

PAPER • OPEN ACCESS

Study on winter indoor thermal environment of temporary shelters built in Nepal after massive earthquake 2015

To cite this article: Rita Thapa *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **294** 012029

View the [article online](#) for updates and enhancements.

Study on winter indoor thermal environment of temporary shelters built in Nepal after massive earthquake 2015

Rita Thapa¹, Hom Bahadur Rijal², Masanori Shukuya², Hikaru Imagawa¹

¹PhD Student, Tokyo City University,

²Professor, Tokyo City University

Corresponding author; Email: thapareeta19@gmail.com

Abstract. After massive earthquake 2015, thousands of Nepalese who lost their permanent houses by the hardest hits were forced to live in makeshift temporary shelters. The people residing in these shelters are facing extreme coldness that causes various health-related problems in winter. The field measurement on indoor thermal environment was conducted in one of the district hit by massive earthquake, Lalitpur. The indoor and outdoor air temperatures of five shelters were measured by a set of thermometers with digital data loggers at the ten minute intervals in winter. The mean indoor and mean outdoor air temperatures during the measured night-time were found to be from 10.3°C and 7.6°C; they were lower than lower limit value of acceptable indoor temperature at 11°C found from our previous research. We analyzed the thermal characteristics of those shelters measured for seeking whether the improvement is possible or not and also how much of it is affordable. Thus, in this study, we evaluated the indoor thermal environment by estimating the heat-transmission characteristics of the used materials in these investigated shelters. The total heat loss coefficient estimated in five shelters per respective floor areas ranged from 11.2 to 15.4 W/(m²·K). These values obtained are very large due to low thermal insulation materials used. The paper ends with important lesson that reduce the total heat loss coefficient needs to reduce down to 2~7 W/(m²·K) for realising the need to indoor air temperature above at 11°C could be 70% of nighttime hours. Such reduction of heat loss was found to be realized by adding affordable materials, i.e. cellular polyethylene foam and clothes for respective walls and roof.

1. Introduction

Temporary housing is defined as a place where families can re-establish household responsibilities and daily activities for an interim period until a permanent housing solution can be found [1]. Indoor environment and living condition under makeshift shelters are to be concerned and need an urgent attention in the context of disasters to come. After massive earthquake 2015, thousands of Nepalese who lost their permanent houses by the hardest hit were forced to live in temporary shelters. Those makeshift shelters were mostly built by using zinc sheets and insufficient thermal characteristics. Their indoor environments are very much affected by outdoor environment. 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 indoor climatic conditions. It is a well-known fact that basic designs 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 well-being of occupants [2].

Three years after the devastating earthquakes that struck Nepal, the recovery is very slow. Many families who lost their permanent houses, they are still living in temporary shelters due to various reasons such as the lack of infrastructure, lands, manpower, economic condition and materials availability. Temporary housing should provide protection from the outdoor environment, and contributes to secure personal health and well-being and bridging the gap until permanent is available [3].

Several studies have been carried out focusing on thermal evaluation of indoor temperature [4]: some have conducted thermal performance analyses of emergency shelter using dynamic building simulation to improve of temporary shelters, [5-8], some others focused on the improvement of design and construction in the post-disaster temporary housing during the emergency phase [9-11]. But in the context of Nepal after the massive earthquake, few researches have been conducted on this issue [12-13].

Our previous survey [13] has found that the people residing in shelters were facing extreme coldness in winter; the lowest limit value of acceptable indoor air temperature of respondents was found to be 11°C which was identified from the survey data obtained from the daytime measurement together with the thermal sensation vote. Since the thermal characteristics of temporary shelters are poor, the indoor air temperature during nighttime could definitely be below the lowest value of acceptable indoor air temperature. With this likeliness in mind, the objectives of this paper are: 1) to evaluate the thermal characteristics of indoor thermal environment on the basis of materials used for the shelters; and 2) to examine the possible improvement of the shelters that can provide the occupants with a better indoor thermal environment.

