https://doi.org/10.1080/13602365.2018.1424227

Toward Healthy Housing for the Displaced

D. Albadra, D. Coley, J. Hart

Abstract

The population of people living in temporary settlements after disasters is in the millions and the average stay in these settlements exceeds a decade. This paper reviews the literature on the design of post-disaster relief shelters in order to: establish the state of the art, identify trends and describe the academic activity of the past forty years. The analysis demonstrates that the academic engagement in this topic is limited, with fewer than sixty publications in the past four decades. Displacement camps are often situated in countries with extreme climates; however the issue of the thermal performance of shelters and their impact on health is found to be further overlooked. In an attempt to rebalance this situation, thermal surveys were conducted in two refugee camps in Jordan. The study found that the refugees were very unsatisfied with the thermal conditions in their shelters, particularly in summer. Internal surface temperatures of 46°C were recorded in September and indoor CO_2 concentration levels of 2700ppm were measured in winter. In addition, this paper reported on the adaptation strategies used by refugees to cope with the heat and cold, and reported on their views on shelter design considerations and satisfaction.

1. Introduction

There are over 60 million people living in conditions of displacement due to natural hazards or conflicts across the world [1] [2]. The recent refugee crisis has resulted in accelerated levels of displacement and temporary camps have been set up by humanitarian agencies to house these displaced populations. However, refugees and internally displaced people can end up living in such encampments for years or even decades [3] [4].

In a prolonged crisis, humanitarian agencies tend to first provide tents as an emergency shelter; these tents are later replaced by more durable structures. Replacements can occur several times over the years depending on the length of crisis and the durability of the shelter provided. Sometimes, as a consequence of the long duration of encampment - for example Shahrawi refugee camps in Tindouf in Algeria, established in 1975, and Palestinian refugee camps in the Levant – camps can form permanent settlement and become highly populated with multi-storey buildings [5]. However, such a process takes decades, especially in the case

https://doi.org/10.1080/13602365.2018.1424227

of refugee populations that are hosted in foreign countries, in which host governments may discourage ‘permanency’. In addition, it is usually unclear how long a crisis can last, and the expectations of a crisis to be temporary leads toward temporary structures being favoured. As a result, the forcibly displaced can end up living in temporary shelters made of lightweight materials for many years.

More often than not, displacement camps are situated in remote areas with no access to electricity. The structures that are provided by humanitarian agencies, whilst offering shelter from the elements, are ineffective against harsh climatic conditions. Prolonged exposure to such extreme thermal conditions can lead to increased morbidity and mortality [6].

It is therefore important that thermal performance is taken into consideration when such shelters are being designed and built. However, this is rarely the case; Baker and Zetter in 1995 reported that the academic activity on refugee shelters and settlements in general was inadequate and their issues “utterly overlooked” [7]. Over two decades on and this seems to still be the case, in particular among the academic community. Our survey of the literature since 1980 has revealed that 60 academic publications (academic journals, books and conference proceedings) exist that are specifically about or touch on the issue of emergency and temporary shelter design. However, it is clear that interest in this topic has increased significantly given the current global crisis as 65% of all publications have been published in the last six years only. Of these sixty publications, only fifteen were on the thermal performance or thermal comfort in shelters; and nine were about shelters’ sustainability, life cycle or impacts.

In order to inform future shelter design that satisfies the ‘temporary’ criteria, but yet addresses the inherent issues with such designs, in terms of their inability to provide ‘healthy’ living and eliminate the health risks to occupants from prolonged exposure to extreme weather conditions, it is important to understand the current trends in shelter design and the thermal conditions in such camps. In this paper this is accomplished through a review of previous work and the administration of a survey in two refugee camps in Jordan.

First a summary of shelter terminology is presented.

https://doi.org/10.1080/13602365.2018.1424227

2. Shelter categories and terminology

The International Federation of Red Cross and Red Crescent IFRC [8] uses the terms 'emergency shelter', 'temporary shelters', 'transitional shelters', 'progressive shelters' and 'core shelters'. The differences between these categories are the length of stay, permanency of the location, durability and expected life-span of the shelter. Emergency shelters are usually provided in the immediate aftermath of a disaster. Temporary shelters or Transitional shelters, commonly referred to as 'T-shelters' are generally designed to be relocated and re-used, while progressive shelters and core shelters are built with the aim of becoming part of permanent solutions [8]. These definitions overlap. For example, in some situations the emergency shelter could simply be a public building while in others tents are distributed. These tents could end up being inhabited for months or years and thus termed 'temporary shelter' rather than 'emergency' in different situations.

The UNHCR shelter catalogue categorises refugee shelter designs under, 'global', 'emergency', 'transitional', and 'durable'. Global shelters include the UNHCR family tent, and flat-packed refugee housing developed by 'Better Shelter'. Emergency shelters include shelters that are made on site using locally available materials (generally timber structures). Transitional shelters are more durable shelters that are also built on site, for instance Azraq camp shelters in Jordan and the compact bamboo shelters in Ethiopia. While durable shelters were built with bricks and concrete blocks on concrete foundations such as the one-room shelters in Pakistan and L-shaped shelters in Iraq [9].

Felix et al, [10] differentiates on the basis of *stages* in post disaster response, emergency shelter, temporary shelter, temporary housing, and permanent housing. The distinction between shelter and housing was based on Johnson's [11] definition of 'temporary housing' as a unit that allows the resumption of everyday activities rather than simply 'sheltering'. Although the terminology used is inconsistent in the literature, it is clear that humanitarian responses are divided into 'emergency', 'temporary' and 'permanent', and the length of each stage and its corresponding shelter type/s will vary in different situations.

IFRC states the following "The decision on which terminology to use is a mixture of contextual factors. These range from the level of permanence expected of the shelters and the materials from which they are made, the site on which they are built and local politics. In some locations governments might take a position against a certain terminology". We will use the term

https://doi.org/10.1080/13602365.2018.1424227

‘temporary shelter’ in this paper to describe all types of shelter *units* used in humanitarian response from the onset of an emergency until prior to the permanent stage [8].

However, the question of what constitutes a ‘temporary’ as opposed to a ‘permanent’ shelter is challenging. As Felix et al., [10] discuss, while the temporary shelters are generally made of light weight structures, the infrastructure required to enable the return to carrying out simple daily activities such as bathing or cooking, is generally permanent. Moreover, building materials seen as permanent in one location may be categorised as temporary in another (for example mud or earth), in accordance with local regulations and laws. In other words, distinction between the categories of ‘permanent’ and ‘temporary’ is socially-constructed and not universal. The following section will shed light on some of the common materials used in temporary shelters.

