Lowland Technology International 2016; 18 (2): 119-128
International Association of Lowland Technology (IALT): ISSN 1344-9656
Special Issue on: Nepal Earthquake & Disaster

Research Paper

Study on thermal environment and thermal comfort in autumn season of temporary shelters in Nepal after massive earthquake 2015

R. Thapa [1] and H.B. Rijal [2]

ARTICLE INFORMATION

Article history:

Received: 27 July, 2016
Received in revised form: 28 August, 2016
Accepted: 31 August, 2016
Publish on: 26 September, 2016

Keywords:

Nepal Earthquake
Temporary shelters
Air temperature
Globe temperature
Comfort temperature

ABSTRACT

Extreme natural disasters are events caused by environmental factors that injure, displace people and damage property. On 25th April 2015 a devastating earthquake of 7.8 on Richter scale struck Nepal causing approximately 9,000 deaths and damage to 900,000 houses. Homeless victims are doomed to live in temporary shelters. In the context of Nepal, after the massive earthquake, no research is done to evaluate the thermal environment in temporary shelters and thermal comfort of habitants. Thermal measurements and thermal comfort surveys were conducted to find out the actual conditions of thermal environment in the temporary shelter and thermal comfort status of respondents. The surveys were carried out for 30 days in autumn covering 202 residents. The mean indoor temperature is 21.1 °C, which is similar to the globe temperature. From the analysis we found that mean day time and night time indoor air temperatures are 18.7 °C and 15.2 °C respectively. The comfort temperature in the temporary shelter is 23.9 °C and the mean clothing insulations of residents is 0.73 clo. The result indicates that the indoor air temperature in the temporary shelter is considerably low in autumn season but residents are maintaining thermal comfort by using various behavioral adaptations.

1. Introduction

Extreme natural disasters are events caused by environmental factors that injure, displace people and damage property. Earthquakes, storms, floods, and disease all strike anywhere on the globe causing unprecedented damage to life and property and compel people to live in temporary shelters as makeshift arrangements. But these makeshift shelters most of the time become long time shelters compromising inhabitants' safety, security and quality of life because of various constraints. On 25th April 2015, a devastating earthquake of 7.8 on Richter scale struck Nepal causing approximately 22,000 injuries, 9,000 casualties and damage to 900,000 houses (Earthquake report.com, 2015).

Nepalese people whose homes are destroyed and respondents who are staying in temporary/make shift shelters deprived of basic facilities are struggling against all odds to bounce back to normalcy. Unconventional shelters in these makeshift camps provide no relief from rain, scorching sun and cold. The sick, injured, pregnant women, children and the elderly are struggling against loss of livelihood, basic services and lack of privacy

[1] Ph.D. Student, Graduate School of Environmental and Information, Tokyo City University, Yokohama, JAPAN, thapareeta19@gmail.com
[2] Associate Professor, Faculty of Environmental Studies, Tokyo City University, Yokohama 224-8551, JAPAN, rijal@tcu.ac.jp
Note: Discussion on this paper is open until March 2017

among many issues (Koirala, 2015). Lack of finance and resources make these people to think and use local and affordable material such as plastics, tarpaulins, bamboo slits, mud plaster and plywood under or over the zinc sheet to protect themselves from harsh climatic conditions. It is a well-known fact that basic design, area, ventilation, daylight and lighting of temporary housing have a direct impact on the residents' well-being and quality of life. Therefore, temporary housing designers must consider various material properties and building structures wisely to ensure overall wellbeing of occupants (FEMA 2009; Chen et al., 2014).

In literature we found thermal performance study of emergency shelters using dynamic simulation tools have been done using simple materials (Cornaro et al., 2015). They designed a kit which is used to build a strong reciprocal frame from bamboo or steel poles based temporary shelters. After a disaster, plastic sheet or tarpaulins are often handed out, and are used in the construction of makeshift shelters. It has been found that these materials are inadequate, too weak or not sturdy enough to withstand the harsh weather events that are being followed by extreme events. Immediately after disasters, providing a safe, stable and convenient living environment for people who cannot return to their own houses is a key issue for every country when conducting post-disaster recovery (Johnson, 2007; Chen et al., 2014).

