

Subjective Experiment on the Habitability of a Temporary Emergency Shelter Made of Corrugated Cardboard

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Abstract: In this study, we investigated indoor thermal environment survey and sleep in temporary shelters. Temporary shelters are three types of outdoor tents and cars, and newly developed temporary emergency shelter made corrugated cardboard. For each temporary shelter, indoor air temperature in summer and winter was measured. In summer, the corrugated shelter and the tent opened windows at night, so the indoor temperature and outside air temperature became the same level. As insects came in the car, it was difficult to open the window at night. In winter, the corrugated shelter and tent have the same level of indoor temperature and outdoor temperature. Because the airtight performance of the car is high, the lowest temperature in the room was maintained at around 10°C. Subject experiments of sleep were carried out on each temporary shelter using OSA sleep inventory. The subjective statements on the quality of sleep indicate that, in summer, the corrugated cardboard temporary shelter received the highest score, followed by the tent, and finally the automobile. In winter, the corrugated cardboard temporary shelter received the highest rating, followed by the automobile, and finally the tent. The Interview survey was conducted on each temporary shelter. The corrugated cardboard temporary shelter was evaluated highly for corrugated floor panels, the size of the space, the freedom of occupancy. The interior space of the car and the tent was narrow, it was difficult to stay for a long term, and it was a low evaluation.

Keywords: Temporary Emergency Shelter, Habitation, Indoor Thermal Environment, Sleep

1. Introduction

During natural disasters like earthquakes and floods, emergency evacuation is necessary to ensure people's safety. Several administrations in Japan use the style of mass evacuation to large spaces in public buildings, such as community centers or gymnasiums, for the sake of both safety and efficiency. Residents will then remain in these group locations before moving into individual- or family-sized temporary shelters, such as prefabricated houses, where they will stay during the process of restoration. However, setting up temporary living quarters requires anywhere from four weeks to six months, meaning people have to endure the challenge of living in austere quarters with little to no privacy for a prolonged period of time.

Immediately following a disaster, in addition to the direct

impact of the disaster itself, people undergo prolonged stress due to the unfamiliar lifestyle of a large group setting. Many choose to live in tents or automobiles to preserve a degree of privacy. After the Mid-Niigata Prefecture Earthquake in 2004 [1], it is estimated that tens of thousands of people spent several nights in automobiles.

Within the confines of an automobile, people are forced to maintain the same body posture for an extended period of time, and with limited availability of water and voluntary restriction of fluid intake due to the difficulty of finding latrines, several cases of economy class syndrome were reported [1, 2]. In order to reduce such stress and maintain the health of refugees, it is necessary to have emergency shelters that can be transported to the disaster site immediately following an event, which are easy enough for anyone to set up, ensure privacy for each family unit, and guarantee a certain level of comfort for up to several months.

However, such a structure has seldom been developed.

For this reason, the authors of this study have been working to develop a light-weight, durable emergency shelter that can be set up easily [3]. To reduce the environmental effect of such temporary shelters, low environmental impact materials from solid wood were considered. However, the high specific gravity of wooden plates proved a hindrance to ease of transportation and handling, which are vital in emergency situations. For this reason, we chose corrugated cardboard as a wood-based material that has a high specific tensile strength and requires less energy for production and disposal. During the development process, evaluations through load tests simulating the load from snow and long-term (one year) exposure to actual usage environments were performed in order to verify the durability of the shelters as well as the efficiency of assembling them and various properties.

The thermal insulation performance of temporary shelters was low and it was reported that it is an environment with large thermal stress. In the temporary shelters after 2011 Great East Japan Earthquake, it was reported that the indoor temperature in winter is reduced to around 5 °C [4]. In the temporary buildings after 2008 Wenchuan Earthquake in China, it was reported that the indoor thermal environment in the summer exceeded 30 °C [5]. In the temporary shelters after 2015 Nepal earthquake, it was reported that the indoor thermal environment is almost equal to the outdoor air temperature [6]. In the study of temporary shelters by numerical analysis, it was reported about construction of prediction model [7] and improvement of heat insulating performance by multilayer insulator [8]. However, there are no reports of subject experiments on Temporary shelter and the comfort of the car and tent.