3. Shelter typologies

There are two main approaches to providing temporary shelters: either they are manufactured and shipped to the intended site, or built on site by the displaced populations or local workers using locally available materials, in most cases under the supervision of humanitarian organisations. The choice of approach will have a significant impact on the design of the shelters, therefore, this paper will categorise all types of temporary shelters that are being developed or are currently in use based on their ‘manufacturing’ approach.

3.1 Transportable shelters

Tents are an obvious example of transportable shelters that are made off-site, stored and then shipped to a disaster-stricken location as and when needed. A lot of research has focused on the transportability and/or the deployability of shelters. For instance, Mira et al., 2014 [12] presented a preliminary concept for a transitional shelter comprised of deployable scissor arches. The structure consisted of three aluminium arches and a fabric membrane. The authors argued that this type of structure is lightweight, could be compact folded for transport, reusable, adaptable, and is rapidly deployed by only three people. The study included numerical analysis, a full scale experimental testing of the structure, and presented a final design according to Eurocodes.

Deployable Origami inspired shelters is another growing research field. The appeal of this type of shelter lies in its combination of the characteristics of deployable soft wall (fabric) shelters - such as ease of transport, light weight and small packaged volume; and the improved thermal

https://doi.org/10.1080/13602365.2018.1424227

performance of rigid wall shelters [13]. Origami-inspired shelters are made of one sheet of material/panel that folds to form a shelter. For example; Tumbeva et al., [14], investigated the structural performance of three quilt-inspired rigid wall sheltering topologies, made of sandwich panels. The faces of the sandwich panel were comprised of 1.27 mm thick fibre-reinforced polymer and a foam core of varying thickness depending on the geometry. They found that the 'Sawtooth Star' design had the lowest weight per area and the highest manufacturing efficiency that reduces waste material.

Several private companies have developed ideas for transitional shelter in recent years. For example; U-Dome by World Shelters was developed following Hurricane Katrina and is now being used to house the homeless in California [15]; Ikea developed flat packed shelters under the initiative 'better shelter' that are currently used in Ethiopian refugee camps among others [16]; Exo stackable shelters [17] were developed by Reaction Housing: they come in two parts, a shell compromising the walls and roof, and a base for the floor (Figure 1); Global Village shelters [18], which are also flat-packed, made of 13mm white polypropylene profile extruded sheet, are currently used in Pakistan and Haiti among other countries; Concrete canvas shelters (Figure 2) were developed by engineers Peter Brewin and Will Carwford [19]: the shelter is deployable in an hour and then the concrete takes 24 hours to set, the life span of the shelters is over ten years and therefore it was not widely used in humanitarian situations as governments were opposed to having something of a semi-permanent nature set up [20].

https://doi.org/10.1080/13602365.2018.1424227

Figure 1: Exo stackable shelters (Photo credit: Michael McDaniel, 2016)

Figure 2: left, U-dome by World Shelter (photo credit: World Shelters); right, concrete canvas shelter by Concrete Canvas (photo credit: Concretecanvas.com)

3.2 Shelters built onsite

These types of shelters are usually built with locally available materials, for example, earth shelters, primarily timber shelters or shelters built of metal sheeting. In these cases actors responsible for the management of the camps provide tool kits and training for refugees to build their own shelters or in some cases the camps could be built in advance of the arrival of refugees.

https://doi.org/10.1080/13602365.2018.1424227

Sand bag shelters were first popularised by Iranian architect Nader Khalili in 1992 and called ‘superadobe’ [21]. UNHCR adopted this technique in 1995 to provide temporary housing for Iraqi refugees in Baninajar Camp in Iran (figure 3). Fourteen shelters were built by the refugees themselves, under the supervision of trained UN personnel. Each shelter was built by a team of six refugees and took just over a week to complete [21]. These structures are made by filling, usually synthetic, long bags with earth taken from the site where the shelters are to be constructed. These bags are then layered, compressed and reinforced with barbed wire. The structures can be made more permanent by adding a plaster layer. This concept has become very popular across the world and used in several disaster relief housing projects including Haiti and Pakistan and has been most recently used in northern Syria to house internally displaced people.

In recent years several researchers have investigated the performance of this technique, Zhao et al., [22] analysed a typical dome superadobe structure in terms of ventilation, lighting and thermal performance. Another study [23] illustrated that generally no structural analysis is conducted prior to building and therefore they identified possible structural failure scenarios and proposed a design method for superadobe shelters.

Figure 3: Left: Baninajar Refugee Camp in Iran, 1995; Right: Superadobe construction technique, (Photo credit: Calearth.org, 2017)

There are several examples of shelters built with metal or plastic sheeting (Figure 4) that are available in a compilation of case studies by IFRC on shelter designs which have been built in significant numbers [8]. For instance, following the Haiti earthquake in 2010 thousands of shelters were built using galvanised steel frame, timber studs, plastic sheeting walls, corrugated steel roof sheeting and concrete foundations. In Aceh, Indonesia, a galvanised steel frame, steel sheet roofing, Radiata Pine/Douglas Fir or equivalent treated timber planks, and steel foundation plates were delivered as a ‘kit’ to build transitional shelters after the Tsunami of 2004. In Vietnam,

https://doi.org/10.1080/13602365.2018.1424227

galvanised steel frame and zincalume corrugated roof sheeting were used for building shelters on concrete platforms [8]. Although the IFRC carried out an assessment on the structural performance of these shelters in terms of wind, seismic and flood resistance, no thermal studies were conducted.

Figure 4: Shelters made of metal sheeting; right: Nepal (photo credit: Emil Helotie, IFRC); Left: Azraq camp, jordan (photo credit: S.Coley)

Timber, bamboo and plywood sheets are commonly used to build shelters in disaster stricken areas (Figure 5). Over five thousand shelters were built of timber frames and plywood sheathing in Haiti following the 2010 earthquake. The timber structures were built either on a timber floor or on a concrete floor and had a metal roof. Another type of shelter used in Haiti was based on traditional techniques found in the region, such as using 'clissage walls' which allows cross ventilation when left uncovered. This type of shelter could be upgraded by reinforcing it with mud or mortar to create a solid wall. In the Philippines; shelters were built from coconut wood frame on concrete footings, plywood floor, 'amaken' walls and corrugated iron roof. Shelters in West Java (2009) consisted of bamboo frame and bamboo matting walls with concrete foundations and terracotta roof tiles. While in Padang, Indonesia, shelters were built of timber frame on concrete bucket foundations, palm matting wall panels and palm fibre roof. The main concern with these types of shelters is their durability, as in some cases they can last for less than a year. This is because the timber materials are generally untreated, meaning that due to the tropical climate and the presence of termites, it is unlikely that the shelters will last for long [8].