2. Thermal measurement method

2.1. Research areas, general climate and temporary shelters

Lalitpur, one of the earthquake severely affected district, has been chosen for continuous field measurement [13]. Nepalese climatic condition varies from one place to another in accordance with its geographical feature whose altitude is 1329m. November, December, January and February are the cold months of the winter season. The climate of Lalitpur is classified as warm and temperate. The mean outdoor air temperatures range between 11.1 and 15.8°C [14].

Originally, it was planned to investigate for seven shelters denoted as S1 to S7; six rectangular-shaped shelters (S1, S2, S4, S5, S6 and S7) and one dome-shaped shelter (S3) were randomly selected for the field measurement as can be seen in Fig. 1. Regrettably, the sensors used in two shelters, S2 and S7, were found to have malfunctioned [15]. Therefore, these two shelters were excluded and in the present investigation, we analyzed the thermal environment of five shelters. These investigated shelters have single room for living, sleeping and kitchen purposes. The shelter's structure, size and materials used as insulation are different from each other. Thus, the thermal characteristics of those investigated shelters must be different from each other. Thus, people used local and available materials such as tarpaulin sheets, cellular polyethylene foam and others like clothes materials used in over or under the zinc sheets for protecting harsh indoor environment as shown in Table 1 [13].



Fig. 1 Seven investigated shelters: S1, S2, S3, S4, S5, S6 and S7

Table 1 The size of investigated shelters and the materials used

S.C.	Depth [m]	Width [m]	Height [m]	No. of people	Density [Persons/m ²]	Wall [mm]	Roof [mm]	Roof (External) [mm]	Roof (Internal) [mm]
S1	5	3.5	2.1	4	0.23	Zinc sheet : 0.26	Zinc sheet : 0.26	Straw : 60	Thick clothes : 5 and CPF : 6
S3	3.7	2.5	2	4	0.43	Zinc sheet : 0.26	Zinc sheet : 0.26	Tarpaulin : 2	CPF: 6
S4	6.0	5.0	2.8	4	0.13	Zinc sheet : 0.26	Zinc sheet : 0.26	None	Thick clothes : 5
S5	7.0	6.0	2.8	4	0.10	Zinc sheet : 0.26	Zinc sheet : 0.26	None	Thick clothes : 5
S6	3.5	2.6	2.1	2	0.22	Bamboo : 8 and mud plaster : 5	Zinc sheet : 0.26	None	CPF: 6

S.C.: Shelter Code, CPF: Cellular Polyethylene Foam.

2.2. Thermal measurement

The continuous thermal environment measurement was performed for 16 days from 30th January to 14th February, 2016. Indoor air temperature (T_i), outdoor air temperature (T_o), indoor globe temperature (T_g), indoor relative humidity (RH_i) and outdoor relative humidity (RH_o) were measured by with respective sensors with data loggers at the interval of 10 minutes (Fig. 2). The data loggers

were placed 1m above the floor. The outdoor air temperature was measured just outside shelter S1. We assumed the same outdoor air temperature for other investigated shelters because all of the investigated shelters are located within the range of 5 km.



Fig. 2 An examples of installed sensors with data loggers for measuring indoor thermal environment of S1

3. Measured results

3.1. Distribution of measured indoor air temperature

Fig. 3 shows cumulative frequency distribution of indoor air temperature of five shelters for 16 days. The indoor air temperatures for all shelters are highly dependent on outdoor air temperature. The mean indoor and mean outdoor air temperatures during the nighttime were found to be from 10.3°C and 7.6°C, they are lower than the lowest limit value of acceptable indoor temperature found from our previous research. Thus, the indoor air temperature of nighttime being intrinsically low is due to very poor thermal insulation. About 50% of time remains below the lowest acceptable temperature at 11°C. From this result, we can conclude that these shelters are not good for winter and create several problems caused by coldness. The people were sleeping such a low condition with low temperature which may effects on their health. This indicates that there must have been quite problem in nighttime is more problematic in comparison to daytime.