This report focuses on comfort of living, summarizing the experiences of test subjects in three different refuge spaces simulating outdoor environments in both summer and winter. Special attention was paid to quality of sleep from the perspective of preventing the fatigue that typically results from prolonged time spent living in a shelter.

2. Method

Several corporations have proposed developing corrugated cardboard temporary shelters with a resulting surge in collaborative research aimed at production and commercialization. The durability of the structure was set at six months after considering typical weather conditions and under the assumption that the shelters would be used until prefabricated housing became available up to six months after the disaster occurred.

The shelters used in this research were octagonal with sides of 1.5m in length and a floor space of 10.86 m². The height of the walls is 1.53m, the maximum height of the room is 2.13m, and the shelter offers an effective room space of 14.25m³ (Figure 1). As a resting space, each shelter accommodates five adults lying on the floor and as a storage space, holds 3,000 two-liter plastic bottles and 700 blankets.

Each building kit will be packed in two rectangular boxes of 926 x 1660 x 256 mm in size and has a gross weight of 82 kg. The packages can be stored in a space occupied by a tatami mat and are small enough to transport on the roof of a passenger car.

Each shelter consists of floor panels, wall panels, and a domed roof, all of which are made from cardboard material. The cardboard is 8 mm thick and impregnated with polystyrene to improve its structural strength and water resistance. The ground where the shelter is built will be covered with a polyethylene sheet before placing the floor panels. The floor panels have an internal structure resembling honeycomb and exhibit adequate resiliency (Figure 2). In addition, the layers of air are utilized to ensure better thermal insulation. The floor and domed roof are built by combining cardboard panels. The strength of the cardboard panels is enhanced by adding ribs along the perimeter. This eliminates the need to install support poles and makes the room more spacious. The cardboard panels are joined together with acrylic adhesive tape. After the shelter is built, the roof is covered with a vinyl tarp, which will be held in place with eight ropes tied to pegs driven into the ground.

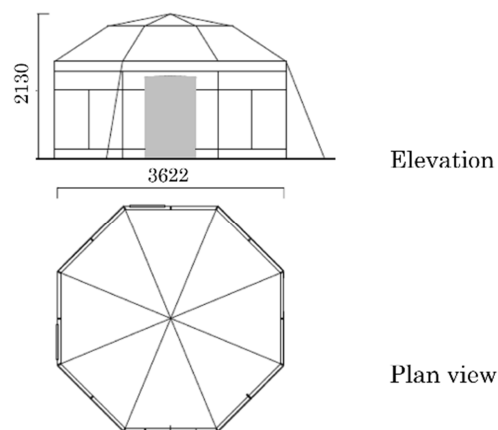


Figure 1. Drawing of a Corrugated Cardboard Temporary Shelter.



Figure 2. Structure of floor panel.

The shelter can be built entirely by joining the panels with the acrylic tape that comes with the kit and there is no need for any other tools. The average time required for two adults to build a single shelter is about a half a day. This means that, in most cases, each household unit can build its own shelter. Disassembling the shelter can be done simply by cutting the tape to separate the joints, which takes about thirty minutes for two adults to accomplish. It has been confirmed that a shelter can also be reused up to three times.