https://doi.org/10.1080/13602365.2018.1424227

Figure 5: Bamboo and timber constructions; right: Philippine (photo credit: Jenelle Eli, IFRC); left: Indonesia (photo credit: IFRC)

Viscuso and Zanelli, as part of S(p)eedkits EU funded project, proposed a concept, in which the structure is built onsite with available materials, such as timber or steel, and a 'shelter kit' is delivered in rolls and fixed to the built structure [24]. They ranked three options; foam roll panels to enclose a structure creating a shelter; foam semi-open module combined together; and a 20mm non-woven polyester fabric forming a complete unit 'cocoon' delivered as a roll and fixed to a structure. The later design option was then selected for computer modelling using EnergyPlus in four climatic zones, Syria, Iran, Senegal and Mongolia. Ten shelters were subsequently tested under real conditions in Senegal. The authors report 'acceptable internal temperatures,' ease of deployability and that dust and sand did not enter the shelters due to the use of mosquito nets. Another possibility proposed recently is 3D printing earthen shelters for displaced populations. A comparison between 3D printing of shelters and conventional building techniques of earthen architecture demonstrated no benefit in costs but revealed that 3D printing was four to five times faster [25].

4. State of the art: Thermal performance of shelters

The Global Shelter Cluster led by the UNHABITAT, IFRC and UNHCR started a compilation of case studies of actual disaster relief shelters across the world. The case studies reported on the strengths and weaknesses of the shelter solutions, the design and materials used, technical solutions, disaster risk reduction and wider project impact. In addition, the IFRC under the shelter cluster project commissioned Arup to conduct a structural survey of 18 different shelters used in displacement camps across the world [8]. However, these studies failed to report on the thermal performance of shelters. Such an important aspect of shelter design remains understudied by the academic community as well.

https://doi.org/10.1080/13602365.2018.1424227

Manfield, [26] modelled a United Nations winter tent and another prototype under cold conditions as part of several studies with the objective of improving the design of standard tents distributed in disasters in cold climates. Crawford et al., [27] also conducted a series of experiments in a warehouse freezer to test the performance of two tents in cold conditions (-20°C), with high internal moisture loads. The two tents had a similar structure but different fabrics and insulating materials and both could accommodate a family of six. The experiments showed that both tents resulted in significant variation of temperature with height. They also used (ESP-r) simulation software to simulate the performance of the tents in three different locations; Islamabad, London and Pristina. They found that both tents were unable to maintain the heat inside and temperatures could drop well below zero without a heating source. Cornaro et al., [28] conducted an experiment to test the performance of a tent made of waterproof fabric (50% cotton and 50% modacrylic fibre) over a steel pole structure. They used the results of the experiment to calibrate a computer model and analyse the shelter performance under two Italian climatic zones for winter and summer, the external temperature range in the cold case (Turin) was from -6 to 12°C, in the warm case (Palermo), the outside temperature ranged from 24 to 30°C.

Several studies looked at Origami inspired shelters. For example, one study looked at material optimisation of folding rigid walls that are made of thermally insulated sandwich panels for minimum weight and maximum energy efficiency [29]. They proposed a panel that is comprised of 0.794 mm thick Epoxy Woven Aramid faces and 127.0 mm thick aramid HRH-10 core. This optimized solution resulted in the annual energy demand being 70% less than the standard military tents. Quaglia et al; [30] focused on the optimization of the shape of the shelter itself for improved energy efficiency. They looked at five geometric variables; these were back wall height, wing wall height, roof height, back wall angle and roof angle. Other variables such as material properties, and location (Chicago, USA) remained constant. They proposed an optimised shape that balances the objectives of minimizing deflection and thermal energy load. However as noted by the authors, no windows were accounted for in the study, assuming the shelter is used for military purposes.

A recent study by Yu et al., [31] monitored the thermal performance in winter conditions of temporary bamboo shelters for people displaced after the 2013 Lushan Earthquake in China. They also conducted a series of experiments on three bamboo-wood shelter models in cold climates to assess the improvement in thermal condition using different roofing materials and

https://doi.org/10.1080/13602365.2018.1424227

internal insulation. The results showed the temperature in the insulated models was about 1 to 2°C higher than that in the uninsulated model. The study was conducted using EnergyPlus software and the shelters studied were built of concrete materials. Ajam, 1998 studied the thermal performance in low-cost, adobe refugee shelters in the arid climate of Waqas in Jordan on behalf of UNRWA, using a computer simulation.

Escamilla and Habert, [32] assessed twenty transitional shelters in eleven different locations worldwide, in terms of their environmental, economic, and structural performances. The results showed that local materials (such as timber and bamboo) and 'global materials' (such as concrete and steel) can both offer sustainable solutions in shelter design if used efficiently. However, local materials had a higher potential for low environmental impact and costs while global materials delivered better structural performance. However, no assessment was made in terms of the shelters' thermal performance. Song et al., [33] performed a life cycle performance analysis of temporary housing in China, looking at embodied, operating and end of life energy. It was found that energy consumed in the construction process contributes to 65% of the life cycle energy resulting in the life cycle energy of post-disaster temporary housing being much higher than that of low energy buildings. Based on this they suggested reducing the life cycle energy of post-disaster shelters by using recycled and less energy intensive materials.

Most of the aforementioned studies focused on the winterisation of shelters or their performance in winter conditions. Moreover, whilst NGOs and other actors responsible for the management of camps conduct frequent needs surveys and other assessments (for example the REACH initiative [34]); fewer academic studies were conducted in actual displacement or refugee camps. A social study in temporary housing settlements for displaced populations after the 1999 earthquake in Turkey involved interviews with 200 individuals and reported on their satisfaction levels. The survey revealed that half of the participants found the unit size was insufficient and therefore they built their own extension. The study also discussed reuse and recycling options for the temporary housing [35]. Ashmore et al., 2003 [36] conducted fieldwork in Afghanistan with the International Committee of the Red Cross. Their study revealed that, compared to blankets and other household and personal items, insulation provision was valued greatly; the tested liner showed that insulation was worth the equivalent of 20–30 blankets.

https://doi.org/10.1080/13602365.2018.1424227

Researchers in Brazil conducted a workshop for displaced population due to floods, the participants learned how to make wall panels for shelters using banana tree leaves. The authors argue that involving the participants in the building process of their shelters had a therapeutic effect and created motivation “to rebuild what they have lost” [37]. A thermal comfort assessment was conducted in Jabalia refugee camp in Gaza strip [38], Palestine, a hot and humid climate, using a questionnaire and computer simulation. A hundred and fifty-five residents were interviewed and their comfort vote was registered. In addition, twenty-one shelters were tested using Thermal Analysis Software (TAS). However similarly to other Palestinian refugee camps the shelters were built with concrete blocks and therefore may not be considered temporary in other scenarios. Several on-site investigations from 2008 to 2013, showed that the living conditions of bamboo temporary shelters in China, used to house displaced people after two earthquakes, were very poor. The occupants of the shelters suffered from extreme heat and humidity in summer and had to endure cold and windy conditions in winter. This proved detrimental to their physical and psychological recovery after the disaster (Long, 2009 cited in [31]).

