठिक्क छ ।
4. A bit cooler	४. अलिकति शितल चाहिन्छ ।
5. Much cooler	५. धेरै शितल चाहिन्छ ।

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:

$$T_i = 0.30T_o + 8.8$$
$$(n = 60, R^2 = 0.63, S.E. = 0.031, p < 0.001)(1)$$

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
	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:
$$T_i = 0.51T_o + 8.1$$
$$(n = 85, R^2 = 0.72, S.E. = 0.035, p < 0.001) \quad (2)$$

Sub-tropical:
$$T_i = 0.52T_o + 9.3$$
$$(n = 130, R^2 = 0.27, S.E. = 0.074, p < 0.001) \quad (3)$$

Where T_i is indoor air temperature [ºC], T_o is outdoor air temperature [ºC]; 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.
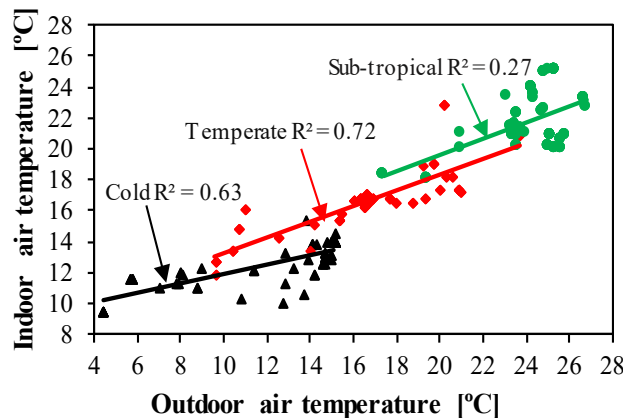

Figure 4: Relationship between indoor and outdoor air temperature

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).

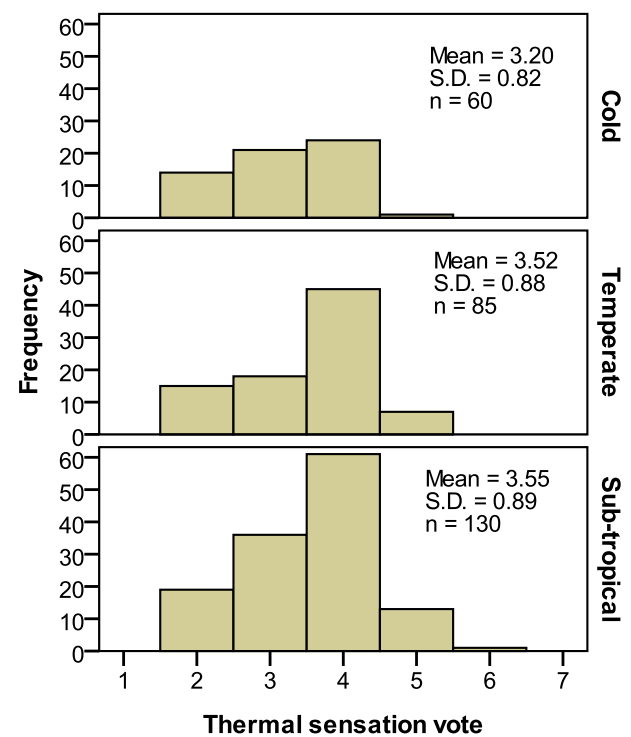## 3.3   Thermal response

3.4   Thermal sensation

Figure 5: Distribution of thermal sensation vote

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.
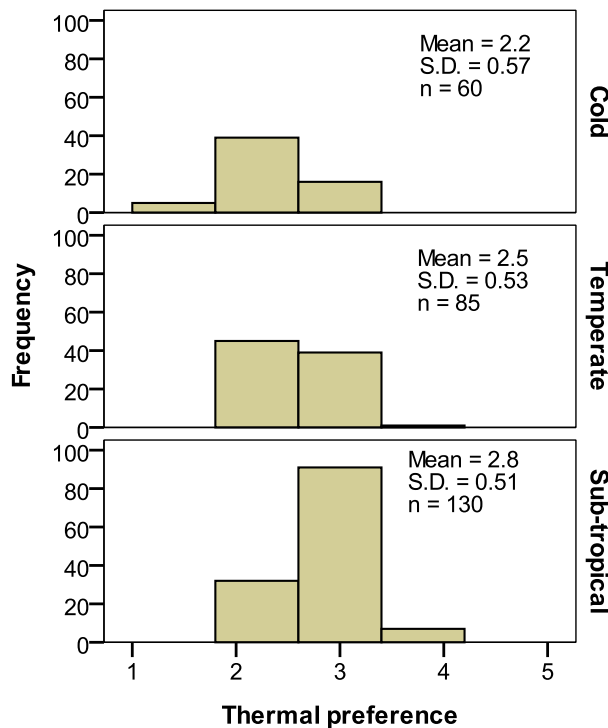

Figure 6: Distribution of thermal preference

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.

