Winter Thermal Comfort of Residents in the Himalaya Region of Nepal

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Abstract
A thermal comfort survey and a thermal investigation were conducted in traditional houses, during the winter in the Mustang district of Nepal. The surveys were carried out over 4 days, gathering a total of 1,584 thermal sensations from 36 subjects. The results show that 1) residents are highly satisfied with the thermal condition of their houses, 2) the mean neutral temperature is 10.7 ^{o}C and 3) the neutral temperatures are different according to the thermal environment of the evaluated spaces. These findings reveal that people are well adapted to the thermal environment of traditional houses, as a result of which the neutral temperature is lower than the thermal comfort standard.

Keywords: Nepal, Himalayas, thermal comfort, thermal comfort zone, neutral temp.

1. Introduction

In order to establish indoor air temperature standards, we have been doing research in the sub-tropical, temperate and cold climate zones of Nepal. Although we have already conducted research in one cold climate zone (the Solukhunbu district) of Nepal, we have again focused on another cold climate area (Mustang district, Lomangtang). The reasons for this are;

1) Due to the high altitude of this Himalayan region, it has a low outdoor air temperature (minimum air temperature –22.5 ^{o}C), high wind velocity and low sensory temperature (H.M.G. of Nepal (1995)). To protect inhabitants from the cold, courtyard houses are built connected to each other. The houses are also constructed with 450 mm thick dry brick walls and small windows.
2) As the area is located in the rain shadow on the northern side of the Himalayas, there is no effect from monsoons and the precipitation is low (113 mm per year, H.M.G. of Nepal (1995)). Consequently, the houses have flat roofs in which small holes are made for lighting and ventilation.
3) Due to the low precipitation, firewood is very scarce. Residents therefore burn livestock dung (yak, goat and horse) for cooking and heating.

Figure 1. Locations of the survey area

C9: 6.63 clo, C1: 2.52 clo

Photo1. Subjects in house C

Table 1. Outline of the investigated area

Survey area	Altitude [m]	Topography	Climate	T_{out} [^{o}C]	H_{out} [%]	Area	Race	Energy
1) Mustang	3,705	himalaya	cool	14.0/-1.3	71/97	village	Sherpa	livestock dung

T_{out} & H_{out} : monthly mean outdoor air temp. & relative humidity (May / January, 1988, Lo-mangtang)

These three factors present significant differences from the previous research area (Solukhumbu district). Lomangtang is an interesting research area from the viewpoint of thermal comfort and how the people manage to live thermally comfortably in such an extremely cold climate. The purposes of this research are to;

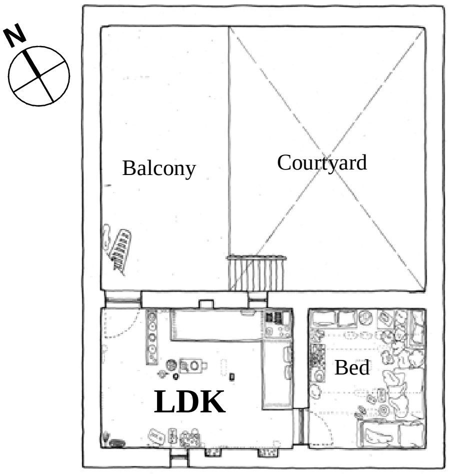
1) evaluate the thermal satisfaction of the houses,
2) establish the neutral temperature of the residents, and
3) show the relation between the neutral temperature and the thermal environment.

2. Outline of the area

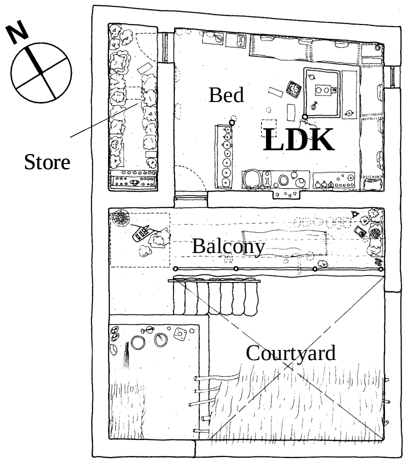
Lomangtang (3,705m), the study area, is located in the Mustang district of Nepal (Figure 1, Table 1, H.M.G. of Nepal (1995)). The climatic zone of this area is cold. It takes 4 days to get there on foot from Josmom airport. To avoid mountain sickness, we adapted by walking slowly and reducing our levels of physical activity.

In Nepal, summer is in May and winter is in January. Because of the landlocked nature of the country, the climate is dry and hot in summer. However, in the sub-tropical climate zone, relative humidity is 53% in May and it can feel cool in the shade (Rijal *et al.*, 2002, 2003). It is warm in winter during the daytime because Nepal lies in low latitudes (26^{o} to 30^{o} N) and insolation is high.