Experiments were carried out for the period of September 1–14, 2008, and January 19–23, 2009, representing summer and winter environments, respectively. Two male subjects were chosen and asked to continue their work (construction work) during the day, while spending their free time in the test facility from evening to morning. Test subjects were given a thorough briefing on the experiment before seeking their consent for participation. The subjects spent weekends at their own homes and weekday nights in the shelters at the refuge spaces. Three different settings—a corrugated cardboard temporary shelter, a tent, and an automobile—were provided in the test facility and the experiment was planned such that an equal amount of time

would be spent in each setting (Figure 3). The time spent in the automobile was cut short because the subjects decided against continuing that phase of the experiment. The tent selected was a generic dome-style tent and the automobile was a van. Our investigation included measuring the interior thermal environment, collecting subjective declaration of sleep quality, and interviewing the subjects. Room temperature was recorded by a portable data logger, which was set at a central location of each test space to avoid the effects of the sun as much as possible. Subjective declarations were acquired using the OSA sleep inventory, and interviews were performed to supplement qualitative information.



Figure 3. External View of an Emergency Shelter and Life in Refuge.

The OSA sleep inventory [9] is a questionnaire used to qualitatively evaluate quality of sleep. Since the questionnaire and tabulation sheets are standardized, results obtained are reliable and, for this reason, the method is widely used in studies on sleep quality. Subjects provide answers to sixteen questions after getting out of bed every morning and Z scores consisting of five factors are calculated from the results. For each factor, a score of fifty points is set as a reference. Any score less than the reference is considered to indicate degradation of sleep quality.

3. Results

3.1. Thermal Environment

Figure 4 shows the transition in room temperature in the respective refuge spaces during the summer experiment. During the day, the room temperature in each space was found to be significantly higher than the outdoor temperature, exceeding 40°C. In the case of the automobile, the transition in room temperature indicates that the air conditioner was operating intermittently. The room temperature never dropped below the outdoor temperature in any of the three settings, and in case of the automobile, the room temperature rose rapidly when the air-conditioning was turned off. The room temperature of the automobile rose or dropped in short intervals because the van was also used for daily work. Because the corrugated cardboard temporary shelter and the tent have almost no thermal capacity, in addition to the fact that there are plenty of gaps, the difference between the room and outdoor temperature narrowed quickly after sunset.

Especially in the tent, the room temperature dropped below the outdoor temperature between 00:00 and 06:00. Because the thermal insulation property of the tent is poorer than that of the corrugated cardboard temporary shelter and the automobile, it is considered that the result shows the effect of thermal radiation during the night. On the other hand, the room temperature of the automobile rose approximately 5 to 10 degrees when the subjects entered the compartment. Since an automobile has a certain degree of air-tightness efficiency, it is expected that body heat will make it difficult to sleep during the summer even at night.

Figure 5 shows the transition in room temperature and humidity in respective refuge spaces during the winter experiment. During the day, the room temperature in the corrugated cardboard temporary shelter ranged from 15 to 20°C and that of the tent ranged from 10 to 15°C. During the night, the room temperature in both settings dropped close to the outdoor temperature if there was no heating, but rose to as high as 15 to 20°C with heating. In the case of the automobile, due to its excellent air-tightness efficiency, the room temperature at night quickly reached 25°C with heating, and even after turning the heater off at around midnight, the temperature remained around 10°C until daybreak. During the winter, it cannot be expected that sunshine would cause the room temperature to rise for the corrugated cardboard temporary shelter or for the tent, and the experiment showed the temperature dropped near to the outdoor temperature during the night.

The acceptable range of the indoor thermal environment of Temporary shelters is reported in Nepal [6] and Jordan [10]. In the survey of temporary shelters built in Nepal after massive

earthquake 2015, it was reported that the acceptable range was from 11 to 30°C [6]. In the survey of Syrian refugee camps in Jordan, it was reported that acceptable range was from 17.2 to 28.4°C [10]. In the winter, the indoor thermal environment

will need to be kept at least 10°C or more. Therefore, it is necessary to raise the room temperature using the heating device and keep the body warm with additional clothes, sleeping bags, floor mats, etc in the each temporary shelter.