According to the previous research [16], the mean indoor air temperature of night time found in traditional house located in Solukhumbu (Himalayan region) was 6.5°C in winter, which was close to our results. Another research has found that the indoor mean maximum air temperature ranges from 12 to 15°C traditional buildings in Nepal [17]. These are all considered to be thermally poor buildings materials used, which cannot protect the indoor thermal conditions from outdoor environment.

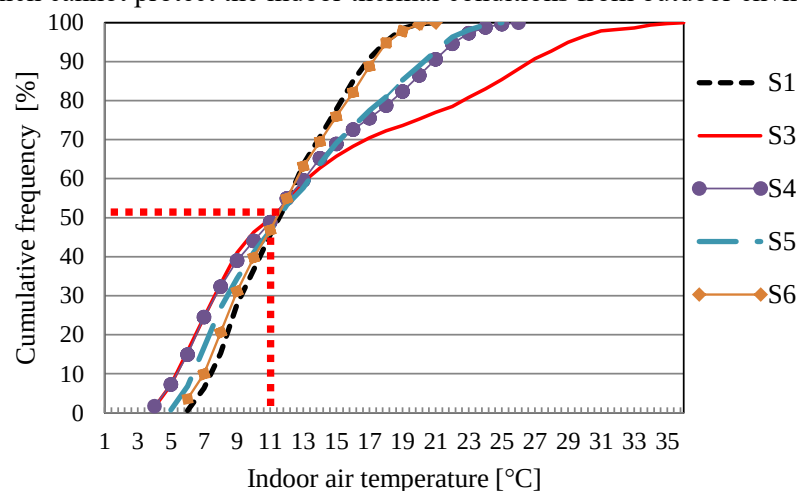


Fig. 3 Cumulative frequency curve of indoor air temperature

4. Method of simulation

In order to assess improvement, it is to set up the possibility of some model for the calculation of indoor air temperature based on the findings by physical measurements. The energy balance equation to be expressed as [Thermal energy] = [Thermal energy stored] + [Thermal energy output] [18] can be written down as follows. So that numerical calculation can be performed.

Here, Energy balance equation can be expressed as follows.

$$Hdt = C\rho VdT_{ei} + \sum_{i=1}^5 A_i U_i (T_{ei} - T_{eo}) dt. \quad (1)$$

where, H : the rate of heat generation [W], dt : infinitesimally short period of time, t [s], C : specific heat capacity of the space inside a shelter [J/(kg.K)], ρ : density of air [kg/m³], V : the volume of shelter space [m³], dT_{ei} : infinitesimal increase of indoor air temperature [°C], A_i : area of “i”th four wall including roof [m²], U_i : heat transfer coefficient of “i”th wall [W/(m².K)], $\sum_{i=1}^5 A_i U_i$: total heat loss coefficient [W/K], T_{ei} : indoor air temperature [°C], T_{eo} : outdoor air temperature [°C].

The heat transmission coefficient (U_i) is expressed as,

$$U_i = \frac{1}{\frac{1}{h_{ro} + h_{co}} + R_1 + R_2 + \frac{1}{h_{ri} + h_{ci}}}, \quad (2)$$

where, h_{ro} : radiative heat transfer coefficient along with the external surface [W/(m².K)], h_{co} : convective heat transfer coefficient along with the external surface [W/(m².K)], h_{ri} : radiative heat transfer coefficient along with the internal surface [W/(m².K)], h_{ci} : convective heat transfer coefficient along with the internal surface [W/(m².K)], R_1 and R_2 : resistance of the two materials assumed in “i”th wall [W/(m².K)]. In the calculation of U_i , we referred to thermal conductivity data of the solid materials available from [19, 20] and we assumed the values of radiative and convective heat transfer coefficient to be follows: $h_{ro} = h_{ri} = 5.2$ W/(m².K), $h_{co} = 12$ W/(m².K) and $h_{ci} = 3$ W/(m².K).