In the context of Nepal, we found some articles about thermal environment of the traditional houses of Kathmandu valley (Bajracharya, 2013). Several researched papers are also found that have addressed the issue of summer and winter thermal environment in traditional vernacular houses in Nepal (Rijal et al., 2002, 2005, 2006, 2010 and 2012). Living condition under different temporary shelters is an important area of concern and needs an urgent attention in the context of looming disasters.

After the massive earthquake many temporary shelters were constructed by people to protect themselves from harsh climate. These temporary shelters turned out to be long time shelters of people because most of them lost their livelihood leading to the question that what kind of thermal environments persists in these shelters and its effect on the occupant's wellbeing.

In this context it became important to study the thermal environment of temporary shelters and thermal comfort of respondents (Thapa and Rijal, 2015 a-d). Through this study we try to find out the actual conditions of thermal environment and adaptive thermal comfort of the occupants. This survey based research is conducted where environmental parameters were recorded so that they can be utilized to design and plan thermally comfortable temporary shelters in the future, considering cost, time and size of family (Possibly combined with hi-tech technology). This research also tries to bring some solutions and innovative ideas to maintain thermal comfort and suitable thermal environment in the temporary shelters and fill the research gap. We hope that this study will be helpful for shelter designers and researchers. Outcome of this research can contribute not only to academic research but can also impact the planning at national and local level.

The objectives of this study are; to clarify the indoor thermal environment in the temporary shelter, and to find out the level of thermal sensation, thermal preference, thermal satisfaction, overall comfort and the comfort temperature of the residents.

2. Methodology

2.1 Research area

The areas worst hit by the massive earthquake have been chosen for research. Places of Gorkha, the epicenter of first tremor; Sindhupalchowk, the most devastated and the epicenter of other large and small aftershocks, the capital city- Kathmandu, a densely populated valley, have been chosen as the research areas (**Fig. 1**).

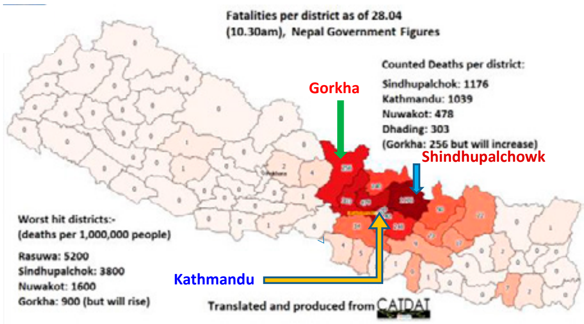


Fig. 1. Research area.

2.2 Thermal measurement

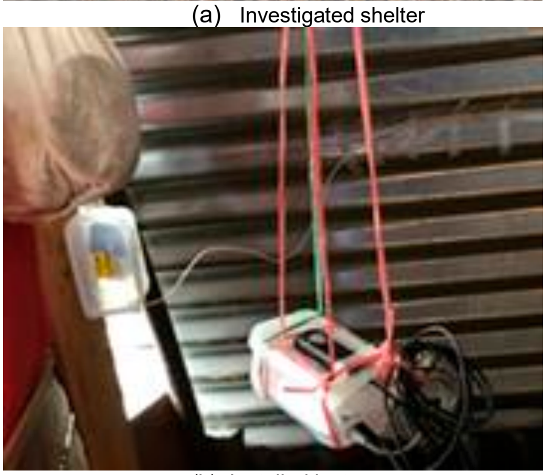
The temporary shelter constructed in Luboo village of Lalitpur district is shown in **Fig. 2**. The temporary shelter is rectangular shaped and is constructed with zinc sheet roof and walls (**Table 1**). Plinth is raised to 400 mm using backed mud bricks to avoid rain water. The door is kept in south side with two small windows in east and west directions walls (**Fig. 2**).

During the survey environmental parameters such as indoor air temperature (T_i), globe temperature (T_g) and outdoor air temperature (T_o) were measured by using digital instruments (**Fig. 2**). Indoor measurements were taken at 1.1 m level from the floor. Indoor environment data is recorded by a data logger at the interval of 10 minutes from 4 to 20 November 2015 (16 days).

