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Examining Thermal Problems in Three Types of Emergency Housing in Japan

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Abstract: This study analyzes thermal problems in three different types of emergency housing: prefabricated, wooden, and trailer homes. We investigated the thermal environment of each housing type by interviewing residents and measuring the indoor air temperature and humidity inside each house during winter and summer. Prefabricated housing had several issues that needed improvement owing to possessing low airtightness and multiple heat bridges. Wooden housing had very few thermal problems, primarily owing to high insulation performance and resident lifestyles. Finally, the long and narrow interior spaces of trailer homes made air circulation and air conditioning difficult. The findings presented here will provide valuable and fundamental information for proposing ways to improve the living environment of disaster victims in emergency housing, making them more comfortable without interfering with the rapid supply system.

1. Introduction

In Japan, where natural disasters such as earthquakes and heavy rain occur frequently, temporary housing is necessary for those who have lost their homes. However, it is difficult for temporary housing to cope with all types of weather conditions because of the varying regional climates in Japan. Therefore, standardized building materials with certain specifications are used and readily available. In the immediate aftermath of a large-scale disaster, such as the Great East Japan Earthquake of 2011, it is difficult to maintain adequate environmental performance, such as heat insulation, at the time of construction, owing to the need to build as quickly, at as low cost, and in as large a quantity as possible.

The environmental performance of temporary housing in Japan has significantly improved. Table 1 reports the changes in the insulation specifications of temporary housing utilized following large-scale disasters from 1991 to 2018 (Cabinet Office, Government of Japan, 2021, May). Despite the improved performance over the past 30 years, residents are still concerned about the thermal problems and solutions of temporary housing. Therefore, continued efforts are required to enhance housing performance.

Recently, many people have lived in temporary housing for several years following large-scale disasters. The longer people live in temporary homes, the more critical their living environments become. In Japan, the policy on temporary housing supply states that the maximum provisional period of temporary housing is two years, and extensions upon application are permitted. In 2016, five years after the Great East Japan Earthquake of March 2011, one-third of the households living in prefabricated temporary housing remained residents of temporary housing (Mitsubishi Research Institute, 2018). Even now, more than ten years after the disaster, some people still live in temporary homes. Therefore, it is crucial to improve the living environment in temporary housing (Reconstruction Agency, 2021, August).

Various studies have been conducted worldwide regarding the indoor environment of temporary housing and shelters after disasters or war. Albadra et al. (2020) investigated air quality such as VOCs inside temporary shelters in the ten locations with different climates and cultures such as Peru and Ethiopia. They showed that the indoor air quality was extremely harmful because many people live in narrow spaces, and also indicated that the condition could be improved by introducing the air flow effectively. In Japan, after the Great East Japan Earthquake in 2011, much research has been conducted on improving the indoor thermal environment in, especially prefabricated, temporary housing. In addition to the thermal environment, some studies have been conducted on indoor air quality (Shinohara, et al., 2013, January and December. 2018, February).

In temporary shelters after a massive earthquake in Nepal in 2015, seasonal changes in the indoor thermal environment and acceptable temperature range were revealed (Rita Thapa et al., 2016 and 2018). It has also been demonstrated that the addition of polyethylene foam and clothing to walls and roofs can reduce the heat loss coefficient during winter (Rita Thapa et al. 2019). Research on bamboo wood temporary shelters after the 2013 earthquake in Lushan, China, suggested that thermal performance could be improved using inexpensive materials (Ying Yu et al., 2016). In addition, a study on the thermal comfort of shelters in refugee camps in the Middle East underlined the significant adaptability of refugees; however, it also highlighted the need to review ventilation systems and improve the insulation of shelters. (D. Albadra, 2017). After the 2008 Wenchuan earthquake in China, many temporary settlements with high building density consisting of prefabricated housing were built. Huang et al. (2015) revealed

Table 1. Changes in standard specifications regarding environmental performance of temporary housing in Japan

Disaster		Unzen-Fugendake Eruption Disaster (1991)	Hokkaido Southwest Offshore Earthquake (1993)	Great Hanshin-Awaji Earthquake (1995)	Usu Eruption (2000)	Niigata Chuetsu Earthquake (2004)	Iwate-Miyagi Nairiku Earthquake (2008)
Site		Nagasaki	Hokkaido	Hyogo	Hokkaido	Niigata	Iwate, Miyagi
Climate		Moderate	Cold	Moderate	Cold	Cold	Cold
Insu-lation*1	Ceiling	100 mm	100 mm	50 mm	100 mm	100 mm	100 mm
	Wall	-	50 mm + 50 mm (doubled wall)	20~30 mm	50 mm	50 mm	50 mm
	Floor	Nothing	100 mm	Nothing	100 mm	100 mm	100 mm
Partition between households		-	PB 12 mm	PB 9.5 mm	PB 9.5 mm And GW 50 mm	PB 9.5 mm and GW 50 mm	PB 9.5 mm and GW 50 mm
Double sash		Nothing	Do	Nothing	Nothing	Do (after construction)	Do (after construction)
damp-proofing		-	-	Nothing	Do	Do	Do
Sick house measures**2		Nothing	Nothing	Nothing	F★★★★	F★★★★	F★★★★
Cooling and heating equipment		Cooler	Nothing	AC (after construction)	FF-type kerosene heater***3	AC	AC