The heat flow, q_i [W/m²], through a wall of may be expressed as

$$q_i = U_i(T_{ei} - T_{eo}) \quad (3)$$

Once the values of heat loss coefficient are estimated, the unknown variable left in eq. (1) becomes the heat capacity, $C\rho V$. In this study, the value of $C\rho V$ is estimated by approximating equation (1) with the finite differential equation. The calculation of $C\rho V$ is made from

$$C\rho V = \frac{[H - \sum_{i=1}^5 A_i U_i \{T_{ei(n)} - T_{eo(n)}\}] \Delta t}{T_{ei(n)} - T_{eo(n)}} \quad (4)$$

where Δt as the finite interval of time, $T_{ei(n)} - T_{ei(n-1)}$ as the finite increase of indoor air change from (n-1) is the finite temperature change from (n-1) Δt to $n\Delta t$, where, n is integer ($n = 0, 1, 2, \dots$).

The values of $C\rho V$ obtained for each time interval, Δt , are averaged to determine the single value of $C\rho V$. Once we come to know the values of total heat loss coefficient ($\sum_{i=1}^5 A_i U_i$) and heat capacity ($C\rho V$), the indoor air temperature, $T_{ei}(n)$, may be simulated by the following equation.

$$T_{ei(n)} = \frac{H \Delta t + C\rho V T_{ei(n-1)} + \sum_{i=1}^5 A_i U_i T_{eo(n)} \Delta t}{C\rho V + \sum_{i=1}^5 A_i U_i \Delta t} \quad (5)$$

The investigated five shelters are different with respect to thermal characteristics. Using the total heat loss coefficient ($\sum_{i=1}^5 A_i U_i$), the values of specific heat capacity estimated are tabulated in the last column of Table 2. The total heat loss coefficient per floor area of five investigated shelters were

found 11.2 to 15.4 $\text{W}/(\text{m}^2 \cdot \text{K})$ as can be seen in Table 2. These results suggest that the shelters have very high heat loss coefficient.

Table 2 Description of investigated shelters with total heat loss coefficient and the estimated heat capacity

S.C.	Wall area [m ²]	Roof area [m ²]	Floor area [m ²]	Total surface area (wall + roof) [m ²]	U_i for wall [$\text{W}/(\text{m}^2 \cdot \text{K})$]	U_i for roof [$\text{W}/(\text{m}^2 \cdot \text{K})$]	Total heat loss coefficient [W/K]	Total heat loss coefficient per floor area [$\text{W}/(\text{m}^2 \cdot \text{K})$]	Total heat loss coefficient per surface area [$\text{W}/(\text{m}^2 \cdot \text{K})$]	Specific heat capacity CpV [kJ/K]
S1	35.7	17.5	17.5	53.2	5.6	1.2	220.9	12.6	4.2	1918
S3	11.6	15.1	9.3	26.7	5.6	2.6	104.2	11.2	4.4	526
S4	61.6	30.5	30.0	92.1	5.6	3.8	460.9	15.4	5.0	4166
S5	72.8	42.2	42.0	115.0	5.6	3.8	568.0	13.5	4.9	4461
S6	25.6	9.1	9.1	34.7	4.4	2.8	138.1	15.2	4.0	1284

S.C.: Shelter Code.

5. Simulation results

5.1. Comparison of measured temperature and simulated temperature

Figure 4 illustrates the comparison of measured indoor air temperature with simulated indoor air temperature. We simulated indoor air temperature from evening 18:00 to early in the morning 5:50 ($n=1152$ of each shelter) with equation (5). As a whole, the correlation coefficients are very high. Through in However, S1, S4 and S6, there are some points.

Thus, comparison of this result suggests that simulation can reproduce quite reasonably the indoor air temperature during nighttime. Thus, we confirmed the applied energy balance equation is fits for simulating the indoor air temperature of the shelters.