Table 1. Dimension of the temporary shelter.

Description	Height (mm)	Length (mm)	Breadth (mm)
Dimension	720	1950	1360

(a) Investigated shelter



(b) Installed instruments

Fig. 2. Thermal measurement in a temporary shelter.

2.3 Thermal comfort survey

Questionnaires based on thermal comfort surveys were conducted in autumn season for about one month in three districts (**Fig. 3**). Questionnaires were designed to collect information about the thermal sensation, thermal preference, thermal satisfaction, overall comfort and clothing (**Table 2**). The questionnaires were translated into Nepalese language (Rijal et al., 2010) for the ease of understanding to subjects. Extensive interaction with the subjects in advance was done to explain the meaning, relationships and evaluation methods of the questionnaires. In this period total 202 subjects were interviewed for data collection.

(a) Temporary shelters.

(b) Thermal comfort survey.

Fig. 3. Thermal comfort survey in the temporary shelters.

Table 2. Scale of thermal comfort.

Scale	1. Thermal sensation	2. Thermal Preference
1	Cold	Much warmer
2	Cool	A bit warmer
3	Slightly cool	No change
4	Neutral	A bit cooler
5	Slightly warm	Much cooler
6	Warm	
7	Hot	
	3. Thermal satisfaction	4. Overall comfort
1	Very satisfy	Very comfortable
2	Moderately satisfy	Moderately comfortable
3	Slightly satisfy	Slightly comfortable
4	Slightly unsatisfied	Slightly uncomfortable
5	Moderately unsatisfied	Moderately uncomfortable
6	Very unsatisfied	Very uncomfortable

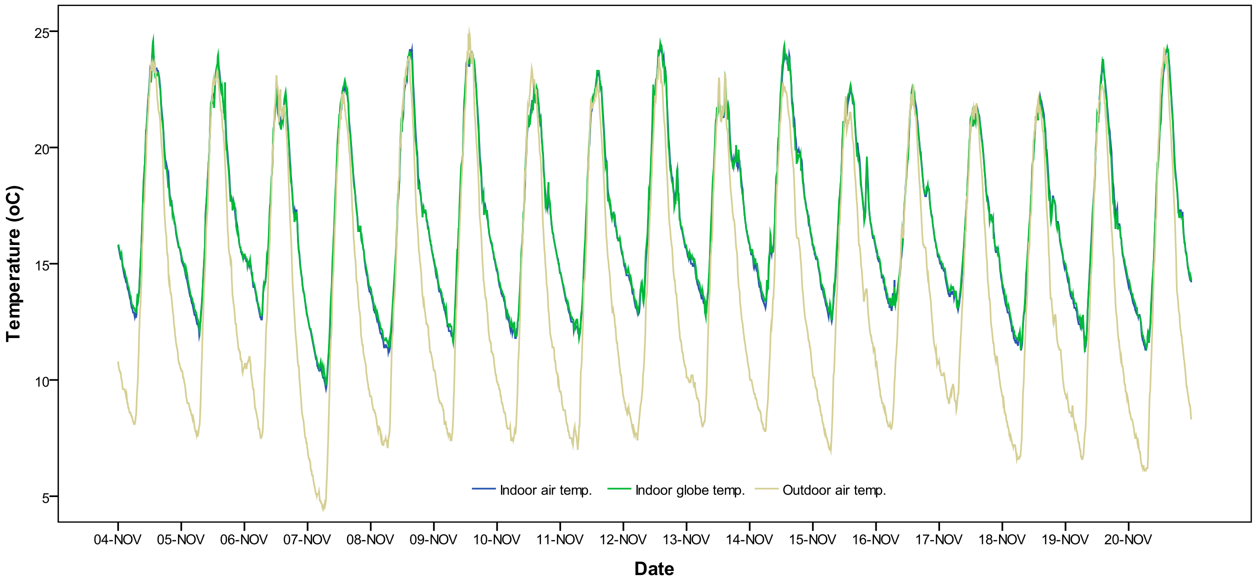


Fig. 4. Variation of indoor air temperature, outdoor air temperature and globe temperature.