In order to address a significant gap in knowledge on the actual living conditions in temporary shelters during periods of hot and cold weather, we conducted summer and winter surveys and took measurements of several environmental variables in Azraq and Zaatari refugee camps in Jordan as explained below.

5. Case studies: Azraq and Zaatari refugee camps in Jordan

The two camps studied are sited in northern Jordan. Jordan is situated between 29° 45' N and 32° 32' N and is characterised by an arid desert climate according to the Köppen-Geiger climate classification [39]. The camps were set up to accommodate Syrian refugees fleeing the war in Syria. The Zaatari camp has a population of around 80,000 and Azraq camp around 54,000 [40]. The mean maximum outdoor temperature in Zaatari is 32.7°C and the mean minimum is 1.9°C. In Azraq the mean maximum outdoor temperature is 36°C and the mean minimum is 2.8°C [41]. Two surveys in summer and winter were conducted in Azraq and Zaatari refugee camps, in addition to thermal monitoring of outdoor and indoor summer and winter conditions. Air temperature, relative humidity, wind speed and direction and solar radiation onto the horizontal were recorded using a weather station that was set up in Zaatari

https://doi.org/10.1080/13602365.2018.1424227

during the summer survey and in Zaatari and Azraq during the winter survey. I-buttons sensors were used to record indoor air temperature and relative humidity, in addition to spot measurements of globe and surface temperature, air speed and CO_2 levels concentration.

The interviewed families were selected randomly. The summer survey consisted of 75 families (38 families in Azraq and 37 families in Zaatari). In the winter, 56 of the 75 families were visited again, and an additional 24 families were interviewed in winter to compensate for those who were not available. The families were interviewed in their shelters. The aim of the surveys was to understand the relationship between the refugees and their shelters, how they used it, how does the weather seasonal change affects this, what adaptations have they made, and how the layout of shelters affect their feeling of privacy, security and other aspects.

5.1 Zaatari Camp

Zaatari (32.29° N, 36.33° E) was established in July 2012 in response to the sudden influx of refugees. Tents were initially provided for the refugees; however, over the past five years caravan-like structures have replaced these (Figure 6). As of 2016, 99% of the population of the camp lived in caravans, 11% of these were static caravans with screed flooring. The remaining caravans were mobile and had a suspended timber floor, which in some cases had been replaced by the refugees with a screed of cement mortar over rubble. Roofs and walls were made of 40mm polyurethane insulated sandwich panels with outer surfaces of 0.35mm steel sheet and inner surfaces of either the same or of timber (G. Barakat, personal communication). The number of shelter units (caravans) per family varied depending on the size of the family and available resources to them. The general rule was that one caravan was provided for every family of up to six members, and two caravans for families of 6-12 members. However, many families stated that they purchased an additional caravan. The caravans also varied in size; interviews with UNHCR and NRC members revealed that this was because their main concern initially was to provide the refugees with a more solid shelter than the tents they were living in for over a year and therefore, they accepted all donations of caravans. However, they now follow the Sphere project guidelines of a minimum of ‘3.6m^2 per person’.

https://doi.org/10.1080/13602365.2018.1424227

Figure 6: Zaatari camp, mobile and static caravans, (photo credit: S.Coley)

5.1.1 The survey findings:

The average number of members per household interviewed was 5.6, and the average number of units per family was 1.5. The refugees in Zaatari camp had a relative freedom in arranging their caravans according to a layout that was favourable to them. Only 8% of the families interviewed did not make any adaptations to their shelters. At least 70% had built an extension or enclosed the space between their caravan units creating shaded makeshift courtyards. The floor of the created courtyards and extensions were made of cement mortar over rubble while metal sheeting and tent like materials were used for the walls and roofs. 16% had created and planted a front or back garden (Figure 7).

Figure 7: makeshift extensions to caravan shelters in Zaatari creating covered courtyards and shaded spaces (photo credit: left: S.Coley, right: D.Albadra)

https://doi.org/10.1080/13602365.2018.1424227

The majority of families cooked outside their caravan units in makeshift kitchens regardless of the number of caravan units they had and regardless of the season (67% in summer compared to 57% in winter). Moreover, in summer, over 55% of the families spent the day time hours in the semi-outdoor makeshift spaces that they have created, while less than 30% did the same in winter. This is because the caravan units were considered too hot in summer and those shaded semi-outdoor spaces with cement flooring were thought of as cooler, while the contrary was desirable in winter. When asked to rank the most important considerations in shelter design, safety and security came first for 63% of the respondents, followed by thermal comfort for 28%; third place was privacy also for 28%, followed by flexibility of design and ease of adaptation by 40% and lastly appearance by 52%.

Families were asked to rank their satisfaction with certain aspects of their shelter from (1) to (5) with (1) being very unsatisfied and (5) being very satisfied. The majority were neither satisfied nor unsatisfied by their shelter in general (52%). However, 62% were satisfied or very satisfied with the security and safety of their shelter while only 32% felt the same toward the provision of privacy in the shelters (many families confused the safety/security of the shelter with the safety of living on the camp in general and always compared this to what they escaped in Syria). With regards to the thermal conditions in the shelters, 48% reported feeling unsatisfied or very unsatisfied with the thermal comfort in their shelters in winter. This increased to 73% in summer.

In order to cope with the heat in summer, 43% of the families reported using wet towels (placed over heads and shoulders), 84% said they showered several times a day even with cloths on to stay cool, only 5% had access to electricity generator during the day and a fan, and 14% said they keep moving between shaded places, avoiding the sunny spots (Figure 8). Given the freedom refugees have in Zaatari in orienting their caravans, 54% thought the windows of their shelter were in the 'best' location, i.e maximising privacy and ventilation. 73% of families keep windows open all the time including at night, with 'sand storms' as the most common reason for closing windows (67% of the time). In winter, the use of gas heater was reported as most widely used strategy to keep warm (95%), with the heater being on for an average of 10 hours a day. Other strategies included the use of blankets, wearing several layers of clothing, and the addition of carpets (Figure 9). Ventilation levels dropped significantly in winter as windows were kept close all the time with only 57% said that they ventilate frequently by opening a window or a door for some time.

https://doi.org/10.1080/13602365.2018.1424227

Several issues were reported such as gaps in the structure, draughts around windows, condensation (in winter), rust and mould growth.