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

Temperate:
$$C = 0.194T_i + 0.3$$
$$(n = 85, R^2 = 0.241, S.E. = 0.040, p < 0.001) \qquad (4)$$

When the comfort temperature was estimated by substituting "4 Neutral" in the equation 4, the comfort temperature would be 19.1ºC 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.
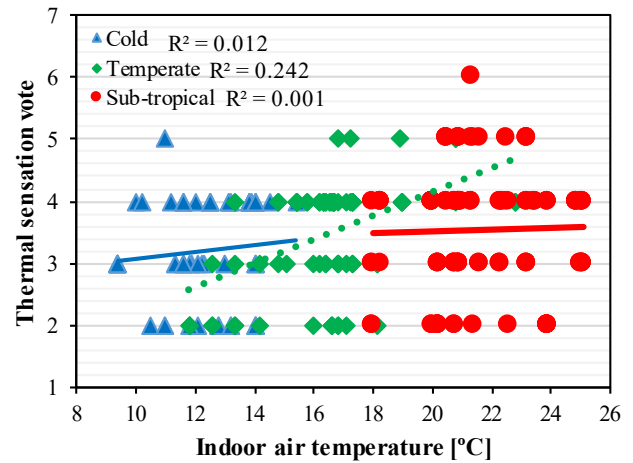

Figure 7: Relationship between thermal sensation vote and indoor air temperature

▉▉▉▉ *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.

$$T_c = T_i + \frac{4 - C}{a^*} \qquad (5)$$

Where, T_c indicates comfort temperature to be estimated by Griffiths' method [ºC], 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].
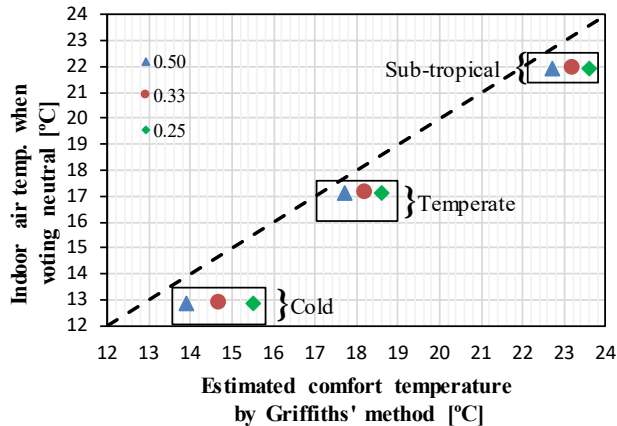

Figure 8: Relation between mean indoor air temperature when voting '4 Neutral' in thermal sensation vote and indoor comfort temperature by Griffiths' method.
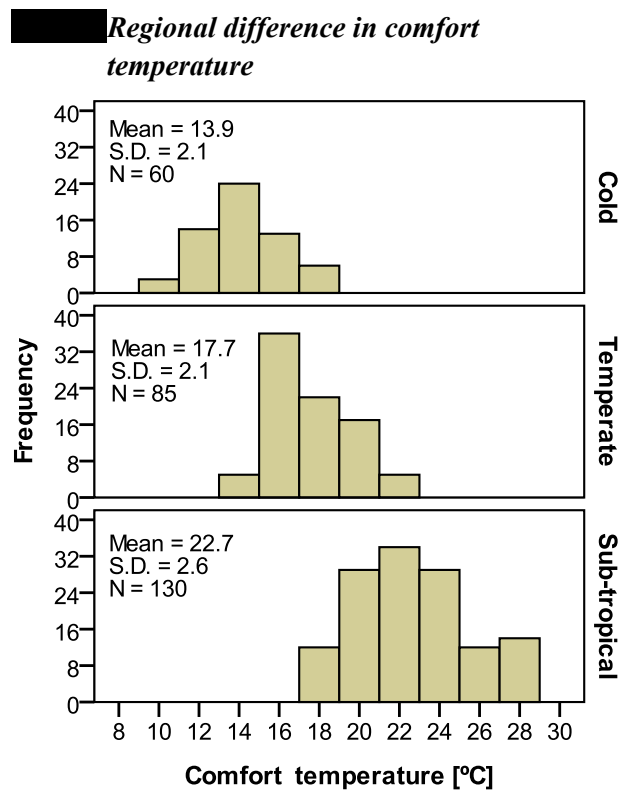
Regional difference in comfort temperature