Table 3. Mean and standard deviation of temperatures.

Variables	Day time			Night time			Sleeping hour		
	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.
Indoor air temp. (°C)	1224	18.7	3.9	1225	15.2	2.1	919	14.3	1.5
Indoor globe temp. (°C)	1224	18.7	3.9	1224	15.2	1.9	918	14.4	1.5
Outdoor air temp. (°C)	1224	17.1	5.1	1225	10.4	2.5	919	9.3	1.6

N: Number of sample, S.D.: Standard Deviation

3. Thermal environment of a temporary shelter

3.1 Variation of indoor and outdoor temperatures

Figure 4 shows the profile of indoor air temperature, indoor globe temperature and outdoor air temperature of overall days (16 days) of selected shelter and **Fig. 5** shows 24 hour temperature profile of a typical day (8th November). We selected November 8th (one day) because on that day no drastic deviation in weather conditions is observed. From the figure we can see that the indoor air temperature and indoor globe temperature are tracing each other and are significantly higher than outdoor air temperature in early morning and at night time.

3.2 Mean temperature in different time zone

Mean indoor, globe and outdoor air temperatures observed during the 16 days of research are shown in **Table 3**. Here, 24 hour of a day is divided into two sections i.e. Day time (6:00 to 17:50) and night time (18:00 to 5:50). We can see the mean indoor air temperature in day time is 18.7 °C which is similar to indoor globe temperature. The mean indoor air temperature in night time is 15.2 °C which is similar to indoor globe temperature (**Table 3**). Sleeping hour mean indoor air temperature is 14.3 °C which is also similar to globe temperature. The result showed that the indoor air temperature is 5 °C higher than outdoor air temperature.

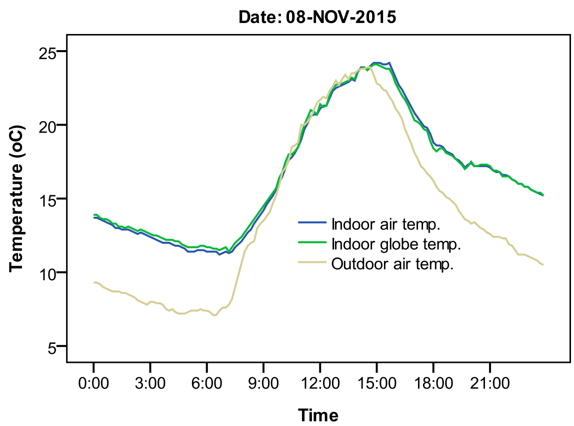


Fig. 5. Variation of indoor air temperature, outdoor air temperatures and globe temperature in a day (8th November).

3.3 Relation between the indoor globe temperature and indoor air temperature

Figure 6 shows the relationship between indoor air temperature (T_i) and indoor globe temperature (T_g) of the studied shelter. They are highly co-related. Here, we obtained the following equation to predict the temperature.

$$T_g = 0.981T_i + 0.379 \quad [1]$$

($N = 2448$, $R^2 = 1.00$, S.E. = 0.001, $P < 0.001$)

N: Number of sample, R^2: Coefficient of determination, S.E.: Standard Error of the regression coefficient, P: Significant level of regression coefficient.

If we know the indoor air temperature, we can predict the indoor globe temperature by using this equation. For example, if indoor air temperature is 18 °C, then the indoor globe temperature would be 18.1 °C.

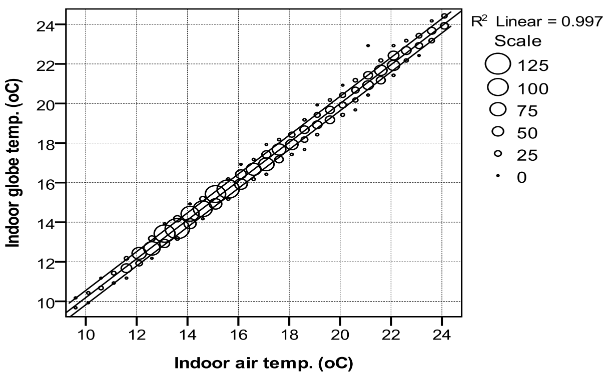


Fig. 6. Relation between the indoor globe temperature and indoor air temperature.