Disaster		Great East Japan Earthquake (2011)			Typhoon No.12 Disaster (2011)	Heavy Rain in Northern Kyushu (2012)		Kumamoto Earthquake (2016)	West Japan Heavy Rain (2018)	Hokkaido Eastern Iburi Earthquake (2018)
Site		Iwate	Miyagi	Fukushima	Wakayama	Fukuoka	Kumamoto	Kumamoto	Hiroshima, Okayama, Ehime	Hokkaido
Climate		Cold	Cold	Cold	Moderate	Moderate	Moderate	Moderate	Moderate	Cold
Insu-lation*	Ceiling	100 mm			100 mm	GW 100 mm	GW 100 mm	100 mm	100 mm	HGW 175 mm
	Wall	50 mm (+ 50 mm after construction)	50 mm	50 mm	50 mm	GW 50 mm	GW 100 mm	50 mm	50 mm	HGW 100 mm
	Floor	50 mm			100 mm	XPS 60 mm	XPS 50 mm	50 mm	50 mm	HGW 100 mm
Partition between households		PB 9.5 mm + 12.5 mm and GW 50 mm	PB 9.5 mm and GW 50 mm	PB 9.5 mm and GW 50 mm	PB 9.5 mm and GW 50 mm	PB 9.5 mm + 12.5 mm and GW 50 mm	PB 12.5 mm + 12.5 mm (both sides) and GW 100 mm	PB 9.5 mm + 12.5 mm and GW 50 mm	PB 9.5 mm + 12.5 mm and GW 50 mm	PB 9.5 mm + 12.5 mm and HGW 50 mm
Double sash		Do (after construction)			Nothing	Nothing	Nothing (pair glass)	Do	Nothing	Do (Inner sash: pair glass)
damp-proofing		Floor polyethylene sheet			Do	Do	Nothing	Do	Do	Do (also ceiling and inner wall)
Sick house measures**2		F★★★★			F★★★★	F★★★★	F★★★★	F★★★★	F★★★★	F★★★★
Cooling and heating equipment		AC			AC	AC	AC	AC	AC	FF-type kerosene heater***3

GW: glass wool, PB: plasterboard, XPS: extruded polystyrene form
*1 Areas not marked with insulation material are considered to be glass wool.
**2 F★★★★: Interior material with low formaldehyde emission rate and not applicable to interior finish restrictions in Japan's Building Standards Act.
***3 FF: forced supply exhaust type

the summer heat and poor natural ventilation inside and outside houses by measuring the air temperature and air velocity.

Some new technologies for temporary housing have also been discussed. Salvalai et al. (2015) showed the thermal performance and the effect of reducing heating load of a new lightweight emergency architecture using a multilayer insulator. PCM-based solutions for the thermal stability of temporary buildings have been examined (Beom Yeol Yun et al., 2022).

Thus, the thermal environments in temporary housing and shelters have been researched extensively, and some methods of improving these aspects have corresponded to the climatic and cultural conditions in each region. Today, three types of temporary housing structures are commonly used: prefabricated, wooden, and trailer.

-Prefabricated Houses

Prefabricated temporary housing has a light-gauge steel structure, it can be used for a field office at a construction site. It is quickly constructed in large quantities because the building parts are manufactured in factories and assembled at the construction site. This is the most common type of temporary housing in Japan. It is especially prevalent when the scale of the disaster is immense. While the supply speed is fast, the effect of thermal bridges is usually significant because of the housing structure. Moreover, it is difficult to ensure sufficient airtightness.

-Wooden Houses

Currently, wooden structures are used for temporary housing as well. Local carpenters are involved in construction work, and local lumber can be used for construction, contributing to the economic recovery of the disaster area. After the Great East Japan Earthquake and Tsunami, wooden housing became increasingly popular in Japan after disasters. Many wooden homes are built when the disaster scale is relatively limited and few units are needed (Fuchigami, 2021). Accordingly, it is challenging to construct numerous wooden homes in a short period of time.

-Trailer Homes

Recently, trailer homes as temporary housing have become increasingly popular in Japan. The term “trailer home” is a Japanese–English term for a towable mobile dwelling unit with an axle, no engine, and cannot be self-driven. Trailer homes are factory-made, quickly constructed, low-cost, and reusable. The finished product is brought to the site by towing and installed by adjusting its level with jacks. There, it connects to electricity, gas, and water. If prepared properly, the installation can be done in a day. In addition, trailer homes are mobile and reusable, able to provide disaster relief housing in multiple areas. Trailer homes became a temporary emergency housing for the first time in Kurashiki, Okayama prefecture, after the West Japan Heavy Rain Disaster in 2018. It has been used as temporary housing for the victims of the 2018 Hokkaido Iburi East Earthquake as well. However, in Japan today, trailer homes remain not widely used, owing to their low supply. Therefore, it is difficult to provide trailer homes as temporary housing following disasters. Some research has been conducted on formaldehyde levels and other factors in trailers after Hurricanes Katrina and Rita (M. W. Murphy, 2013). However, research on the thermal environments of trailer homes is lacking.

Several types of temporary housing structures were provided in Kurashiki, including the three types previously described. Each type of temporary housing has distinct advantages and disadvantages regarding its supply-chain. Immediately after a disaster, selecting and providing the appropriate housing type is critical according to unique circumstances, scale, and location.

Understanding the thermal environmental characteristics and problems of different types of temporary housing can help improve the overall quality of disaster relief. As stated, research in this area is sparse. Only a few studies have examined the thermal environment characteristics of different temporary housing types in the same climatic region. This study identifies the characteristics and challenges related to thermal environments of three different temporary housing types within the same area. We interviewed temporary housing residents living in the three different housing types and measured the air temperature and humidity during winter and summer in Kurashiki, which was damaged by the West Japan Heavy Rain Disaster in 2018.