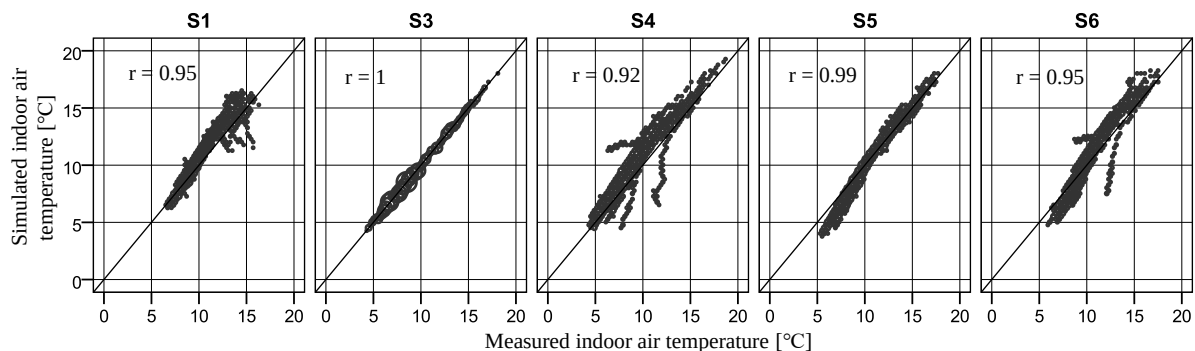


Fig. 4 Relationship between measured and simulated indoor air temperature

5.2. Reduction of heat loss coefficient for the possible improvement

The basic phenomenon determining the heat exchange between indoors and outdoors is the conductive heat transfer through the walls and roof. If the walls and roof are insulated, then the heat transmission must become small. Based on this principle, we have tried to reduce the heat loss coefficient being for improving the investigated shelters. The target was assumed to make the indoor air temperature remain above the lowest acceptable indoor air temperature at 11°C.

We examined the possible replacement of the present walls with some affordable materials to have the nighttime hours being above the acceptable indoor air temperature at 11°C at 70, 80 or 90% of the whole nighttime hours. The acceptability of 80% and 90% refers in ordinary buildings [21]. Therefore, in this study we consider that 70% of time for the indoor air temperature being higher than 11°C should be fine. Previous research [22] showed that the room air temperature about 11°C would not have much effect on the quality of sleep.

Fig. 5 shows that the result of total heat loss coefficient needs to be reduced about 2~7 $\text{W}/(\text{m}^2\cdot\text{K})$ to have the indoor temperature being higher than at 11°C for 70% of nighttime hours. We need to consider how much of additional materials need to be implemented.

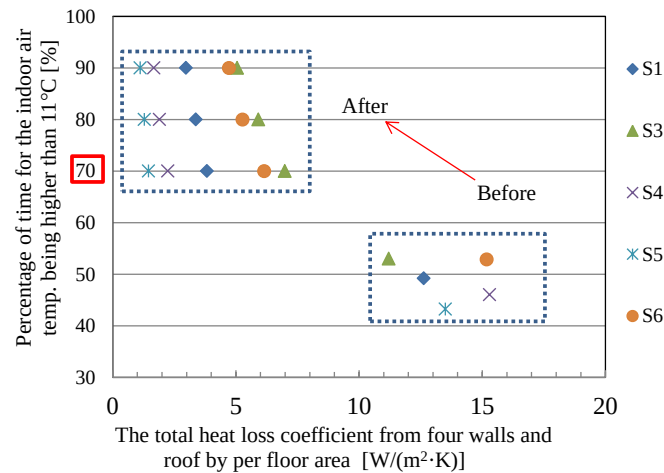


Fig. 5 Relationship between total heat loss coefficient from four walls and roof by per floor area and the percentage of time for the indoor air temperature being higher than 11°C

Previous research addressed that, in each construction systems should be based on light and small elements, which are easy to handle, assemble and dismantle [8], and another research reported that the use of naturally available materials for constructing houses are well adapt in each climate, season and culture [23]. Therefore, concerning the people health, it is necessary to investigate whether it is possible to improve the indoor air temperature above the lowest limit value of acceptable temperature at 11°C . The latest research [24], experiments on corrugated cardboard temporary shelters or tent showed that temperature dropped near to the outdoor temperature during the night time, so the author suggested that the wintry indoor thermal environment should be kept at least 10°C or more. Thus, here in this paper we required some additional affordable materials which could remain the indoor air temperature above at 11°C could be 70% of nighttime hours.