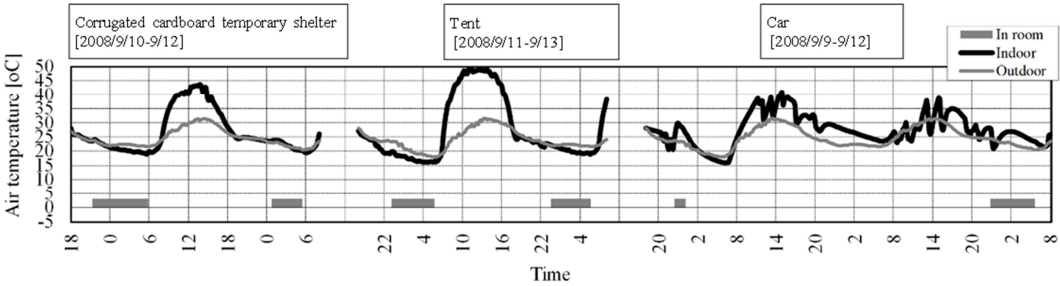


Figure 4. Thermal Environment Test Results in Summer.

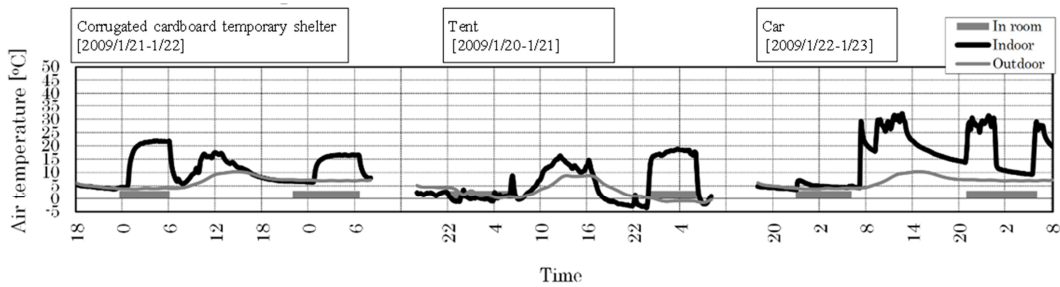


Figure 5. Thermal Environment Test Results in Winter.

3.2. Subjective Declaration of Sleep Quality

The authors analyzed quality of sleep according to the time of the experiment and the type of refuge space using the OSA sleep inventory and calculating the average score of the two subjects. Subjective sleep quality by type of refuge space for the summer experiment is summarized in Figure 6. As for the “refreshing” and “initiation and maintenance of sleep” factors, which are important in maintaining strength and stamina for day-to-day living, the score for the corrugated cardboard temporary shelter and subjects’ homes reached fifty points, showing that quality of sleep was maintained in these environments. Although the “frequent dreaming and anxiety” factor was rated low for subjects’ homes, it is possible that the subjects were affected because the evaluation was made one day before the experiment commenced. As for the tent, the score was around forty points for most factors. The rating for

sleeping in an automobile was poor and its score for the “initiation and maintenance of sleep” factor was a mere 28.5 points. Although the subjects were healthy construction workers in their thirties, this score indicates why one of them chose to terminate his stay in the automobile after several hours. Figure 7 shows the subjective analysis of sleep by type of refuge space in the winter experiment. The corrugated cardboard temporary shelter got the highest rating and its score for the “initiation and maintenance of sleep” factor exceeded fifty points. For the automobile and home settings, scores for the same factor ranged from forty to fifty. The reason for the low scores for the home setting is, again, conjectured to have been impacted by the anticipation of the experiment commencing the next day. The rating for the tent was the lowest and its score for the “initiation and maintenance of sleep” factor was only 27.5 points.