2. Method of field survey

2.1. OUTLINE OF SURVEY SITE

In July 2018, heavy rains caused widespread and simultaneous flooding and landslides, particularly in western Japan. According to a report from the Ministry of Land, Infrastructure, Transport, and Tourism (2018, September), 20,663 houses were washed out or partially destroyed. A total of 29,766 houses were flooded and 223 people died throughout Japan. In Kurashiki, 5,977 houses were washed out or partially destroyed, and 52 people died owing to embankment breaches in several rivers and landslides. After the disaster, Kurashiki built 158 prefabricated houses, 57 wooden houses, and 51 trailer homes (Disaster Prevention and Crisis Management Office, Kurashiki City, 2020, October).

Fig.1 shows the annual average weather data for the past 30 years (1991–2020) in Kurashiki from the Japan Meteorological Agency.

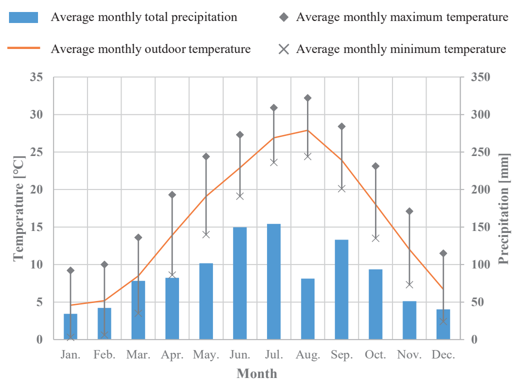

Figure 1. Annual average weather data over the past 30 years (1991–2020) in Kurashiki

In Kurashiki, the average annual air temperature is 15.8°C, and it rains throughout the year, especially during the rainy season from June to July. During winter, it snows occasionally but rarely piles up.

2.2. SURVEYED HOUSES AND RESIDENTS

Fig. 2 shows the appearances and plans of the surveyed houses. Table 2 lists the insulation specifications for each type of temporary housing considered in this survey. The thermal insulation specifications for each housing type meet the Japanese Energy Efficiency Standards for residential buildings for exterior skin performance (Institute for Building Environment and Energy Conservation, 2016, April).

Prefabricated temporary housing applications have only one air conditioner in the living room. Ventilation fans are installed in the kitchen, bathroom, and toilet. There are air supply outlets in the living room and Japanese-style room. In wooden house applications, the room with an air conditioner is used as the bedroom, and the other room without air conditioning serves as the utility room and is rarely used. The trailer homes are equipped

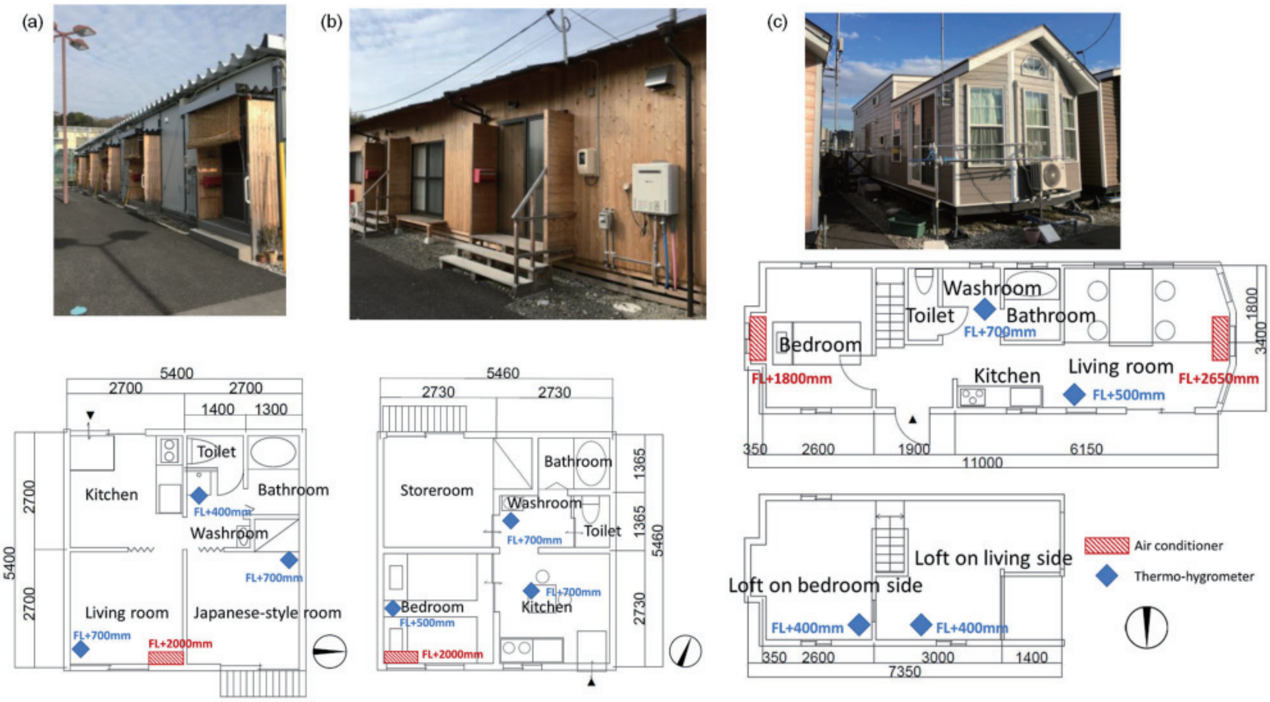

Figure 2. Appearance and floor plan of surveyed emergency housing (left: prefabricated house, center: wooden house, right: trailer home)