Fig. 6 shows two examples of affordable improvement for the wall and roof in the cases of S1 and S5. In S1, the heat loss coefficients of four walls and the roof at present $5.6 \text{ W}/(\text{m}^2\cdot\text{K})$ and $1.2 \text{ W}/(\text{m}^2\cdot\text{K})$, respectively. Addition of tarpaulin (2 mm) and cellular polyethylene foam (12 mm) lets the heat loss coefficient of the walls be $1.4 \text{ W}/(\text{m}^2\cdot\text{K})$. The heat loss coefficient of roof $1.2 \text{ W}/(\text{m}^2\cdot\text{K})$ is small enough so that no improvement is needed.

In S5, the heat loss coefficient of the walls and roof are $5.6 \text{ W}/(\text{m}^2\cdot\text{K})$ and $3.8 \text{ W}/(\text{m}^2\cdot\text{K})$, respectively. The same addition as for S5 lets the heat loss coefficient of the walls be $1.4 \text{ W}/(\text{m}^2\cdot\text{K})$. The heat loss coefficient of roof is $3.8 \text{ W}/(\text{m}^2\cdot\text{K})$ is quite high so that addition of cellular polyethylene foam (12 mm) and clothes (5 mm) makes the heat loss coefficient be $1.2 \text{ W}/(\text{m}^2\cdot\text{K})$.

In a summary, we can improve the walls and roof rather easily by adding locally available materials as thermal insulation i.e., cellular polyethylene foam and clothes to make the indoor air temperature become higher than 11°C for 70% of the wintry nighttime. This type of research on the affordable improvement is also considered to be necessary for finding effective solutions for the preparation to be made before a disaster to occur in the future. Thus, it hopefully helps to make policies for the government.