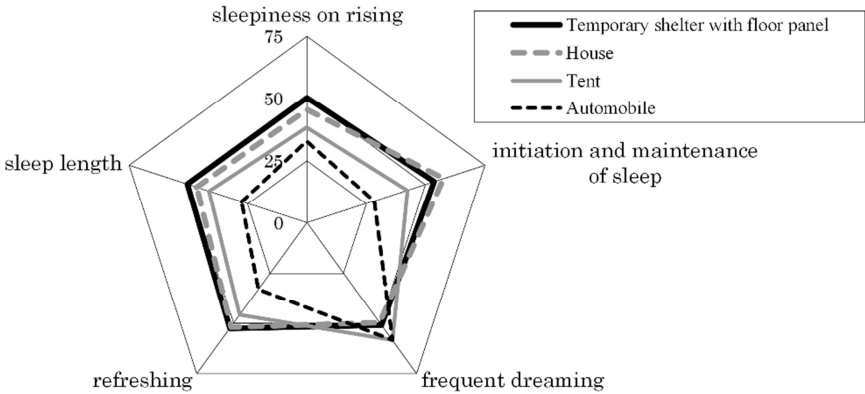


Figure 6. Summary of Subjective Statements on the Quality of Sleep in Summer.

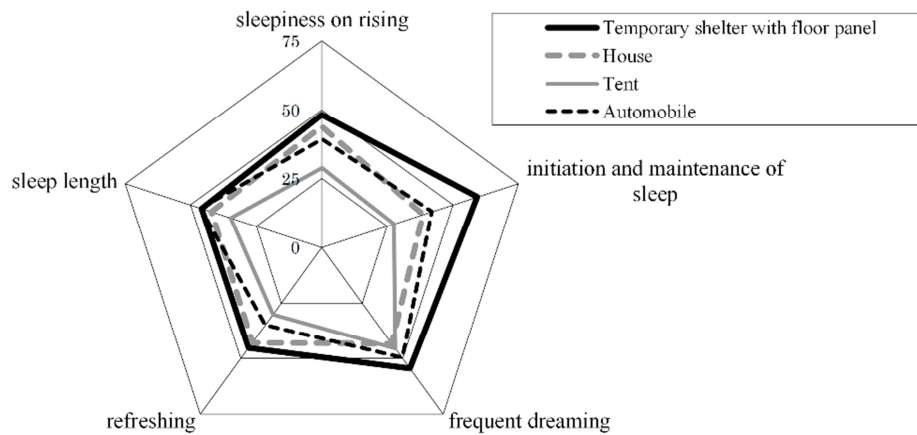


Figure 7. Summary of Subjective Statements on the Quality of Sleep in Winter.

3.3. Interviews

In order to supplement the above thermal environment measurements and OSA sleep inventory analysis, the authors analyzed interviews and open-ended questions on comfort, as well as miscellaneous personal items used in the refuge spaces during the experiments. The results are shown in Table 1. From the interviews conducted in the summer, high ratings were obtained for the corrugated cardboard temporary shelter in terms of floor panels, space, and freedom of activities. There was a request to enlarge the window to improve air circulation and alleviate the summer heat. As for the automobile, which scored very low in subjective declaration, statements such as “the space is too small,” “unable to keep the air-conditioning on for a prolonged period,” and “opening the window would attract insects” were obtained during the interview process. As for the tent, the subjects responded favorably to improved air circulation thanks to the large mesh screens. In terms of living environment, subjects implied that a prolonged stay in the corrugated cardboard temporary shelter, even with other family members, would be viable. Use of an automobile was deemed only possible for a very short period, and the use of tent was deemed possible to an extent if it were only for a single person but not for an entire family. Overall, the quality of living was considered important during summer, in addition to the level of ventilation.

The results of the interviews in winter showed a high rating for the corrugated cardboard temporary shelter because

of the softness and heat insulation of the cardboard floor panels, along with the large space and freedom of activities. Negative comments on the automobile setting pointed out the limited space and condensation resulting from lack of ventilation. As for the tent, which got the lowest rating in the subjective declaration, subjects complained of the coldness conveyed through the ground and the danger of heating devices tipping over. In terms of the living environment in winter, the corrugated cardboard temporary shelter was rated high for comfort, while subjects had a negative stance toward a prolonged stay in the automobile or tent. No positive comment was made about quality of living for the latter two spaces. From this, it is reasonable to conclude that room temperature is more important for shelter during winter than in summer. Although low temperatures can be moderated by wearing more clothes and using sleeping bags, the safe use of heating devices, adequate ventilation, and measures against the coldness of the ground made the shelter a more desirable living space.