Table 2. Insulation specifications of three types of temporary housing

	Prefabricated house	Wooden house	Trailer home
Ceiling or roof	Ceiling: GW 100mm	Ceiling: HGW 100 mm	Roof: GW 100 mm
Wall	‣Exterior: PUF 40 mm and GW 50 mm ‣Separation: GB 12.5 + 9.5 mm and GW 50 mm	HGW 100 mm	GW 100 mm
Floor	XPS 40 mm	XPS 100 mm (50 mm double)	GW 42 mm
Window	Aluminum sash and single glass	Aluminum sash and pair glass	PVC sash and Low-E pair glass
Front door	‣Upper: Figured glass ‣Lower: Spandrel wall panel	Upper: Figured glass	‣Frame: wooden ‣Door: wood insulation laminated structure

GW: glass wool, HGW: high performance glass wool,
PUF: Polyurethane form, GB: gypsum board,
XPS: extruded polystyrene foam, PVC: polyvinyl chloride

with two air conditioners: one for the living room and another for the bedroom. Ventilation fans are located in the kitchen, bathroom, toilet, and loft on the living room side.

The prefabricated house is home to a couple, and the wooden house belongs to the parent and her child. The trailer home houses a family, that is, a couple with a child. The first-floor bedroom is closed during the daytime so that the husband can sleep.

In this survey, we asked the residents about their lifestyles. They provided a subjective evaluation of the thermal environment in their homes during winter and summer. We inquired about particularly hot and cold areas in their homes, air conditioning use, ventilation fans, and what measures were taken against heat and cold. They were also asked about condensation, mold, and drafts during winter, and if they had complaints about solar radiation during summer.

2.3. OUTLINE OF MEASUREMENTS

Several air temperature and humidity meters (HOBO UX100-011A, ONSET) were installed in the three temporary housing applications (prefabricated, wooden, and trailer homes). The air temperature and relative humidity were recorded every 10 min from December 3 to August 30, 2020. The locations of the air temperature and humidity meters are indicated in the floor plans presented in Fig. 2. In the prefabricated house and trailer home, the residents installed the measuring devices themselves, indicating the locations on the floor plans. Because some of the measuring instruments in the prefabricated house were installed near the wall, they may not have accurately captured the air temperature and humidity. Therefore, measurement results from the prefabricated home should be carefully evaluated. The graph shows the measured air temperature and humidity ratio calculated from air temperature and relative humidity.

3. Results

3.1. INTERVIEW SURVEY

Tables 3 and 4 list the interview results.

3.1.1. Prefabricated house

During winter, the living room was heated all day at a high air temperature of 28 °C. However, the house remained cold in several areas. Residents commented that it was cold near windows and floorboards. In the prefabricated housing, the ventilation fans in the toilet and bathroom were continuously running to prevent condensation and mold. Nevertheless, condensation and mold were observed. Furthermore, the residents stated that there were cold drafts coming from the entrance door and ventilation fans. To reduce the intrusion of cold air, they placed urethane mats near the locations where they felt the drafts.

During summer, solar radiation is the primary heat source in a prefabricated house. As shown in the floor plan presented in Fig. 2(a), the west solar radiation enters the kitchen and bathroom, creating warmth. An exposed steel column in the toilet becomes very hot in the evenings because of solar heat. Steel pillars can become too hot to touch and harm the residents.

3.1.2. Wooden house

The results showed that wooden housing residents had fewer complaints about thermal conditions throughout summer and winter. During summer, the only hot place was the kitchen while cooking, and during winter, no cold areas, condensation, mold, or drafts were observed.

3.1.3. Trailer home

During winter, areas far from the air conditioner appeared particularly cold. Owing to the cold floor, the residents put down rugs and wore slippers. During summer, the excess heat from solar radiation was a problem. The residents reported that the loft area was particularly hot and felt the direct effect of solar radiation on the roof. They cope with this issue by opening windows and closing curtains to ensure ventilation while reducing the solar heat in the living room.

3.2. AIR TEMPERATURE AND HUMIDITY

The results for sunny days with particularly low air temperatures during winter and high air temperatures during summer over the measurement period are presented in Figs. 3–8. We obtained the outdoor air temperature data from the Japan Meteorological Agency (JMA) in Kurashiki City. The humidity ratio was calculated using the outside air temperature and relative humidity measured at the site.

3.2.1. Winter

Table 3. Winter conditions–Interview lists and results (AC: air conditioner)

Interview list / structure types	**Prefabricated house**	**Wooden house**	**Trailer home**
Cold areas	・Japanese-style room (with no AC) ・Toilet・Near the windows ・Coldness of the floor	Nothing	・Loft on the bedroom side, bathroom and washroom ・Coldness of the floor
Heat setting	AC heating set at 28℃ all day	AC heating set at 24.5℃ all times except when out	AC heating set at 23℃ all day in living room, 24℃ setting during daytime in bedroom
Ventilation	・Ventilation fan: constant use in toilet and bathroom, used when cooking in the kitchen ・Air supply outlet: closed	・All ventilation fans used intermittently ・Air supply outlet: open	・All ventilation fans used intermittently ・Air supply outlet: open
Condensation and mold growth	・Condensation on the front door and all windows ・Mold on tatami mats and behind the curtains	Nothing	Condensation on windows in bedroom, loft above the bedroom, and kitchen
Cold drafts	From the kitchen ventilation fan in early morning, gaps in the front door and windows	Nothing	From bottom of the window in living room
Measures against the cold	・Place urethane mats on the floor ・Place urethane mats wherever drafts occur	Nothing	・Place urethane mats against the window where drafts occur ・Place rug mats on the floor ・Wear slippers