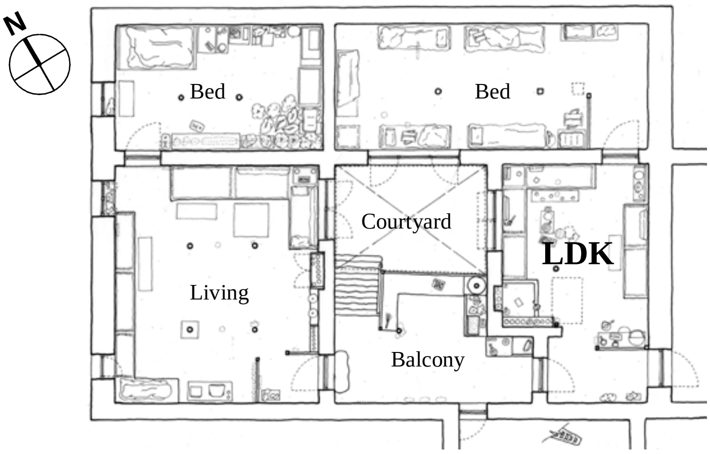
Figure 2 shows the plan of investigated houses. Most houses are 2-storey courtyard houses, built from sun dried brick (approx. 450 mm thick). Houses are constructed using the natural materials available in the area. The houses have few windows –



(a) House A



(b) House B



(c) House C

Figure 2. Plan of the investigated house (2F, Scale: 1:200)
(LDK(Living/Dining/Kitchen): Space of thermal comfort survey)

these are also small. Small holes are found in the roof for ventilation and lighting. The 1st floor is used for sheltering cattle and storage, and the 2nd floor is used for living space. The kitchen is used not only for cooking but also for living and dining. In some houses, it is also used for sleeping. Because of the low temperatures, people spend most of their time in the kitchen, keeping warm by burning livestock dung (yak, goat and horse). Recently, residents have begun using iron stoves for cooking and heating instead of the traditional open-hearth stove. The iron stove improves indoor air quality; however it requires more energy than the open-hearth.

3. Investigation method

Two surveys were conducted - 1) thermal comfort and 2) the thermal environment. From survey 1, the thermal satisfaction of the houses was identified and from the relationship between the two surveys, the neutral temperature of the residents was determined.

3.1 Thermal comfort survey

(1) Sensation scale

The English and Nepalese thermal comfort questionnaires are shown in Table 2. The questionnaire was translated into Nepali, the official language of Nepal, so that people could be interviewed. Some of the female subjects could not speak Nepali very well and the questionnaire was translated for them by local people fluent in Nepali. To evaluate the wide range of thermal environments in which the Nepalese live, a 9-point thermal sensation scale was used. The meaning, relationships and evaluation methods of the questionnaires were explained in advance to all the subjects either individually or in groups to improve the accuracy of the responses.

(2) Subjects

The mean age, height, body surface area and clothing insulation are shown in Table 3. 36 healthy local men and women were selected as subjects. Ages ranged from 17 to 60 years old. The mean age was 46.4 for the men and 37.8 for the women. At the time the questionnaire was conducted, the subjects were either sitting down resting, or sitting down and working. The residents are in the habit of wearing the same clothes for many days. Therefore, the subjects were asked to wear the same clothes during the investigation period (4 days) and if they wanted to change clothes, they were asked to wear similar clothes to the previous ones. Clothing insulation values were calculated by measuring the weight of the clothes (Hanada *et al.*, 1981, 1983). The clo value of

Table 2. Questionnaire form

<table>
<tr><th colspan="2">(a) English</th><th colspan="2">(b) Nepali</th></tr>
<tr><td>(1) Thermal sensation</td><td>(2) Thermal comfort</td><td>(१) चिसो-तातोको अनुभब</td><td>(२) चिसो-तातोको आनन्दपन</td></tr>
<tr><td rowspan="3">-4. very cold
-3. cold
-2. cool
-1. slightly cool
0. neutral
1. slightly warm
2. warm
3. hot
4. very hot</td><td>0. comfortable
1. slightly uncomfortable
2. uncomfortable
3. very uncomfortable</td><td rowspan="3">−४. धेरै जाडो
−३. जाडो
−२. चिसो
−१. अलिकती चिसो
०. ठिक्क
१. अलिकती तातो
२. तातो
३. गर्मी
४. धेरै गर्मी</td><td>०. आनन्द
१. अलिकती असुबिधा
२. असुबिधा
३. धेरै असुबिधा</td></tr>
<tr><td>(3) Thermal preference</td><td>(३) न्यानो-शितलको चाहाना</td></tr>
<tr><td>-2. much warmer
-1. slightly warmer
0. no change
1. slightly cooler
2. much cooler</td><td>−२. न्यानो चाहिन्छ
−१. अलिकती न्यानो चाहिन्छ
०. एतिकै ठिक्क छ
१. अलिकती शितल चाहिन्छ
२. शितल चाहिन्छ</td></tr>
<tr><td>(4) Skin moisture</td><td>(5) Activity</td><td>(४) शरिरको पसिना</td><td>(५) शरिरको कार्यशीलता</td></tr>
<tr><td>0. none
1. slightly
2. moderate
3. profuse</td><td>1. lying down
2. sitting resting
3. sitting working
4. standing
5. moving around</td><td>०. छैन
१. अलिकती छ
२. केही मात्रामा छ
३. धेरै छ</td><td>१. पल्टिरहेको
२. बसेर आराम गरिरहेको
३. बसेर काम गरिरहेको
४. उभिरहेको
५. उभिएर काम गरिरहेको</td></tr>
<tr><td>(6) Do you have any cold / hot part in the body?</td><td>(7) Can you accept the present cold / hot environment or not?</td><td>(६) तपाईको शरिरको कुनै भाग चिसा / तातो छ ?</td><td>(७) तपाई अहिलेको जाडो / गर्मी वातावरण खप्न सक्नु हुन्छ कि हुदैन् ?</td></tr>
</table>