3.4 Prediction of indoor air temperature by outdoor air temperature

Figure 7 shows relationship between indoor air temperature (T_i) and outdoor air temperature (T_o) within the 95 % limits of the data. We have obtained the following regression equation from the regression analysis.

$$T_i = 0.658T_o+7.869 \quad [2]$$

($N=2449$, $R^2= 0.93$, S.E.=0.004, $P < 0.001$)

If we know outdoor air temperature then we can predict the indoor air temperature by using this equation. For example, if outdoor air temperature is 15°C, then indoor air temperature would be 17.1°C.

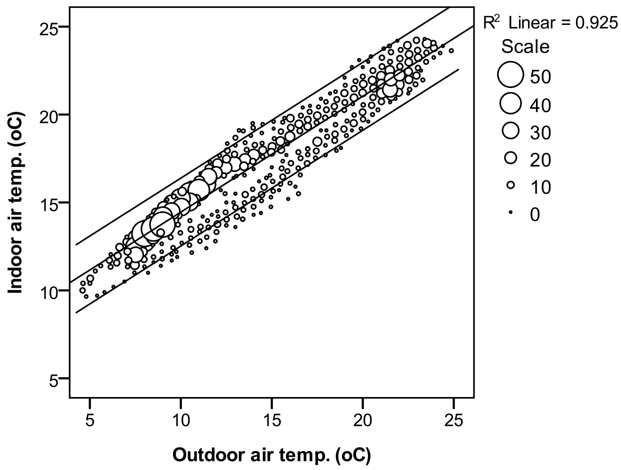


Fig. 7. Relation between the indoor air temperature and outdoor air temperature.

4. Thermal comfort surveys of temporary shelters

4.1 Evaluation of thermal environment during voting

The mean indoor temperature and humidity are shown in **Table 4**. The mean indoor air temperature is 21.1 °C, which is similar to the globe temperature, mean radiant temperature and operative temperature. This supported by T_g value which is higher than T_i. Thus we get this result because of surrounding surfaces have radiative effect. The mean indoor relative humidity is 58%.

Figure 8 shows scatter-plot between T_i and T_g during the voting. There is almost no difference between them. They are interrelated to each other except the T_i is low nearly 19 °C compare to T_g due to cold surface of temporary houses. From regression analysis we obtained the following equation to predict T_g by T_i.

Table 4. Mean and standard deviation of temperatures during voting.

Variables	Lalitpur (N=148)		Gorkha (N=25)		Shindhupalchowk (N=29)		All (N=202)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
T_i (°C)	20.6	3.4	20.9	3.1	24.1	1.9	21.1	3.4
T_g (°C)	20.8	3.5	21.4	3.2	24.6	2.0	21.4	3.5
T_{mrt} (°C)	20.9	3.6	21.6	3.2	24.7	2.1	21.5	3.6
T_{op} (°C)	20.7	3.4	21.3	3.2	24.4	2.0	21.3	3.5
RH_i (%)	59	14	64	11	52	5	58	13

N: Number of sample, S.D.: Standard deviation, T_i: Indoor air temp., T_g: Indoor globe temp., T_{mrt}: Mean radiant temp. T_{op}: Operative temp., RH_i: Indoor relative humidity

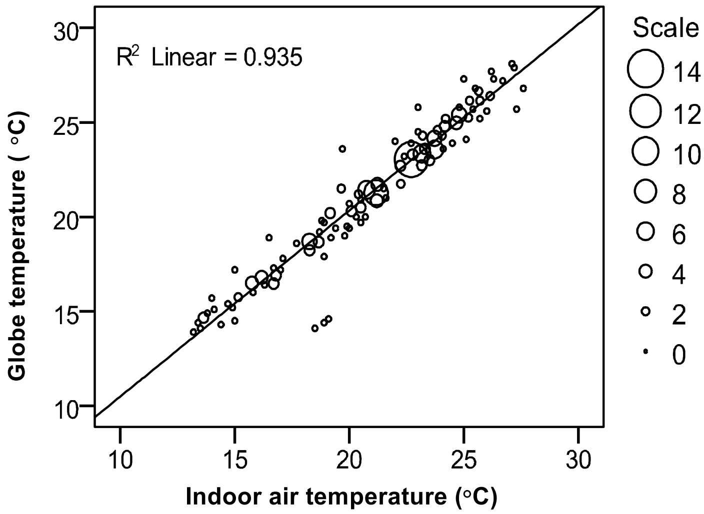


Fig. 8. Relation between the indoor globe temperature and indoor temperature during voting.