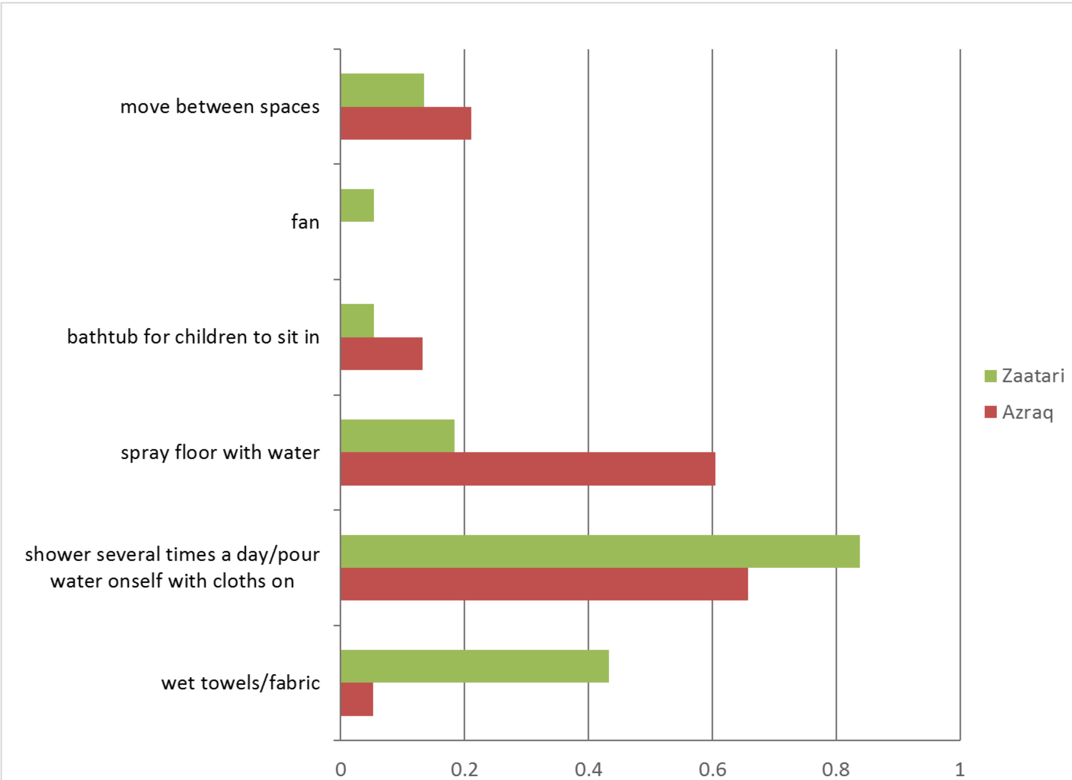
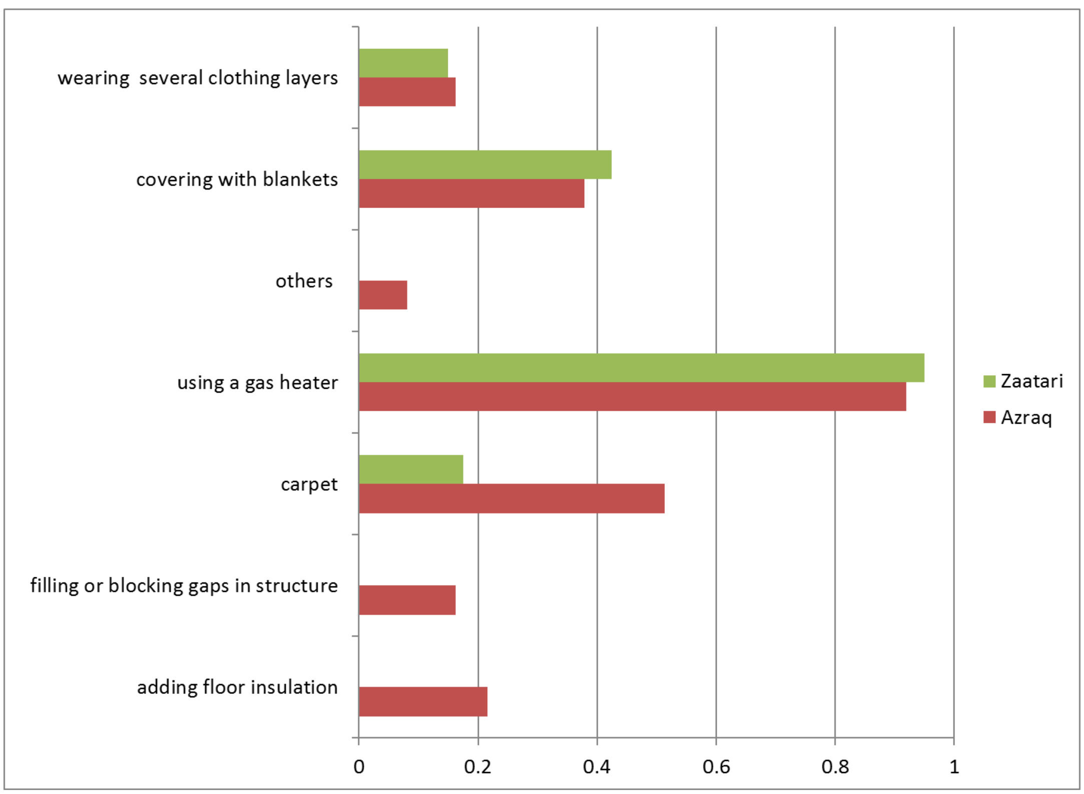


Figure 8: Summer adaptation strategies in Zaatari and Azraq camps



https://doi.org/10.1080/13602365.2018.1424227

Figure 9: Winter adaptation strategies in Zaatari and Azraq camps in Jordan, (others includes having hot drinks and sitting in the sun

5.1.2 Environmental monitoring

Indoor air temperature was recorded from the 15th to the 23rd of September and from the 4th to the 11th of January in two caravans with suspended timber flooring. I-button sensors were placed in the middle of the shelter units at 0.8-1m above the floor, windows were left open all day and night in summer as was revealed to be the case in the majority of occupied units. In winter windows were left closed.