Table 3. Outline of the investigated subjects

Investigated house	Subject		Age [year]		Height [cm]		Weight [kg]		S [m^2]		CI [clo]	
	M	F	M	F	M	F	M	F	M	F	M	F
1) A	3	9	47.0	38.9	164.0	154.2	52.0	44.4	1.56	1.41	3.25	6.04
2) B	4	7	40.8	31.3	162.3	155.3	53.9	46.4	1.57	1.44	2.63	5.20
3) C	3	10	53.3	41.3	160.0	155.5	58.1	50.1	1.59	1.48	2.80	6.41
mean	10	26	46.4	37.8	162.1	155.0	54.6	47.1	1.57	1.44	2.87	5.96

S: Body surface area ($S=100.315\ W^{0.383}\ H^{0.693}$, W: Weight (kg), H: Height (cm)), M: Male, F: Female
CI: Clothing insulation ($CI_M=0.000558w+0.068$, $CI_F=0.00103w-0.0253$, w: Cloth weight (g))

female clothing (mean 5.96) is higher than that of male clothing (mean 2.87) (Table 3). However, due to the high weight of the traditional clothing of this area, the clo value estimate may not be precise (Photo 1). It is said that a clo value of 7 is necessary when ‘at rest’ in –20 ^oC (Inoue, 1981), which is relevant to the high clo values and low outdoor air temperature (minimum –22.5 ^oC) of this research.

The physiques of Nepalese people are similar to those of the Japanese, therefore body surface areas were estimated using the formula for the Japanese (Kurazumi *et al.*, 1994). Because of heavy weight of the clothes (mean 5.4 kg, maximum 8.6 kg), they were excluded from the weight and body surface area calculations. The body surface areas are 1.57 m^2 for men and 1.44 m^2 for women. Daily allowances were paid to the subjects appropriate to the cost of living of the investigated area.

(3) Method of evaluation

The survey was carried out by one of the authors. Every hour subjects were gathered in the space to be evaluated 15 minutes before recording their answer so that they would have time to adapt to the environment before answering. Questionnaires were started 15 minutes before the hour in house A, on the hour in house B and 15 minutes past the hour in house C.

Thermal sensations were taken by approaching the subjects individually and collecting the answers orally, as many subjects cannot read. To get an accurate response, questions such as, “How do you feel in this place now?” were asked. Some subjects answered “It is colder/warmer than before.” They were asked not to compare their sensations to previous ones, but rather to choose an answer provided on the scale. If they could not differentiate the values on the scales, they were asked to rate the sensation numerically. If there were any ambiguous answers, the interview was repeated. When the questionnaire was completed, the subjects were permitted to leave the evaluated space. However, most of them stayed around the evaluated space. Subjects were asked to describe their sensations while together according to their own feelings, as mutual influences on the answers were expected.

Table 4. Description of evaluated house, space and period

Investigated house	Description of the house				Evaluated space	Period (2005)	
	storey	wall	roof	roof material		date	time
1) A	2	sun dried brick	flat	mud	LDK (2F)	1/5 to 1/8	7:45 to 17:45
2) B	2				LDKB (2F)		8:00 to 18:00
3) C	3				LDK (2F)		8:15 to 18:15

L: Living, D: Dining, K: Kitchen, B: Bed

(4) Evaluated spaces

The evaluated houses and spaces, the time of year and the time of day when the questionnaire was conducted, are shown in Table 4. The thermal comfort survey was conducted in the rooms of houses A, B and C (Figure 2). The evaluated space of house A and C are used for living/dining/cooking. While for the house B, it is also used for sleeping (Table 4). The subjects were divided into three groups. The subjects are members of the investigated houses and their neighbors.