Table 4. Summer conditions–Interview lists and results (AC: air conditioner)

Interview list / Structure types	**Prefabricated house**	**Wooden house**	**Trailer home**
Hot areas	・Western-facing room ・The toilet's exposed steel pillar gets very hot due to sunlight.	Kitchen when cooking (a little hot)	・Feel the radiant heat from the ceiling in lofts ・Livingroom during daytime ・Bedroom in evenings
AC setting	AC set at 26℃ and full-time fan use except when out	AC set at 24℃ at all times except when out	AC set at 26℃ in evenings to next mornings in the living room, set at 20℃ during daytime
Ventilation	・Ventilation fan: constant use in toilet and bathroom, use when cooking in the kitchen ・Air supply outlet: open	・All ventilation fans used intermittently ・Air supply outlet: open	・Intermittent use: ventilation fans in toilet, bathroom, and kitchen ・Constant use: ventilation fan in the loft on the living room side ・Air supply outlet: open
Solar radiation heat complaints	Too much west sunlight	Nothing	Too much western sunlight to the living room
Measures against the heat	・Bamboo screen installed to shade solar radiation from the west ・A fan between rooms to circulate cool air from the air conditioner.	Nothing	Close curtains for shading solar radiation and open windows for ventilation

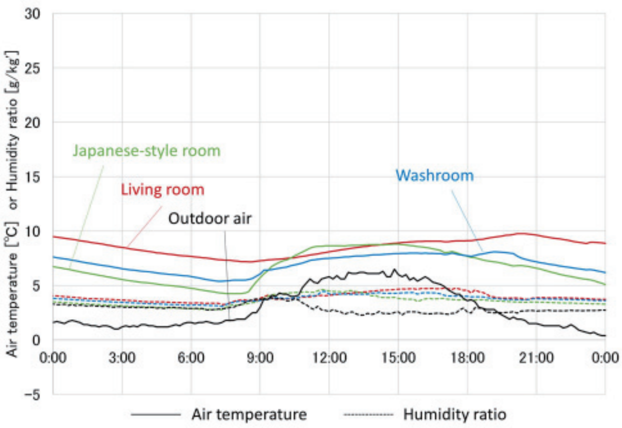

Figure 3. Air temperature and humidity ratio measured inside the prefabricated house during winter (February 6, 2020)

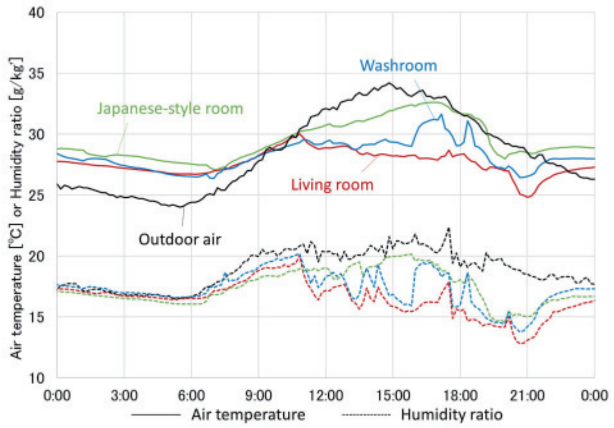

Figure 4. Air temperature and humidity ratio measured inside the prefabricated house during summer (August 5, 2020)

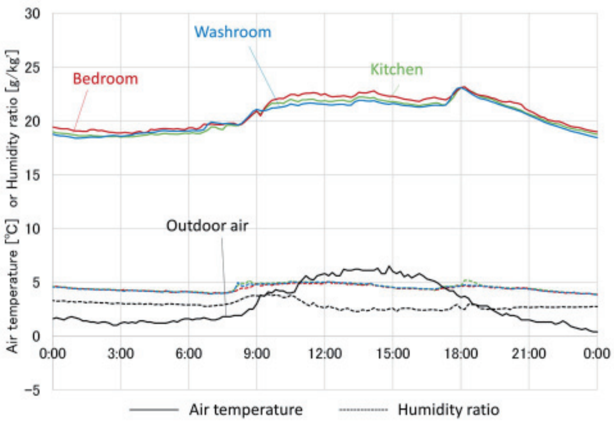

Figure 5. Air temperature and humidity ratio measured inside the wooden house during winter (February 6, 2020)

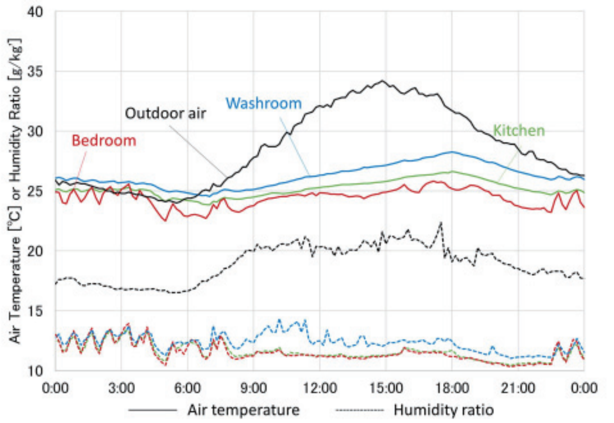

Figure 6. Air temperature and humidity ratio measured inside the wooden house during summer (August 5, 2020)