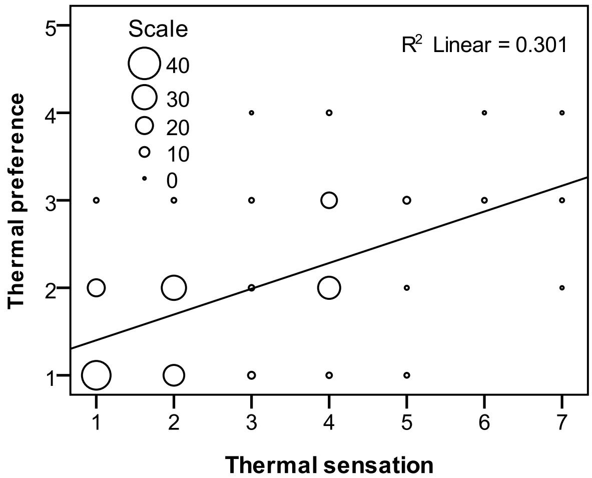


Fig. 9. Relation between the thermal preference and thermal sensation.

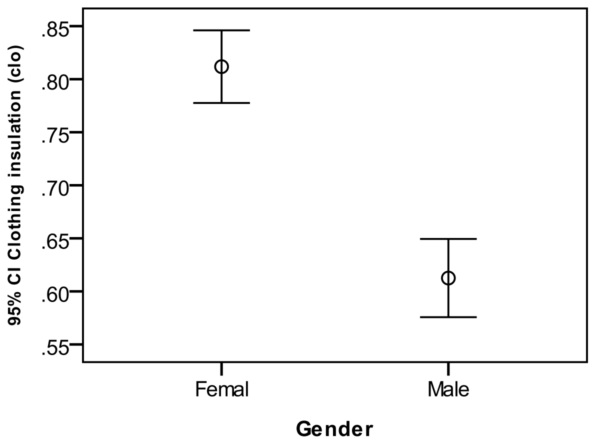


Fig. 10. Clothing insulations of female and male.

Table 5. Subjective evaluation of residents.

District	Scale	TSV		TP		TS		OC	
		N	P [%]	N	P [%]	N	P [%]	N	P [%]
Lalitpur	1	40	27.0	48	32.4	0	0.0	0	0.0
	2	40	27.0	64	43.2	23	15.5	18	12.2
	3	13	8.8	30	20.3	29	19.6	32	21.6
	4	40	27.0	6	4.1	40	27.0	45	30.4
	5	8	5.4	0	0.0	33	22.3	33	22.3
	6	3	2.0	-	-	23	15.5	20	13.5
	7	4	2.7	-	-	-	-	-	-
	Total	148	100	148	100	148	100	148	100
Gorkha	1	15	60.0	13	52.0	0	0.0	0	0.0
	2	5	20.0	9	36.0	0	0.0	0	0.0
	3	0	0.0	3	12.0	2	8.0	2	8.0
	4	3	12.0	0	0.0	5	20.0	9	36.0
	5	2	8.0	0	0.0	10	40.0	10	40.0
	6	0	0.0	-	-	8	32.0	4	16.0
	7	0	0.0	-	-	-	-	-	-
	Total	25	100	25	100	25	100	25	100
Shindhupalchowk	1	4	13.8	13	44.8	0	0.0	0	0.0
	2	13	44.8	11	37.9	0	0.0	0	0.0
	3	1	3.4	5	17.2	0	0.0	0	0.0
	4	9	31.0	0	0.0	7	24.1	7	24.1
	5	1	3.4	0	0.0	6	20.7	9	31.0
	6	1	3.4	-	-	16	55.2	13	44.8
	7	0	0.0	-	-	-	-	-	-
	Total	29	100	29	100	29	100	29	100
All	1	59	29.2	74	36.6	0	0.0	0	0.0
	2	58	28.7	84	41.6	23	11.4	18	8.9
	3	14	6.9	38	18.8	31	15.3	34	16.8
	4	52	25.7	6	3.0	52	25.7	61	30.2
	5	11	5.4	0	0.0	49	24.3	52	25.7
	6	4	2.0	-	-	47	23.3	37	18.3
	7	4	2.0	-	-	-	-	-	-
	Total	202	100	202	100	202	100	202	100