(5) Period

The survey was carried out over 4 days (Table 4). A total of 1,584 thermal sensations were gathered. The sensations were gathered at intervals of one hour. There is no electricity supply in the winter and residents go to bed at around 8 p.m. Therefore the sensations were collected only during the daytime (Table 4).

3.2 Thermal measurement

The thermal investigations were conducted during the winter, January 2005. The conditions measured were air temperature, relative humidity, globe temperature (15cm diameter), wind speed, wind direction and solar radiation. Outdoor environmental conditions were measured at a height of 1.5m above roof level. Indoor conditions were measured in the centre part of the rooms at a height of 0.6m above floor level. All data were recorded at intervals of 5 minutes. Measured data were calibrated.

4. Results and discussion

4.1 Thermal environment

The mean indoor and outdoor air temperature, globe temperature and relative humidity are shown in Table 5. The daily mean outdoor and indoor air temperatures (relative humidity) were –2.4 ^{o}C (30%) and 6.0 ^{o}C (38%) respectively. The results show that the indoor air temperature and humidity are higher than the outdoor. The indoor air temperatures are also higher that the globe temperature. Daytime indoor air temperature and globe temperature are higher than at night. The opposite applies to relative humidity. It can be said that residents are living in a thermal environment far below the accepted thermal comfort standard.

Table 5 Mean air temp., globe temp. and relative humidity (January 5 to 8, 2005)

Investigated house	Outdoor (T_{out}) & Indoor (T_{in}) air temp. [°C]			Globe temp. (Tg) [°C]			Outdoor (H_{out}) & Indoor (H_{in}) relative humidity [%]		
	daily	DM	NM	daily	DM	NM	daily	DM	NM
T_{out}, H_{out}	-2.4	0.6	-5.4	-	-	-	30	23	37
A	3.9	5.5	2.4	3.5	4.9	2.1	38	34	43
B	7.4	8.1	6.6	6.9	7.7	6.1	36	33	39
C	6.7	8.9	4.5	6.0	8.1	4.0	39	32	45
mean	6.0	7.5	4.5	5.5	6.9	4.0	38	33	42

DM: Day mean (6:00 to 18:00), NM: Night mean (0:00 to 6:00 & 18:00 to 24:00)

4.2 Thermal satisfaction

To evaluate the thermal comfort, we have proposed the following ‘thermal comfort zone’: ±1 for thermal sensation (on a 9-point scale); 0. & 1. for thermal comfort (4-point scale); and ±1 for thermal preference (5-point scale) as in the PMV (±0.5 on the 7 point ASHRAE scale) (Rijal *et al.*, 2005). The ‘thermal comfort zone’ of thermal sensation is wider than the PMV because residents are accustomed to living in a natural environment and have a wider comfort zone than the subjects of an artificial environment (laboratory experiment). We used a 9-point thermal sensation scale in the thermal comfort survey, thus the difference between the ‘thermal comfort zone’ of thermal sensation and PMV is only 0.33. Although the ‘thermal comfort zones’ include discomfort scales, it is assumed that residents achieve thermal satisfaction by adjusting several passive methods. It may sound strange to use ‘comfortable’ as a term of thermal sensation and thermal preference. However the words ‘neutral’ and “no change” include the meaning of comfortable thus it is decided to use ‘comfortable’.

To clarify the thermal comfort of the residents, thermal sensation, thermal comfort and thermal preferences were analyzed. The distribution of sensation is shown in Figure 3. The mean values of the thermal comfort survey and the globe temperatures are shown in Table 6.

(1) Thermal sensation

The mean thermal sensation was –1.6 to –0.9 on the 9-point scale. When results from all the spaces are added together, the relative frequency is 22 % for ‘neutral’ and 59% for ‘thermal comfort zone’. The ‘cold’ sensations are seen in the cold periods of morning and evening, however most sensations are given as ‘slightly cool’. When reporting a ‘cold’ sensation, subjects mentioned cold parts of the body such as soles of the feet, knees, feet, hands and ears.

(2) Thermal comfort

The mean thermal comfort was 0.5 to 0.8. When the results from all the spaces were added together, the relative frequency was 43% for "comfortable" and 97% for 'thermal comfort zone'.