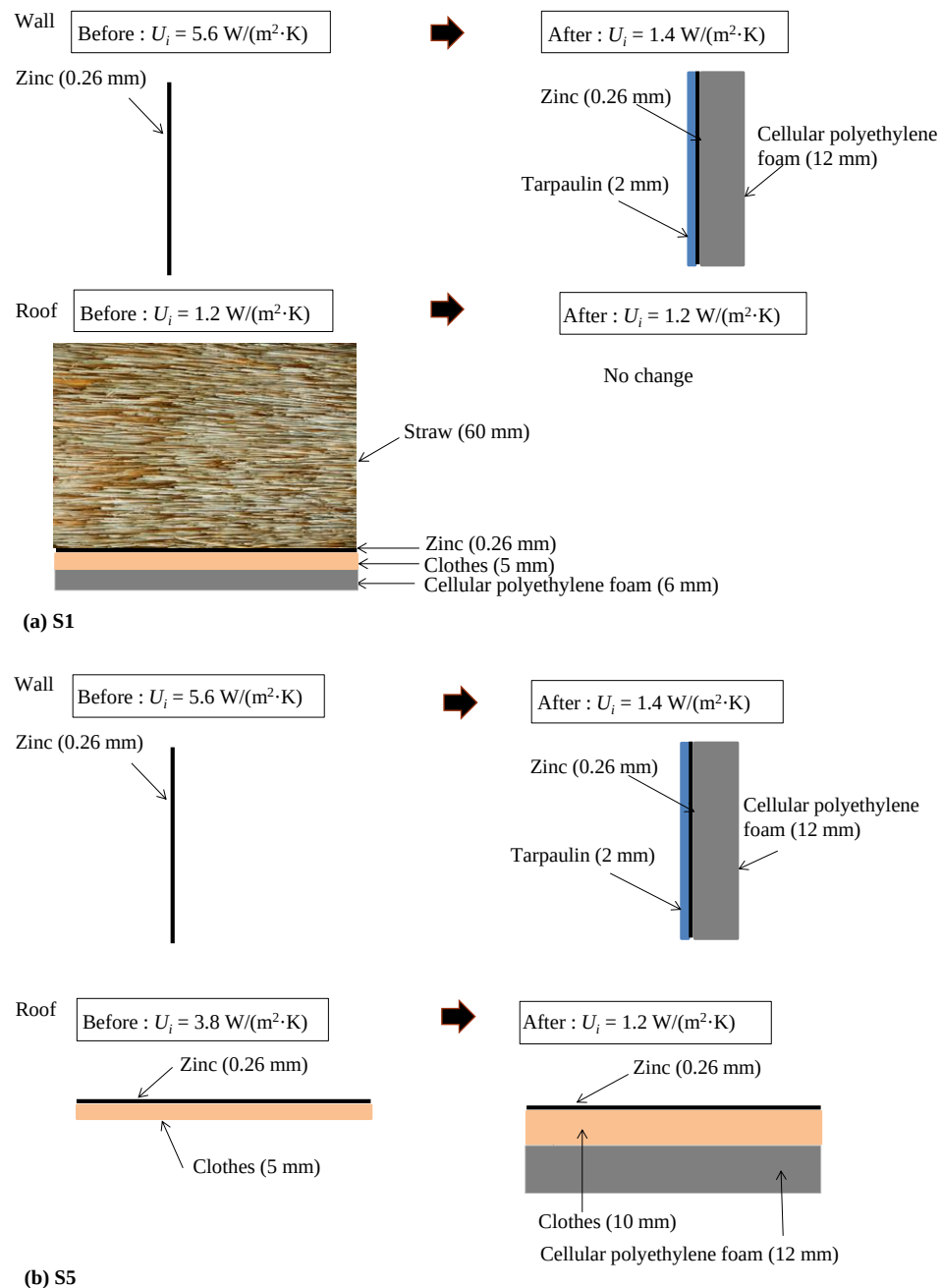


Fig. 6 Improvement the shelters (a) S1 and (b) S5

6. Conclusions

In this study, five makeshift shelters' indoor thermal environment was investigated and has found following results:

1. The indoor air temperatures for all investigated shelters are highly dependent on outdoor air temperature. The mean indoor and mean outdoor air temperatures during the night-time were found to be from 10.3°C and 7.6°C ; which are found to be lowest than lower case of acceptable indoor temperature at 11°C , which was found during daytime according to the our previous research.

2. The nighttime indoor air temperature tends to decrease as the heat loss coefficient increase. The people were sleeping such a low temperature which may effects on their health.
3. About 50% of time remains below the lowest acceptable temperature at 11°C in five investigated shelters.
4. The simple energy balance equation made for simulation to reproduce the indoor air temperature. The results were quite consistent with the measured indoor air temperature. Thus, we confirmed the applied energy balance equation fit.
5. The total heat loss coefficient per floor area needs to be reduced down to 2~7 W/(m²·K) to reach the indoor air temperature being higher than at 11°C for 70% of nocturnal hours.
6. The reduction of heat loss coefficient could be achieved by adding cellular polyethylene foam of 6 to 12 mm and clothes of 5 to 10 mm for the walls and roof of temporary shelters in order to keep the indoor air temperature be acceptable for 70% of the whole nocturnal hours.

Acknowledgements

The authors would like to express their special thanks to the people who provides us with the chance for measuring indoor thermal environment inside in their shelters and to Mr. Arun Khatri KC for helping in the field survey.