TSV: Thermal sensation vote, TP: Thermal preference, TS: Thermal satisfaction, OC: Overall comfort, N: Number of sample, P: Proportion

Table 6. Comfort temperature and standard deviation.

Variables	Lalitpur (N=148)		Gorkha (N=25)		Shindhupalchowk (N=29)		All (N=202)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
T_{ci} (ºC)	23.1	3.5	25.1	2.5	26.6	2.8	23.9	3.5
T_{cg} (ºC)	23.4	3.5	25.7	2.6	27.0	2.8	24.2	3.6
T_{cmrt} (ºC)	23.5	3.6	25.9	2.6	27.2	2.8	24.3	3.7
T_{cop} (ºC)	23.3	3.5	25.5	2.5	26.9	2.8	24.1	3.5

N: Number of person, S.D.: Standard deviation, T_{ci}: Indoor air temp., T_{cg}: Comfort globe temp., T_{cmrt}: Comfort mean radiant temp. T_{cop}: Comfort operative temp.

T_g=0.985T_i+0.635 [3]

(N=202, R^2=0.94, S.E.=0.018, P<0.001)
N: Number of sample, R^2: Coefficient of determination,
S.E: Standard Error of the regression coefficient,
P: Significant level of regression coefficient.

4.2 Subjective evaluation

4.2.1 Thermal sensation

Table 5 shows the percentage of thermal sensation vote in three districts. When result from three district are added together, the relative frequency is 25.7 % for 'neutral' and 38.0 % for 'thermal comfort zone' (votes 3 to 5). The percentage of cold side (votes 1 to 3) is 64.8 % and the percentage of hot side (votes 5 to 7) is 9.4 %. This might be the reason of zinc sheets are radiative in nature and so the cold sensation as outdoor temperature drops. The results showed that most of residents were feeling cold in the temporary shelter houses. These trends are similar in three districts.

4.2.2 Thermal preference

People always prefer to live comfortably in terms of temperature. They want to be neither hot nor cold. When results from three districts added together, the relative frequency is 18.8 % for 'No change' and 78.2 % for warmer side and 3.0 % for cooler side (**Table 5**). Most of residents prefer a bit warmer temperature compare to a bit cooler. As we know that the zinc sheets are radiative in nature and so the cold sensation as outdoor temperature drops. There was no one residents who prefer the much cooler air temperature. This might be the human nature. One saying that people are never satisfied what they have, they prefer more and more.

4.2.3 Thermal satisfaction

An ideal thermal comfort level is preferred by people living in their shelters. In temporary shelters occupants are finding it difficult to attain thermal satisfaction. The thermal satisfaction in this research has been defined as feeling of people regarding the temperature. The thermal satisfaction vote is 26.7 % and unsatisfaction vote is 73.3 % (**Table 5**). The result showed that most of residents felt unsatisfied in staying in temporary shelters. No one answered 'very satisfied'.

4.2.4 Overall comfort

The comfortable vote is 25.7 % and thermal uncomfortable vote is 74.2 % (**Table 5**). The results showed that most of residents felt uncomfortable during their stay in temporary shelters. During the interview, we noted the residents reminiscing about their past houses destroyed during the earthquake and were noted to be emotionally disturbed. Understandably, temporary houses could not create a comfortable environment.