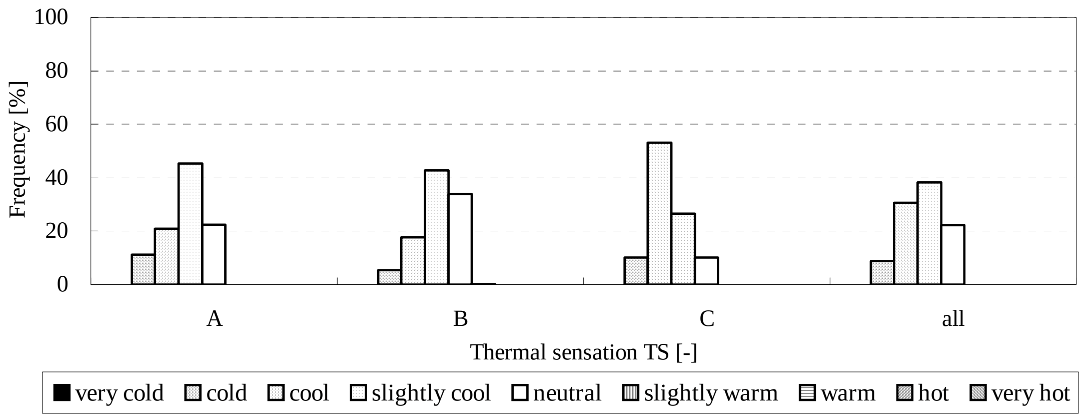
(3) Thermal preference

The mean thermal preference was –1.1 to –0.8. When the thermal sensation is on the 'cold' side, a 'warmer' vote is reported as a thermal preference. When results from all the spaces were added together, the relative frequency was 11% for 'no change' and 86% for 'thermal comfort zone'.

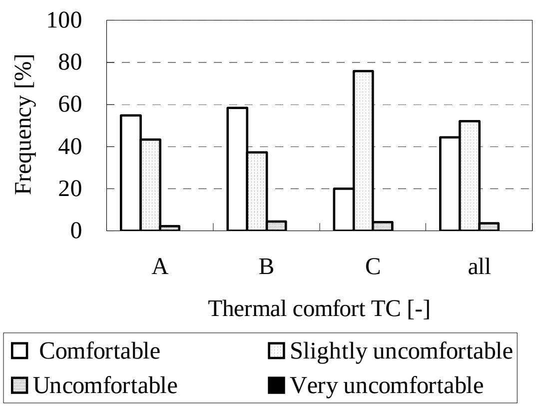
Table 6. Subjective evaluation of thermal environment

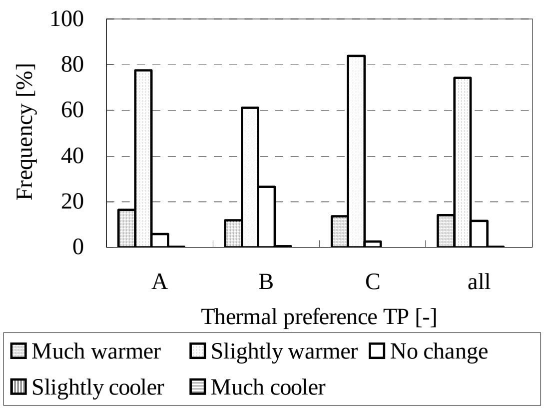
Investigated house	No. of sample	TS [-]				TC [-]				TP [-]				T_{gm} [^{o}C]		T_{gmn} [^{o}C]	
		mean	SD	N	±1	mean	SD	C	0. 1.	mean	SD	Nc	±1	mean	SD	mean	SD
1) A	528	-1.2	0.9	23	68	0.5	0.5	55	98	-1.1	0.5	6	84	5.6	3.0	7.6	2.0
2) B	484	-0.9	0.9	34	77	0.5	0.6	58	96	-0.8	0.6	26	88	8.5	1.6	8.6	1.3
3) C	572	-1.6	0.8	10	37	0.8	0.5	20	96	-1.1	0.4	2	86	9.2	1.9	10.6	1.7
mean	1,584	-1.3	0.9	22	59	0.6	0.5	43	97	-1.0	0.5	11	86	7.8	2.2	9.0	1.7

TS: Thermal sensation, TC: Thermal comfort, TP: Thermal preference, SD: Standard deviation, N, C & Nc: Frequency of 'Neutral', 'Comfortable' & 'No change' [%], *Tgm* & *Tgmn* : mean globe temp. when voting & for 'Neutral' vote, ±1 & 0.1.: Frequency of 'thermal comfort zone'



(a) Thermal sensation





(b) Thermal comfort (c) Thermal preference

Figure 3. Distribution of sensation

We have found an interesting relationship between the thermal sensation and thermal preference votes. Even though subjects reported ‘neutral’ in the thermal sensation (n=342), 52% of the votes were for ‘slightly warmer’ in the thermal preference survey. When the subjects were asked the reason for this, they were unable to give one. The reason could be that 1) they would prefer a warmer environment in the winter, 2) they experience a very cold outdoor environment in their everyday life and like to secure a warmer environment, 3) while they are satisfied with the current conditions, they would prefer a warmer environment if possible; a natural desire for most people.

(4) Discussion on thermal sensation

The frequency of ‘thermal comfort zone’ of thermal sensation, thermal comfort and thermal preference are high in the evaluated spaces. In all the houses, ‘thermal comfort zone’ of thermal comfort and thermal preference are very similar. While for the ‘thermal comfort zone’ of thermal sensation, house C is lower than the house A and B. It can be said that the thermal satisfaction in traditional houses is considerably high.