As can be seen in the Figure 10, in summer, indoor temperatures either followed the outdoor temperature closely or was even several degrees higher. Indoor temperatures as high as 40°C were recorded in September; this demonstrated how ineffective the shelters are in protecting against high summer temperatures and that indeed they could be exacerbating the issue due to the construction materials chosen. As expected in a desert climate the relative humidity was generally low during the day at 30-40%, this was the same indoor and outdoor. In winter, indoor temperatures dropped to below zero at night, while they were up to six degrees higher than outdoor at midday due to solar gains alone given that windows were left closed (Figure 10). Spot measurements taken in occupied caravans showed that indoor CO_2 concentration level were similar to that of outdoors (about 600ppm) in summer. However, in winter, the figure varied significantly amongst households but levels as high as 2700ppm were recorded. Inadequate ventilation, all members of the family gathering in one space around a gas heater, and sometimes smoking indoors are all factors that have contributed to high levels of CO_2. Whilst these levels are not deadly, they are considerably high especially for children.

https://doi.org/10.1080/13602365.2018.1424227

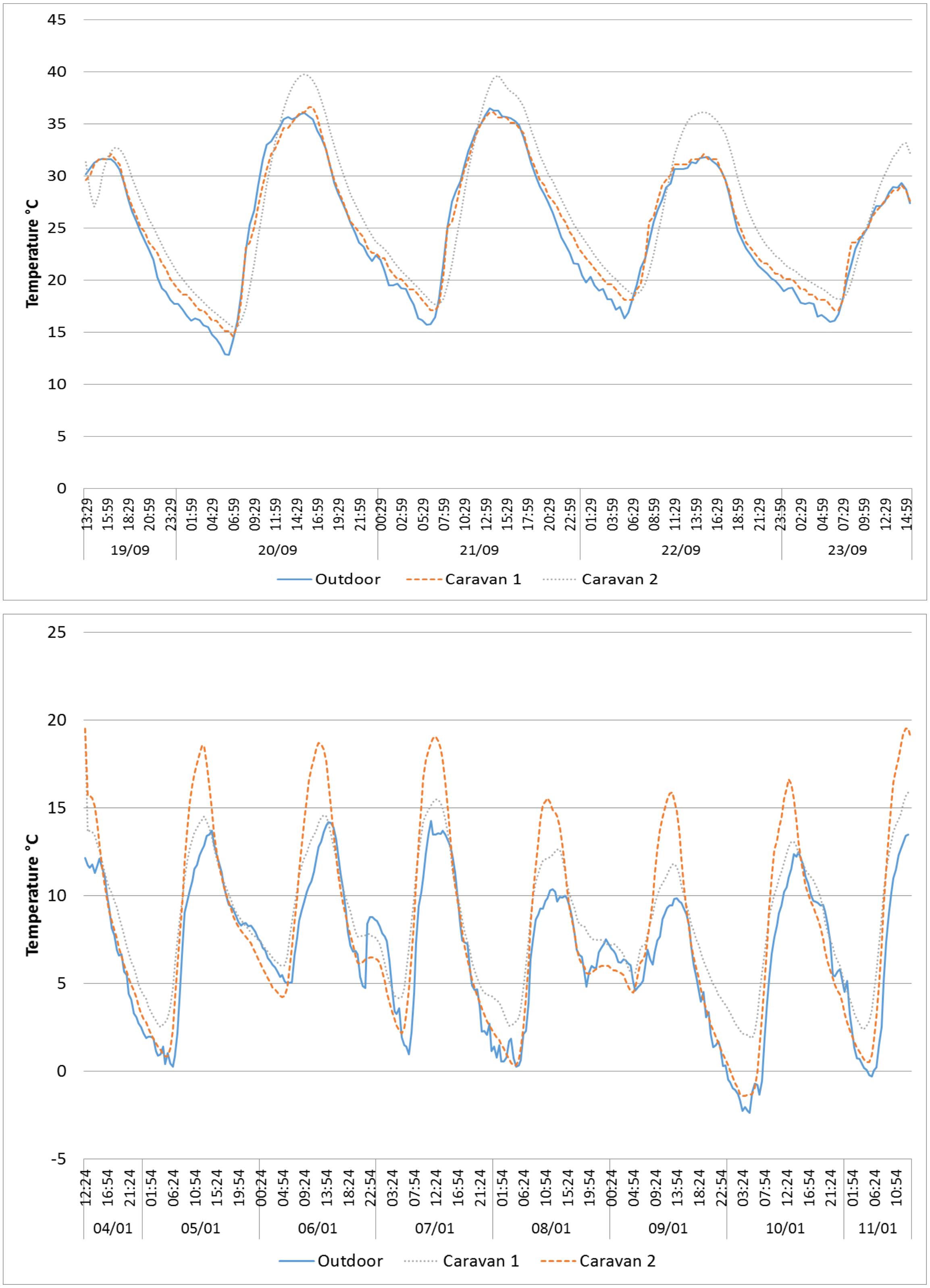


Figure 10: Top: measured indoor temperature in two caravans in September (summer period) against outdoor temperature in Zaatari camp – Windows open; Bottom: measured indoor

https://doi.org/10.1080/13602365.2018.1424227

temperature in two caravans in January (winter period) against outdoor temperature in Zaatari camp – Windows closed.

5.2 Azraq

Azraq camp (31.91° N, 36.59° E) was pre-planned, on a site that had been developed in the 90s to accommodate Iraqi refugees [42], Inverted Box Rib (IBR) corrugated sheets were used to build over 13,000 shelters in Azraq (Figure 11). The shelters built in Azraq camp had a steel frame and a concrete floor. The walls were composed of two layers of IBR sheets and a core of 10-15mm of aluminium foam as insulation. The roof consisted of one layer of IBR and layer of the same foam insulation covered on the interior surface with tent materials. Ease of manufacturing and assembly, reusability and positive impact on the local labour market were cited as strengths of this project and a main factor behind the government approval of it, in addition to "protection against the strong winds, dust, and extreme changes in climate" [42]. These shelters are described as transitional shelters by UNHCR and IFRC. When commissioning the design and manufacturing of these shelters; the perceived need for privacy observed in Zaatari camp, has led to a design with limited openings. Mainly, one window on a side wall and high level openings consisting of short lengths of 152mm pipes on the gables, thereby restricting the ability to cross ventilate.

https://doi.org/10.1080/13602365.2018.1424227

Figure 11: Azraq camp – From top left to bottom right notice: fabric and metal sheeting are used to enclose the space between adjacent shelters and windows self-cut by the refugees; interior of a shelter showing the roof and blocked ventilation pipes; a makeshift winter shade in front of the window that still allows sun in while providing privacy; additional layer of aluminium foam insulation stuck to the interiors of the walls. (Photo credit: left: S.Coley; right: D.Albadra).