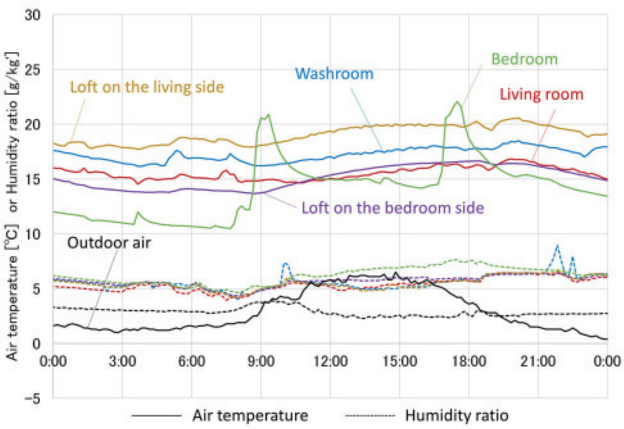

Figure 7. Air temperature and humidity ratio measured inside the trailer home during winter (February 6, 2020)

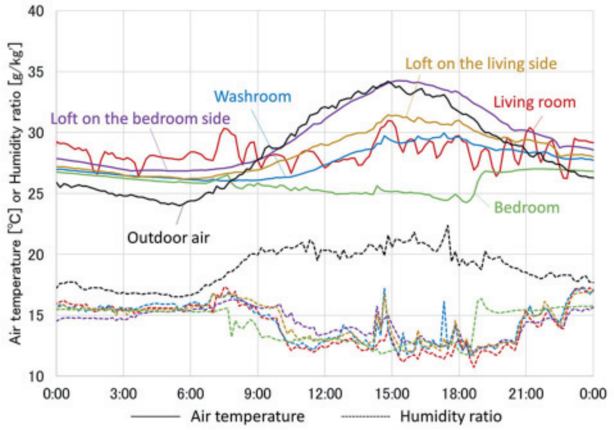

Figure 8. Air temperature and humidity ratio measured inside the trailer home during summer (August 5, 2020)

(a) Prefabricated house

The measured air temperatures in prefabricated housing were low. As previously mentioned, the results may not accurately reflect the actual room air temperature owing to the the measurement instruments being positioned near the walls and windows. The instruments may have been installed at a relatively low height, resulting in lower air temperatures. However, even accounting for this, the thermal environment in prefabricated houses is insufficient for residents' health and comfort.

In this type of housing, the heating system was set high during winter (28°C); however, the actual measurement results indicated an indoor air temperature below 10°C throughout the day. The further the distance was from the living room, the lower was the air temperature. In addition, the humidity ratio in the rooms was close to that measured outside the house.

(b) Wooden house

The air temperature and humidity measurements indicated very few problems in the thermal environment of wooden housing during winter. The three living areas the residents commonly used remained at approximately 20 °C even on low temperature days, and the humidity ratio difference between the inside and outside of the house was maintained.

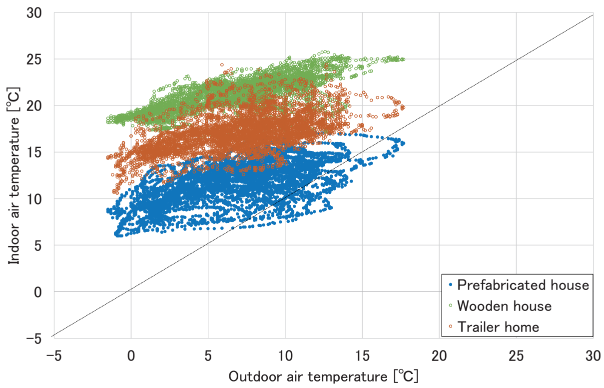

Figure 9. Scatter diagram of indoor air temperature versus outside temperature for each temporary housing during winter (January 20 to February 20, 2020)

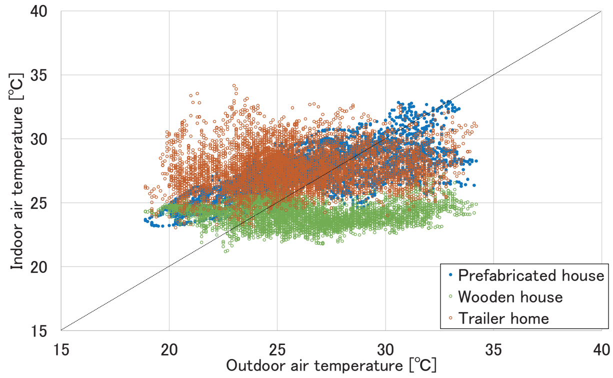

Figure 10. Scatter diagram of indoor air temperature versus outside temperature for each temporary housing during summer (July 9 to August 9, 2020)

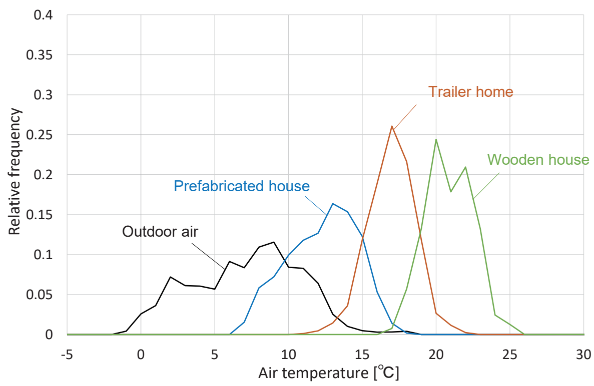

Figure 11. Relative frequency distribution of air temperature in the air-conditioned room of each temporary housing during winter (January 20 to February 20, 2020)