4.3 The neutral temperature

(1) Calculation of neutral temperature

The correlations between globe temperature and thermal sensation are shown in Figure 4. In determining the mean globe temperature for a certain vote time, temperature readings were taken every five minutes for one hour starting thirty minutes before the vote time and ending thirty minutes afterwards.

In this paper, the neutral temperature is defined as the globe temperature corresponding to a ‘neutral’ thermal sensation. Table 7 shows the neutral temperature and coefficient of correlation for each subject. Simple regression sometimes gives unreliable neutral temperatures, such as 120.7^{o}C. The neutral temperatures also show large individual differences in each space. To solve these problems, Nicol *et al.* (1994, 1996) obtained neutral temperatures using Griffiths’ (1990) method, modifying the unreliable values of neutral temperature obtained by simple regression as follows:

$T_{nG} = T_{gm} + (0 - TS_m) / a^*$………………….(1)

where,

T_{nG}: neutral temperature by Griffiths’ method

T_{gm}: mean globe temperature when votes are recorded

TS_m: mean thermal sensation vote

a^*: regression coefficient

Nicol *et al.* obtained three neutral temperatures by using regression coefficient values (a*) of a) 0.19, b) 0.25 and c) 0.33 according to Griffiths' method. a) A coefficient of 0.19 (summer) was obtained by Nicol *et al.* in Pakistan. On a 9-point scale, the coefficient obtained in this study is 0.08 from all data (Figure 4 (d)). This value is very small compared with the value of 0.19 (0.25, when converted on the 9-point scale) obtained in Pakistan by Nicol *et al.* Nepalese who live in the natural environment may use some methods of 'adaptation', since they always report an almost comfortable thermal response in different environments. b) A coefficient of 0.25 is often obtained in field surveys, according to Nicol *et al.* c) A coefficient of 0.33 was obtained by Fanger (1970) in the climate chamber using the probit method. Nicol *et al.* finally used this value.