5.2.1 Survey findings

The average number of shelter units per family was 1.6, and the average number of members per family was 6.7. 18% of interviewed families reported not doing any modifications to their shelters. However, the survey results showed that the limited areas of windows resulted in over 35% of families cutting an additional window in the walls. Consequently, creating gaps that were difficult to seal in winter (Figure 11). Moreover, it was observed that the high-level pipe openings provided for ventilation in Azraq shelters were generally blocked by residents to eliminate sand ingress in summer and cold draughts in winter. Other adaptations made to the shelters included, building a makeshift extension (37%), enclosing the space between the units (26%), planting a garden (11%), and covering the interior surface of the metal sheeting that forms the walls of the shelter by an additional layer of thin insulation boards (16%).

When asked about the most important design consideration for shelters, similarly to Zaatari the provision of security and safety was cited first, followed by thermal comfort then privacy. However, the provision of thermal comfort was cited by 22% of respondents as the most important aspect in shelter design, and as the second most important by 44%. In terms of satisfaction, the majority of families reported that they found their shelters to be unbearably hot in July and August, 100% of families said they were unsatisfied or very unsatisfied with the thermal conditions in summer compared to 18% in winter, despite stating that they found their shelters freezing in winters especially at nights. This is because, similarly to Zaatari, refugee families had higher thermal adaptation opportunity such as access to a gas heater in winter and the ability to add layer of cloths and use blankets while in summer this thermal adaptation opportunity was limited especially for women as they were only able to reduce the level of their clothing to a socially acceptable levels, given that they kept doors and windows open. In order to cope with the heat, 66% reported showering several times a day (including showering with cloths on). The other most common strategy (61%) was to spray the cemented floor of the shelters with water frequently; this was used as a form of evaporative cooling technique. 21% reported moving between spaces and sitting in shaded spaces. Removing carpets and sitting on the screed floor was frequently reported in Azraq (Figure 8). In winter, similarly to Zaatari, the use of gas heater was the most

https://doi.org/10.1080/13602365.2018.1424227

common strategy of keeping warm (92%), using carpets (51%), adding a layer of insulation under the carpet was cited by 22% of the families; and covering up with blankets (38%), (Figure 9).

5.2.2 Environmental monitoring

It was not possible to monitor indoor and outdoor environmental variables in Azraq camp in the summer due to lack of necessary permits. However, spot measurements of air, globe and surface temperature were taken in addition to CO_2 levels. In winter, a weather station similar to Zaatari was set up and two I-buttons sensors were placed at 1.2m above the ground in occupied shelters. Thus, ventilation and heating patterns were representative of actual conditions experienced by the refugee families. The use of a gas heater in winter has mitigated the cold during the day as 20°C could be maintained. However, at night, when the gas heater was switched of due to safety concerns or lack of gas, temperatures dropped to 5°C or below (Figure 12). This was highly concerning for parents with young children who had no means of keeping them warm at night.

Spot measurement in September recorded surface temperatures as high as 46°C on the inner surface of south facing pitched roof made of a single layer of IBR. Surface temperatures between 36 - 38°C were also measured on the inner surface of a standard south facing wall at 13:30. Average recorded daytime air temperature was 32.8°C with a standard deviation of 2.5°C. In regards to indoor CO_2 levels, no difference was noticed between Zaatari and Azraq camps, in that indoor CO_2 concentration was similar to outdoor in summer and considerably higher in winter.

https://doi.org/10.1080/13602365.2018.1424227

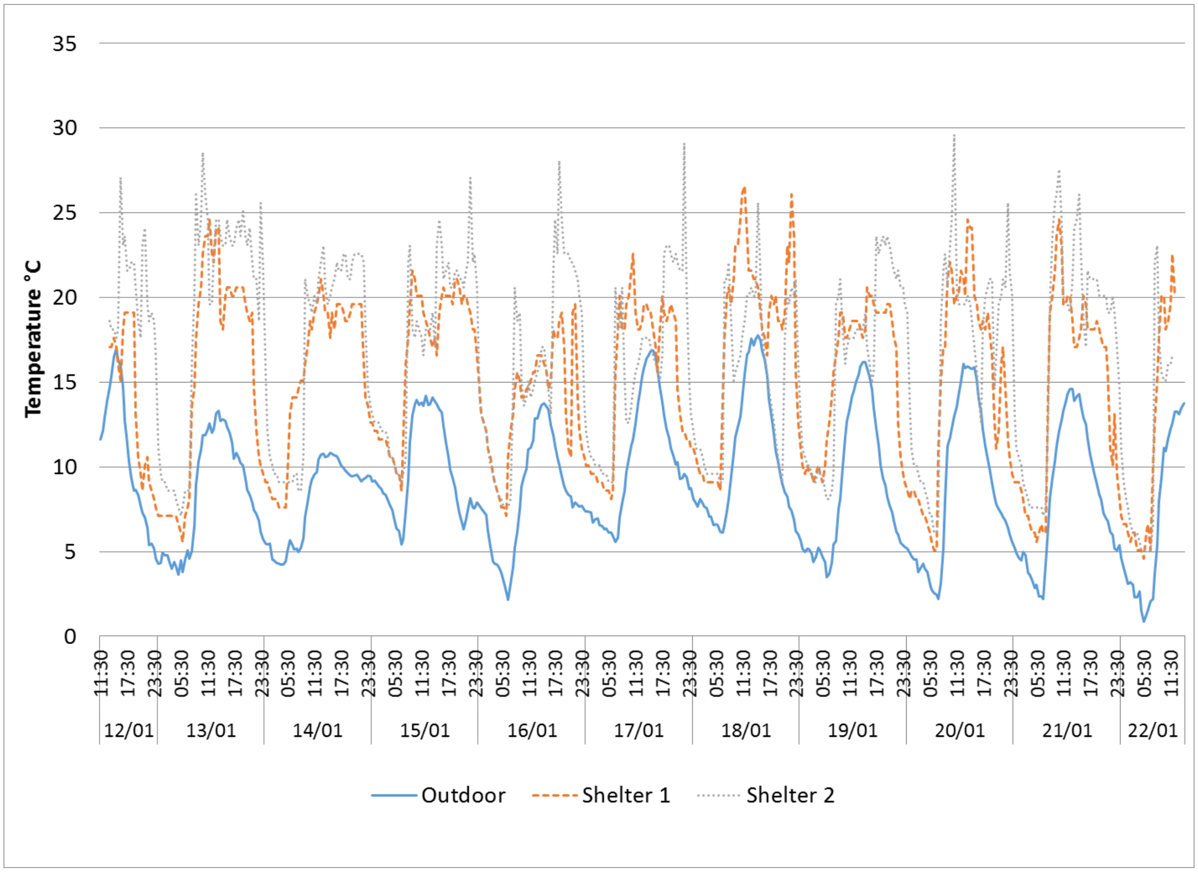


Figure 12: measured indoor temperature in two occupied caravans in January (winter period) against outdoor temperature in Azraq camp – heating was on between 6-11 am & 5-11 pm