Figure 9: Distribution of comfort temperature of each climate

Figure 9 shows the distribution of the estimated mean comfort temperature in each climatic region. The mean comfort temperate in cold climatic zone is 13.9ºC 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
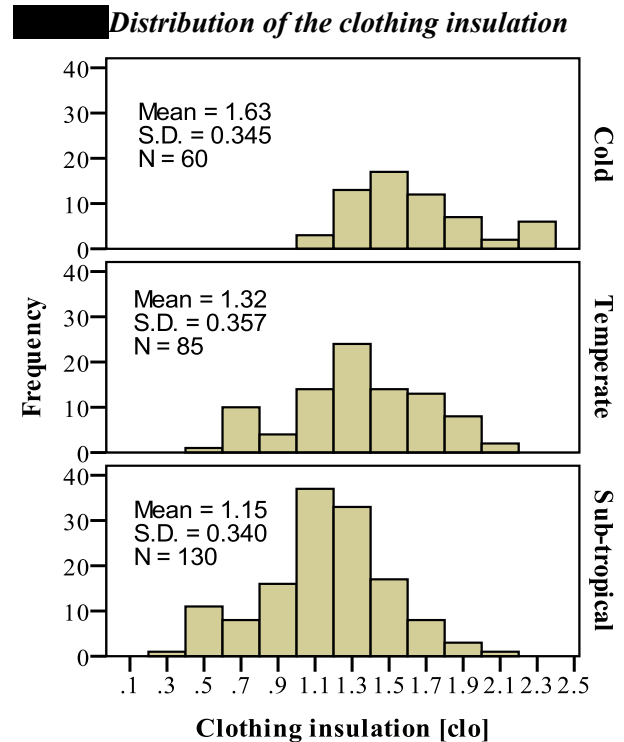
Distribution of the clothing insulation

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				13.9
	Kavrepalanchok	1451	This study	Traditional	T_i	17.7
	Sarlahi	157				22.7
	Solukhumbu	2410	Rijal et al.			13.4
	Dhading	1048	2010	Traditional	T_g	24.2
	Banke	161				16.2
Pakistan	Quetta	1672	Nicol and	Naturally ventilated	T_i	20.2
	Saidu	961	Roaf 1996	buildings		19.8
	Maltun	122				22.6
India	Tiger Hills	2565	Thapa et al.	Residintial	T_i	15.6
	Kurseong	1420	2018	buildings		18.1

thermal comfort of the respondents in different thermal environment. We have analyzed the clothing insulation of the respondents. Figure 10 shows the mean clothing insulation of three climatic regions. 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 climate. They do not wear less than 1 clo in cold climate and not more than 2 clo in the sub-tropical climate. This is similar to what was found in the research of Watanabe et al. [21].

█████ *Relationship between clothing insulation and outdoor temperature*
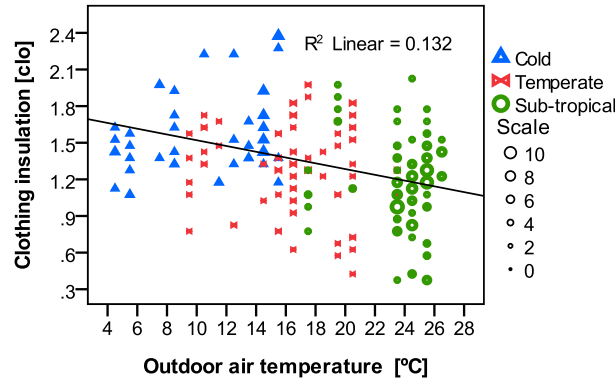

Figure 11: Relation between the clothing insulation and outdoor air temperature

We made a regression analysis on the clothing insulation and outdoor air temperature. Figure 11 shows the relationship between clothing insulation and outdoor air temperature in three climatic regions. In the cold climate, the outdoor air temperature is low and people wore more clothes, and in the sub-tropical climate, outdoor air temperature is high, and people wore less clothes. The following regression equation was obtained between the clothing insulation and outdoor air temperature.

$$I_{cl} = -0.024T_o + 1.8$$
$$(n = 275, R^2 = 0.13, S.E. = 0.004, p < 0.001) \qquad (6)$$

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.

We would like to express our gratitude to all the respondents residing in Mustang, Kavrepalanchok and Sarlahi districts for their valuable time and participation in the study.

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