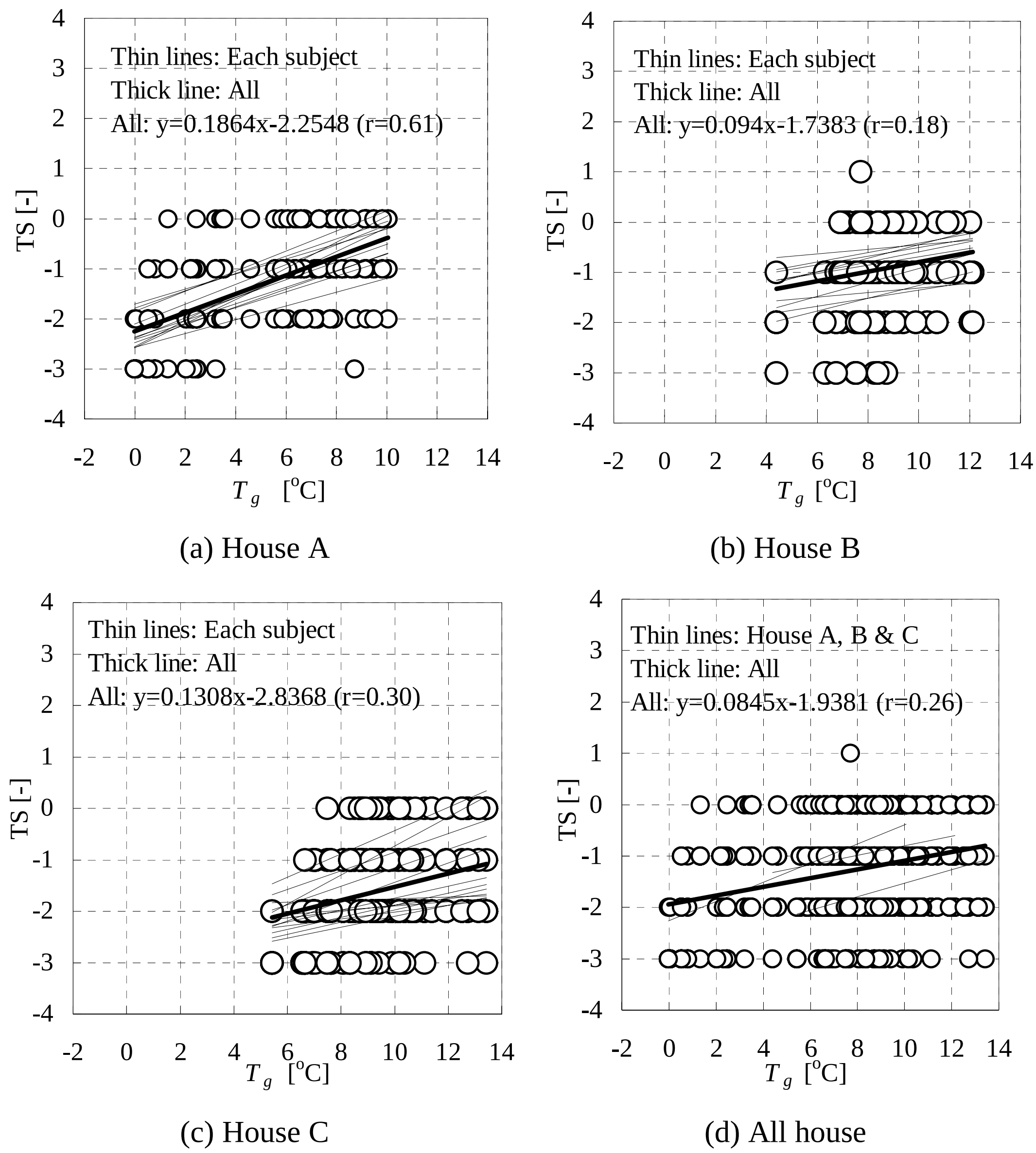


Figure 4. Relationships in between the globe temp. (T_g) and thermal sensation (TS)

Table 7. Neutral temperature of each subject

Investigated house	Subject	Sex	Neutral temperature [℃]				
			Regression		Griffiths (T_{nG})		
			T_n	r	0.08*	0.33*	0.44*
1) A	A1	M	9.2	0.74	14.7	7.8	7.3
	A2		10.7	0.62	18.1	8.6	7.9
	A3		11.4	0.64	16.4	8.2	7.6
	A4	F	15.3	0.63	24.6	10.2	9.1
	A5		14.3	0.53	23.5	10.0	8.9
	A6		13.9	0.71	24.1	10.1	9.0
	A7		12.9	0.63	21.8	9.5	8.6
	A8		10.4	0.55	15.8	8.1	7.5
	A9		9.8	0.76	19.2	8.9	8.1
	A10		11.8	0.71	21.2	9.4	8.5
	A11		10.7	0.74	21.0	9.3	8.4
	A12		18.7	0.54	28.1	11.1	9.7
	A all		12.1	0.61	20.7	9.3	8.4
	SD		2.7	0.08	4.0	1.0	0.7
2) B	B1	M	13.4	0.34	16.7	10.5	10.0
	B2		15.9	0.24	17.8	10.7	10.2
	B3		38.8	0.13	25.8	12.7	11.6
	B4		14.5	0.21	15.6	10.2	9.8
	B5	F	19.7	0.15	15.0	10.1	9.7
	B6		15.8	0.27	16.4	10.4	9.9
	B7		18.3	0.17	18.7	11.0	10.3
	B8		16.6	0.20	22.7	11.9	11.1
	B9		18.5	0.17	20.4	11.4	10.6
	B10		26.7	0.15	26.9	12.9	11.8
	B11		19.9	0.20	26.7	12.9	11.8
	B all		18.5	0.18	20.2	11.3	10.6
	SD		7.2	0.06	4.6	1.1	0.8
3) C	C1	M	14.7	0.59	21.7	12.2	11.5
	C2		16.4	0.47	25.4	13.1	12.1
	C3		12.6	0.70	21.1	12.1	11.4
	C4	F	17.7	0.40	29.1	14.0	12.8
	C5		120.7	0.04	31.4	14.6	13.2
	C6		25.0	0.27	32.2	14.8	13.4
	C7		56.0	0.19	33.3	15.1	13.6
	C8		40.6	0.19	33.3	15.1	13.6
	C9		11.9	0.58	16.9	11.1	10.6
	C10		29.7	0.40	36.5	15.8	14.2
	C11		26.6	0.35	35.1	15.5	13.9
	C12		40.7	0.36	35.1	15.5	13.9
	C13		26.2	0.43	33.9	15.2	13.7
	C all		21.7	0.30	29.6	14.1	12.9
	SD		29.1	0.18	6.3	1.5	1.1
mean			22.9	0.26	23.8	11.6	10.7

T_n : Neutral temperature of regression method,
T_{nG} : Neutral temperature of Griffiths analysis,
r: Corelation cofficient, *: Regression coefficient,
M: Male, F: Female, SD: Standard deviation

Table 8. Difference in neutral temp. in the same area (present research)

Investigated district	Neutral temperature [°C]			Difference [K]	
	A	B	C	C-A	C-B
1) Mustang	8.4	10.6	12.9	4.6	2.3

Table 9. Difference in neutral temp. in the same area (previous research)

Investigated districts	Neutral temperature [°C]		Difference [K]
	Indoor (I)	Semi-open (S)	S-I
1) Banke	16.2	19.9	3.7
2) Dhading	24.2	19.1	-5.1
3) Kaski	18.0	20.3	2.3