During the experiments, various personal items were provided as much as possible based on the subjects’ requests. In case of the corrugated cardboard temporary shelter, a greater variety of items were used, indicating that the large space and the high degree of freedom in the cardboard shelters made it possible for residents to improve the environment to suit their needs. We expect that this would further improve the quality of living in refuge situations.

Table 1. Summary of Interviews on Comfort of Living.

Season	Type	Good point	Bad point
Summer	Temporary shelter	The floor of corrugated cardboard temporary shelter was the best compared to the tent and automobile. It felt good when I lied down and felt good on my feet as we walked around. The touch on the floor panel of corrugated cardboard temporary shelter felt soft and comforting. Because of its roomy space, there was no sense of confinement. In addition, it was nice to be able to move my body freely.	Ventilation of the room is poor. It will be very hot in summer unless the window opening is widened.
	Tent	Since the tent had many openings covered with meshes, it was quick to ventilate the room. The tall ceiling made the room look spacious. Compared to staying in a gym or an automobile, staying in the tent was more	Since there is no flooring and the floor is the ground, I used a mattress under my sleeping bag. But that did not help and I could not sleep well.

Season	Type	Good point	Bad point
Winter	Automobile	comfortable. It had the convenience of being able to use the air-conditioner when I sleep. The seats are soft and felt better than the floor of the tent. Since the room is spacious in the corrugated cardboard temporary shelter, I could use an electric heater safely.	There was a large amount of dew on the inside of the canvas. Compared to the corrugated cardboard temporary shelter, noises from nearby cars were disturbing.
	Temporary shelter	At night, I could sleep soundly with an electric heater and a sleeping bag. Since the heat insulation property of the cardboard floor panel, the coldness of the ground did not wake me up during the night. I had a good sleep and did not feel like waking up.	When the heater was turned off, it was too cold and uncomfortable.
	Tent	No comment	During the night, the ground took my body heat away and my back felt very cold. Because the space in the tent was limited, there was no space for an electric heater with two persons sleeping. In addition, I had to worry about accidentally knocking over the electric heater during sleep. I could not find the right position to rest my head, and my neck and shoulders became stiff. I felt pain in my body in the morning.
	Automobile	No comment	The room was airtight with poor ventilation and there was a large amount of dew. As a result, the interior got all wet and even my sleeping bag felt damp.

4. Conclusion

This study aims at the development of a temporary emergency shelter made of corrugated cardboard. We measured the thermal environment in order to verify the shelter's comfort level both in summer and winter, surveyed users for their subjective statements on quality of sleep, and interviewed subjects regarding the living conditions. We came to the following conclusions.

1. The room temperature in summer was high in all refuge spaces due to the sunlight. During the night, the room temperatures of the corrugated cardboard temporary shelter and the tent were roughly equal to the outdoor temperatures, while the room temperatures of the automobile, which has an airtight construction, tend to rise due to body heat thus leading to difficulty in sleeping.
2. The subjective statements on the quality of sleep indicate that, in summer, the corrugated cardboard temporary shelter received the highest score, followed by the tent, and finally the automobile. In winter, the corrugated cardboard temporary shelter received the highest rating, followed by the automobile, and finally the tent.
3. In interviews, the corrugated cardboard temporary shelter was rated high both in summer and winter. Coldness in winter was a problem associated with the tent, while insufficient space, insects in summer, and condensation were brought up for the automobile in winter.

By applying a water repellent finish to the corrugated cardboard material and by carefully considering the structure, it is possible to render properties to the cardboard that are necessary for the comfort and long-term (six months) durability of emergency shelters. Cardboard is also a low environmental impact material produced from solid wood.

For all of these reasons, it is desirable to increase its use in the production and distribution of temporary emergency shelters.

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