References

- [1] J. Cassidy, Impacts of prefabricated temporary housing after disasters; 1999 Earthquakes in Turkey. Habitat International. 31 (1) (2007) 36-52.
- [2] FEMA (Federal Emergency Management Agency), 2009. "2009 disaster housing plan", [http://www.fema.gov/pdf/emergenvy/disasterhousing/FEMA 2009 Housing plan.pdf](http://www.fema.gov/pdf/emergenvy/disasterhousing/FEMA%2009%20Housing%20plan.pdf).
- [3] J. Da Silva, Quality and standards in post-disaster shelter. The structural Engineer. 17 (2007) 25-32.
- [4] N. Shinohara, M. Tokumura, M. Kazama, Y. Yonemoto, K. Hasegawa, H. Yoshino, U. Yanagi, Indoor air quality and thermal comfort in temporary houses occupied after the Great East Japan Earthquake. Indoor air. 24 (2014) 425-437.
- [5] C. Critina, D. Saporì, B.F. Pierro, Thermal performance analysis of an emergency shelter using dynamic Building simulation, Energy and buildings, 88 (2015), 122 -134.
- [6] Yu. Y, L. Enshen, S. Yuan, Y. Hongxing, Assessing the thermal performance of temporary shelters, Procedia Engineering. 159 (2016) 174-178.
- [7] S. Obyn, G. van Moeseke, V. Virgo, Thermal performance of shelter modelling: Improvement of temporary structures, Energy Building. 89 (2015) 170-182.
- [8] D. Felix, I.M. Branco, A.O. Feio, Improving sustainability and culture integration in post-disaster temporary housing, Sustainable post-disaster reconstruction: from recovery to risk reduction, i-Rec conference. (2013)
- [9] A. H. Abulnour, The post-disaster temporary dwelling: Fundamentals of provision, design and construction, HBRC Journal. 10 (2014) 10-24.
- [10] H. Arslan, N. Cosgun, Reuse and recycle potentials of the temporary house after occupancy: Example of Duzce, turkey. Building and Environment. 43 (2008) 702-709.
- [11] G. Salvalai, M. Imperadori, D. Scaccabarozzi, C. Pusceddu, Thermal performance measurement and application of a multilayer insulator for emergency architecture, Applied Thermal Engineering. 82 (2015) 110-119.
- [12] R. Thapa, H.B. Rijal, Study on thermal environment and thermal comfort in autumn season of temporary shelters in Nepal after massive earthquake 2015, Lowland Technology International. 18 (2) (2016) 119-128.
- [13] R. Thapa, H.B. Rijal, M. Shukuya, I. Hikaru, Field study on acceptable indoor temperature in temporary shelters built in Nepal after massive earthquake 2015, Building and Environment. 135 (2018) 330-343.
- [14] Meteorological observatory: H.M.G, of Nepal. Climatological records of Nepal: Ministry of Science and Technology, Department of Hydrology and meteorology Kathmandu. (2017).

- [15] R. Thapa, H.B. Rijal, M. Shukuya, I. Hikaru, An Investigation of Thermal Characteristics of Temporary Shelters in Nepal During Wintery Night Time, Architectural Institute of Japan (AIJ_Kanto). (2019).
- [16] H.B. Rijal, Thermal improvements of the traditional houses in Nepal for the sustainable building design, Journal of the Human-Environment System. 15 (1) (2012) 1-11.
- [17] S.B. Bajracharya, The thermal performance of traditional residential buildings in Kathmandu valley, Journal of the institute of Engineering. 10 (2013) 172-183.
- [18] M. Shukuya, Exergy, Theory and applications in the built environment, Springer, (2013) pp. 161-162.
- [19] M. Shukuya, Bio-climalogy for built environment, CRC press, (2019) pp. 143, pp. 254-258.
- [20] Japanese Society of Mechanical Engineers (JSME), Data book of Heat transfer, (1987) pp. 319.
- [21] T. Mohammad, T. Martin, K. Stanley, D. Andy van den, A review into thermal comfort in buildings, Renewable and sustainable energy reviews, 26 (2013) 201-215.
- [22] M. Miyazawa, Seasonal changes of sleep environment at bed time and on arising. The proceeding of the 18th symposium on human environment system, 1994 [In Japanese]
- [23] T. Kubota, H.B. Rijal, H. Takaguchi, Sustainable houses and living in the hot-humid climates of Asia, Part 1. Vernacular architecture, chapter 6, Nepal: Traditional houses, (2018) 59-66.
- [24] N. Takashi, Subjective experiment on the habitability of a temporary emergency shelter made of corrugated cardboard, Journal of civil, construction and environmental engineering, 3 (5) (2018) 147-153.