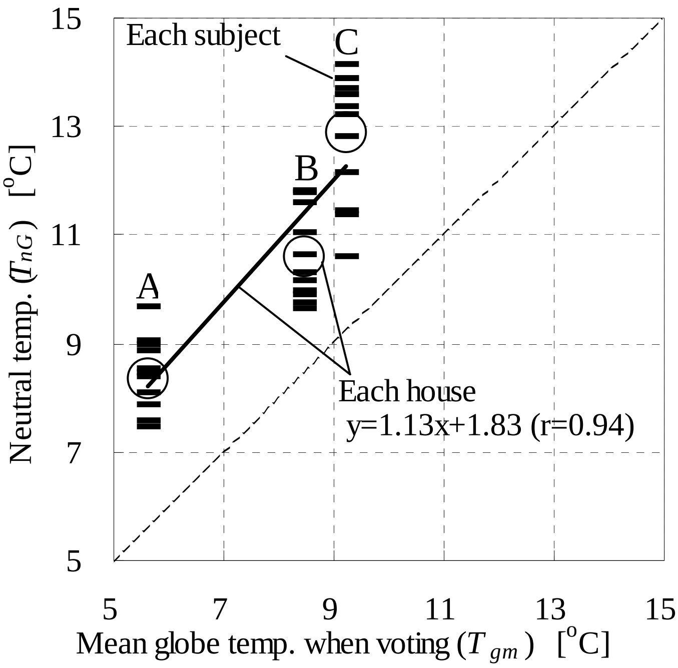


Figure 5. Relation between T_{nG} and T_{gm}

In this study we also used three coefficients a) 0.08, b) 0.33 and c) 0.44 (converted to the 9-point scale) in a similar manner, and compared them with the results obtained using simple regression. The results are shown in Table 7. Calculating the neutral temperature using a) 0.08 modified the unreliable value of the neutral temperature of the regression analysis, although the individual differences were still large. On the other hand, calculations using b) or c) yielded small individual differences in neutral temperature and the difference in neutral temperature between b) and c) are also within +1.7 K. In addition, the neutral temperature is close to the mean globe temperature for the 'neutral' vote (T_{gmn}, Table 6). However, the standard deviation of neutral temperature using a coefficient of 0.44 is the lowest, and the one we used in this study. The neutral temperature difference (T_{nG}–T_n) between Griffths' (T_{nG}) method and the regression analysis (T_n) in Nepal is similar to that in Pakistan (–8 to +5K), excluding the unreliable difference, which is smaller than -10K.

(2) Satisfaction with a low neutral temperature

The neutral temperature of the cold climate was determined. When the results from all the spaces are added together, the neutral temperature is 10.7℃, which was lower than the thermal comfort standard. This may be related to adjustment of the clo value and adaptation in winter. The neutral temperature is 2.7K lower than that of the Solukhumbu district (cold climate). This may be related to the clo value, which was 2.71 clo higher than that of the Solukhumbu district (Rijal *et al.*, 2002, 2003).

(3) Difference in neutral temperature in the same area

To show the differences in neutral temperatures within the same area, the neutral temperatures of houses A, B and C were compared. The neutral temperature of house C is 12.9℃, which is 4.6K and 2.3K higher than those of houses A and B respectively (Table 8). The mean globe temperature during the investigation period was 5.6 ^{o}C (house A), 8.5 ^{o}C (house B) and 9.2 ^{o}C (house C) (Table 6). In previous research, we also found differences in neutral temperature between the semi-open and indoor spaces (Rijal *et al.*, 2002, 2003, Table 9). The results show that if globe temperature is high, neutral temperature is also high, and the neutral temperatures are different in the same area (Figure 5). The thermal comfort survey was conducted among residents who were born and grew up in the same investigated area, and if the subjects of house A, B and C were to be changed around and another thermal comfort survey was conducted, a similar kind of neutral temperature could be expected.

5. Conclusion

A survey of the thermal environment and thermal sensations was conducted in the winter among residents of traditional houses in the Mustang district in Nepal. The results are:

1) The frequency of the 'thermal comfort zone' is high in thermal sensation, thermal comfort and thermal preference. The residents are satisfied with the thermal condition of the traditional houses.
2) The average neutral temperature was 10.7 ^{o}C, which is lower than the thermal comfort standard. Due to modifications in clothing and adaptation to winter conditions, the neutral temperature is lower than that of the Solukhumbu district (cold climate).
3) The neutral temperature of 'House C' was 12.9 ^{o}C, which is 4.6 K and 2.3 K higher than houses 'A' and 'B' respectively. There are differences in neutral temperatures within the same area. Residents appear to have a certain range of

comfort zones, and the neutral temperature could be determined by the degree of exposed air temperature. It means that the neutral temperature is directly proportion to the thermal environment.

Acknowledgments

We would like to thank 'The Japan Society of the Promotion for Science' for its financial support, the Hata Laboratory (Shibaura Institute of Technology) for their drawings, and the investigated households and subjects for their cooperation.

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