4.2.5 Relation between the thermal preference and thermal sensation

To analyze the characteristic of words used in the thermal comfort survey, the regression analysis of thermal preference and thermal sensation was analyzed as shown as the **Fig. 9**. It showed as the occupants vote for cool sensation, they prefer warmer sensation condition and vice versa. The correlation coefficient of thermal preference and thermal sensation is 0.55. The correlation coefficient is not very high because residents prefer 'slightly warmer' even though they voted neutral on the thermal sensation scale. It might be due to the low indoor and outdoor temperature during investigated period and the residents preferred a 'warmer' environment. Even though subjects reported 'neutral' on the thermal sensation (n=52 votes), 27 (52.0 %) of the votes for 'slightly warmer' in the thermal preference scale. According to an earlier study (Rijal and Yoshida, 2006), the reason might be; 1) the subjects would prefer a warmer environment in the winter. 2) They experience a very cold outdoor environment in their preference in their everyday life and would 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.

4.3 Comfort temperature

The ranges of temperatures recorded during the field survey were quite narrow. Therefore, it would be unreliable to use the regression method for calculating comfort temperature. Consequentially, we used 'Griffiths' method to calculate comfort temperature based on TSV (Griffiths 1990; Rijal et al., 2010; Humphreys et al., 2013).

$$T_c = T + (4-C)/a \quad [4]$$

Here T_c indicates comfort temperature (°C), T is the indoor air temperature or globe temperature or mean radiant temperature or operative temperature, C is thermal sensation vote and '4' is the scale point for 'neutral' condition. The constant 'a' indicates a constant rate of thermal sensation change with room temperature. In this case 0.5 is used as the constant, as applied by Humphreys et al. (2013) at 7-point thermal sensation scale.

The mean comfort temperatures estimated by Griffith's method are shown in **Table 6**. The overall mean comfort air temperature is 23.9 °C, which is similar to the comfort globe temperature, comfort mean radiant temperature and comfort operative temperature. We found the comfort temperatures are highest in Shindhupalchowk, medium in Gorkha and lowest in Lalitpur because of two former districts Shindhupalchok and Gorkha which are not only geographically remote but also have climatic variations. The residents of temporary housing from disaster-struck areas often have a geographical relationship and have various social relationships (Olshansky et al., 2006; Chen et al., 2014).

4.4 Clothing Insulation

People have a natural tendency to adapt to changing conditions in their environment. This natural tendency is expressed in the adaptive approach to thermal comfort. The comfort temperature is a result of the interaction between the subjects and the building or other environment they are occupying (Nicol and Humphreys, 2002).

In this section we clarify about the clothing insulations in the investigated period. **Figure 10** shows the mean clothing insulation with 95 % confidence interval for both genders. The mean clothing insulations noted in this study is 0.73 clo (standard deviation = 0.21 clo). The mean clothing insulation of female (0.81 clo) is significantly higher than that of male clothing (0.61 clo). This trend is similar to previous study (Rijal et al., 2010).

5. Conclusions

In this research, we measured the thermal environment and conducted thermal comfort survey in the temporary shelters, and found the following results.

1) The daytime indoor air temperature is 18.7 °C which is similar to indoor globe temperature. The mean nighttime indoor air temperature is 15.2 °C which is also similar to indoor globe temperature.
2) Respondents slept where the mean indoor air temperature is 14.3 °C which is 5 °C higher than outdoor air temperature. The result showed that indoor air temperature is significantly higher than outdoor air temperature at night time.
3) The respondents felt cold and preferred to be much warmer. Similarly they were ‘slightly unsatisfied’ and ‘slightly uncomfortable’ with their present thermal environment. This might be the reason of zinc sheets are radiative in nature and so the cold sensation as outdoor temperature drops.
4) The mean comfort air temperature in the temporary shelter is 23.9 °C which is similar to globe temperature, radiant temperature and operative temperature.
5) The mean clothing insulations of the study is 0.73 clo. The result showed that female clothing insulation is significantly higher than male clothing.

Acknowledgements

We would like to thanks to Dr. Madhavi Indraganti, Dr. Manoj Kumar Singh and Hikaru Imagawa for providing valuable advice, and investigated shelter and respondents for their cooperation. Finally, thanks to Arun KC for supporting in the field survey.

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