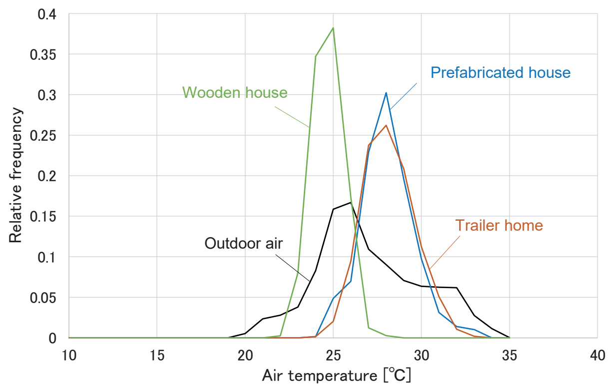

Figure 12. Relative frequency distribution of air temperature in the air-conditioned room of each temporary housing during summer (July 9 to August 9, 2020)

(c) Trailer home

The results indicated that the trailer home had an air temperature difference of approximately 5°C between the loft on the living side and loft on the bedroom side. Furthermore, the living room air temperature was lower than that of the upstairs loft on the living side and washroom, even though the living room was a heated room.

3.2.2. Summer

(1) Prefabricated house

The results showed that the bedroom air temperature, without air conditioning, tended to be higher. At approximately 11:00, the washroom and living room air temperatures decreased by cooling, while the Japanese-style room air temperature continued to rise. Conversely, the indoor air temperature exceeded the outdoor air temperature during the night and early morning.

(2) Wooden house

In the wooden house during summer, the room air temperature was maintained at approximately 25°C, even on days with high air temperatures. The results demonstrated almost no air temperature difference between the rooms.

(3) Trailer home

During summer, the loft area air temperature exceeded 30 °C, especially on the bedroom side, which rose to 34 °C during daytime. In addition, the air temperature difference between the two upstairs loft spaces reached a maximum of approximately 4 °C. The living room was air-conditioned, but the air temperature was sometimes lower in the washroom. Moreover, the room air temperature was higher inside than outside during night and early morning.

4. Discussion

4.1. ENVIRONMENTAL FACTORS AND POSSIBLE COUNTERMEASURES AGAINST THERMAL PROBLEMS

Our goal was to understand the characteristics and issues of winter and summer thermal environments in three types of emergency housing in the same climatic region. We collected subjective evaluations from residents and objective calculations by measuring air temperatures and humidity in a prefabricated, wooden, and trailer type temporary housing in Kurashiki. To understand the summer thermal environment, we measured air temperature and humidity changes on sunny and hot days. Conversely, to measure the winter thermal environment, we extracted and evaluated the changes in air temperature and humidity on sunny and cold days. To specify the differences among the three types of houses, scatter diagrams (Figs. 9 and 10) and relative frequency distributions (Figs. 11 and 12) were constructed for the winter and summer periods. The temperatures shown in these figures are the air temperatures in the air-conditioned living rooms in each house. The winter period was defined as lasting from January 20 to February 20, 2020, and the summer period was defined as lasting from July 9 to August 9, 2020. During winter, the air temperature in each house differed significantly. The difference between the average temperature of the wooden house (20.4°C) and prefabricated house (11.8°C) reached as much as 8°C. The average temperature in the trailer home was 16.5°C. Furthermore, the temperature range in the prefabricated house was relatively wide, and the minimum temperature was much lower than those measured in the other two houses. During summer, prefabricated house and trailer home showed approximately the same air temperature distribution, with an average temperature of 27.6°C. In both houses, the set cooling temperature was maintained at 26°C.On the other hand, in wooden house, the average temperature was 24.2°C, which was approximately the same as the set temperature of 24°C.

4.1.1. Prefabricated house

In prefabricated house, the main cause of the strenuous thermal environment, which is cold during winter and hot during summer, can be attributed to low thermal performance.

During winter, the low air temperature inside the prefabricated housing most likely resulted from the low airtightness and thermal bridge effects. Drafts from the kitchen ventilation fan and other openings let cold inside the house. Drafts can be reduced by lining the openings where they occur and by installing thick drapes on the windows. In addition, constantly running the ventilation fans in the toilet and bathroom may not have been sufficient to prevent condensation and mold, but rather an of cold air. Therefore, it may be necessary to review the practicality of running a ventilation fan.

During summer, the temperature difference between the living room and Japanese-style room after operating the air conditioner may be owing to closing the partition curtain to improve the cooling efficiency in the living room. Alternatively, if the curtain was open, it would be difficult for the cooled air to reach the Japanese-style room, which would make the living room hotter. In addition, it may be possible to live more comfortably by promoting more ventilation at relatively cooler periods throughout the day. The results indicate that it is possible to create a comfortable thermal environment by making lifestyle changes according to the outdoor conditions. However, exposed steel pillars heated by solar radiation pose an injury risk to the residents. The bare pillars should be covered to reduce heat gain and ensure safety.

Finally, during both seasons, it was difficult to channel air-conditioned air into the Japanese-style room that was not air-conditioned. This is a critical issue for the health of residents. Therefore, it is necessary to reconsider the effective use of circulators.

4.1.2. Wooden house

In the wooden house, occupant evaluation and air temperature and humidity measurements suggested that the thermal environment was stable. The reason for this consistency may be the high level of airtightness of wooden structures, high thermal insulation performance, and fact that the thermal bridges are less prominent than those occurring in lightweight steel constructions. In addition, the small living area of this housing style may have contributed to its increased heating and cooling efficiency. However, because family structure and resident lifestyles vary, we do not suggest that residents limit their living areas. Furthermore, not all wooden houses would provide the stable thermal environment depicted by the results of this study. Therefore, to obtain the general characteristics and issues of the thermal environment of wooden houses, it will be necessary to conduct more surveys of temporary wooden houses with different family structures and lifestyles and in areas with disparate climatic conditions.

4.1.3. Trailer home

In the trailer home, it was difficult to channel air-conditioned air toward the back of the loft during both winter and summer. This was because trailer homes pack residential functions into long and narrow spaces. Circulators must promote air circulation more effectively in the rooms. In addition, we need to solve the issue of cold floors during winter, which occurs because of the hollow space under the floorboards. Closing the hollow space and laying mats or providing insulation on or under the floor would make a significant difference in keeping the floors warm. By addressing the cold floor issue, we reduced the vertical air temperature difference in the room.

During summer, the distribution of air temperature is higher than that of the outdoor air temperature, suggesting that the air temperature tends to be higher during the day due to solar radiation and does not decrease over nighttime. Therefore, measures against heat absorption owing to solar radiation are critical. Because trailer homes do not have attic spaces, the effect of solar radiation on roofs is particularly intense. Therefore, it may be necessary to reinforce the thermal insulation of the roof and select materials to reduce the rate of solar radiation absorption. Furthermore, trailer homes are limited in width to comply with the “wide load” road rules when driving the house to its destination (taken from Japan RV and Trailer House Association). They have few or no eaves, making it difficult to shade them from solar radiation. However, when used as temporary housing, additional eaves and other sun-shielding materials cannot be fixed directly to the housing because the original condition must be maintained and returned at the end of the service period. Therefore, trailer homes should be designed for temporary use only and by installing boards in advance to attach additional eaves and other components as needed.

4.2. SUMMARY OF SURVEY RESULTS

As described above, differences exist in the thermal environments of different temporary housing types built in the same climatic region. Although the thermal environment was very stable in the wooden house, several issues were found in other types of housing. However, this does not mean that there should be fewer prefabricated houses and trailer homes and more wooden houses built. During a disaster, it is often necessary to construct as many units as possible, as quickly as possible. Prefabricated housing can be supplied in much larger quantities than wooden houses. Additionally, trailer homes are highly mobile and reusable. They can be moved from one site to another depending on the disaster recovery situation (Tsuchiya, et al., 2019). In summary, each type of temporary housing has unique advantages and disadvantages, and it is critical to select the appropriate type according to the scale and location of the disaster. This study aimed to examine all three types of temporary housing to analyze the living environment comfort of disaster victims.

5. Conclusions

To understand and compare the seasonal and thermal characteristics of the three types of emergency temporary housing provided to disaster victims, we gathered subjective and objective data to determine the most comfortable option. Our subjective evaluations were conducted by the residents. Our objective evaluations entailed taking air temperature and humidity measurements inside a prefabricated house, wooden house, and trailer home built after the West Japan Heavy Rain Disaster in 2018.

The survey results showed that there are several ways to improve the thermal environment of prefabricated housing. Heat and cold can be attributed to low thermal performance and air circulation difficulties. In the wooden house, the residents' evaluations and air temperature and humidity measurements indicated to a stable thermal environment. We found that this was primarily because of the airtightness, high thermal insulation performance, small influence of thermal bridges, and small living area of the residents. In the trailer home, the long, narrow space made air circulation difficult during winter and summer. The floor was cold during winter because of the hollow space under the floor caused by jacking the structure above the ground. During summer, the sun's heat affected the environment. Improving the use of air circulators, closing or insulating the gap under the floor, improving roof insulation, and reducing solar radiation absorption are viable options for mitigating complaints. In summary, the characteristics and issues of the thermal environment varied depending on the structure of temporary housing in a given climatic region.

This study contributes to improving the living standards of disaster victims in temporary housing by outlining how to achieve a more physically comfortable environment. We considered the advantages and disadvantages of each temporary housing type. By selecting and supplying the appropriate housing type with respect to the disaster scale and location, we can reduce the damage to resident health and aid disaster recovery.

Furthermore, this research contributes to speeding up disaster rescue efforts by leveraging the advantages of trailer homes through identifying the issues and characteristics of their thermal environments and promoting their production as temporary housing for disaster victims. As a next step, as Song et al. (2016) pointed out, each type of temporary housing should be assessed also from the viewpoint of life-cycle energy.

Notably, prefabricated housing measurement results require careful evaluation. Some measurements were insufficient because of the installation position of the measurement equipment used in this study. In addition, as this study only surveyed one case for each temporary housing type. Therefore, it is necessary to expand the survey scope in the future to generalize the findings.

In future research, we will verify the effectiveness of the improvement measures for thermal environment issues in each temporary housing type identified in this study through experiments and computational fluid dynamics analyses. We plan to visit an increased number of temporary housing sites to observe more general thermal environmental characteristics and issues. Finally, we aim to expand the target area and continue our research to present appropriate ways of living and operating under various climatic conditions.

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