6. Summary and conclusions:

Refugees and displaced people can end up living in temporary structures for decades. Such shelters are incapable of providing healthy living conditions as they are ineffective in protecting against outdoor weather conditions especially in locations with extreme climates where many camps are located. A literature review has shown that the thermal performance of temporary shelters is rarely evaluated; despite the population housed in these types of shelters being in the tens of millions. Although interest in shelter design increased in recent years following the current refugee crisis, and that several architects and researchers in the industry have developed more robust types of shelters; thermal comfort in shelters remains under-researched. This study has demonstrated through environmental monitoring and surveys of two refugee camps in Jordan that the provision of healthy shelters that are thermally evaluated is of utmost and urgent importance; and that the thermal environment is one of the refugees' main priorities following the provision of security. Living conditions inside the shelters were shown to be very unsatisfactory especially in summer, and that refugee families were having

https://doi.org/10.1080/13602365.2018.1424227

to resort to debilitating strategies such as showering with clothes on in order to keep cool. Moreover, the refugees had no means of heating at night in winter when temperatures are at their coldest.

Furthermore, this study highlighted the importance of creating private semi-outdoor spaces in front of the shelters. The grid style layout of shelters has resulted in families having to build their own extensions to stop passers-by from looking in through their shelters. Such spaces were very desirable in the summer as they were shaded but well ventilated, while in winter they protected from the winds, thus allowing the opening of a window and maintaining ventilation. Such spaces were particularly vital for women who had a very limited ability to adapt their clothing as they felt exposed to the outdoors while in their own shelters. Therefore, it is vital that shelter design should take into account cultural and social aspects as well as the thermal performance in order to provide healthy and dignified living for a population that has lost a lot as a result of being displaced.

Acknowledgment

This research was funded by EPSRC/GCRF (EP/P510907/1), EPSRC (EP/P029175/1) and was conducted in collaboration with UNHCR Jordan and NRC Jordan. We thank Prof Abdullah Alzoubi and Dr Omar Bani-Ahmad Otum from PSUT for their efforts in facilitating our data collection in the camps, and Ahmad Otum and Ahmad Muhaisen (PSUT) and Zain Aboabeid (Bath) for help with conducting the surveys. We also thank Scarlett-Tiger Coley for her photography, and Dr John Orr and Dr Stephen Lo (Bath) for their comments on the social survey.

Research data used in this paper is available at: https://doi.org/10.15125/BATH-00433

References

[1] UNHCR, Figures at a glance http://www.unhcr.org/uk/figures-at-a-glance.html , 2017 (accessed 14 April 2017)

[2] IDMC, International Displacement Monitoring Centre database http://www.internal-displacement.org/database/, 2017 (accessed 14 April 2017)

https://doi.org/10.1080/13602365.2018.1424227

[3] UNHCR executive committee of the high commissioner's programme. Protracted refugee situations (2004), http://www.unhcr.org/40c982172.pdf (accessed 14 April 2017)

[4] IDMC, Global overview 2015: People internally displaced by conflict and violence. International Displacement Monitoring Centre, Geneva, 2015 available at http://www.internal-displacement.org/assets/library/Media/201505-Global-Overview-2015/20150506-global-overview-2015-en.pdf (accessed 14 April 2017)

[5] UNRWA, Palestinian Refugees https://www.unrwa.org/palestine-refugees (accessed 14 April 2017)

[6] M. Lee, L. Shi, A. Zanobetti, J.D. Schwartz, Study on the association between ambient temperature and mortality using spatially resolved exposure data, Environmental research. 151 (2016) 610-617

[7] J. Baker and R. Zetter, Refugee and labour movements in Sub-Saharan Africa: a review; and, Shelter provision and settlement policies for refugees: a state of the art review. Studies on Emergencies and Disaster Relief. Report No. 2. Nordiska Afrikainstitutet, Uppsala, Sweden, in co-operation with the Swedish International Development Authority, 1995, 106pp.

[8] IFRC, Post disaster shelter: 10 designs. Geneva: IFRC, 2013

[9] UNHCR Division of programme support and management – Shelter and settlement section, Shelter design catalogue. Geneva: UNHCR, 2016

[10] D. Felix, J.M. Branco, A.Feio, Temporary housing after disasters: A state of the art survey. Habitat International 40 (2013), 136-141

[11] Johnson, C. (2002). What's the big deal about temporary housing? Planning considerations for temporary accommodation after disasters: example of the 1999 Turkish earthquakes. In 2002 TIEMS disaster management conference. Waterloo.

[12] L.A. Mira, A.P. Thrall, N.D. Temmerman, Deployable scissor arch for transitional shelters. Automation in Construction 43 (2014), 123-131

[13] C.P. Quaglia, A.J. Dascanio, A.P. Thrall, Bascule shelters: a novel erection strategyfor origami-inspired structures, Engineering Structures 75 (2014) 276–287.

[14] M.D. Tumbeva, Y. Wang, M.M. Sowar, A.J. Dascanio, A.P. Thrall, Quilt pattern inspired engineering: Efficient manufacturing of shelter topologies. Automation in Construction, 63 (2016), 57-65

[15] World shelters, http://worldshelters.org/shelters/u-dome (accessed 14 April 2017)

https://doi.org/10.1080/13602365.2018.1424227

[16] Better shelter, http://www.bettershelter.org/product/ (accessed 14 April 2017)

[17] The Guardian, Exo units: the shelters redefining emergency housing – in pictures https://www.theguardian.com/housing-network/gallery/2014/apr/03/exo-units-shelters-emergency-housing-gallery (accessed 14 April 2017)

[18] Technology exchange lab http://www.techxlab.org/solutions/global-village-shelters-shelter (accessed 14 April 2017)

[19] Concrete Canvas, http://www.concretecanvas.com/faq/general/ (accessed 14 April 2017)

[20] B.C. Howard, Behind the Viral Sensation: Concrete Canvas Goes Beyond Fast-Deploying Shelters. National Geographic (2013)

[21] Calearth, http://www.calearth.org/ (accessed 14 April 2017)

[21] Z. Zhao, Q. Li, X. Jiang, An energy efficient building system using natural resources – Superadobe system research. Procedia Engineering 121 (2015) 1179-1185

[23] S. Canadell, A. Blanco, S.H.P. Cavalaro, Comprehensive method for earthbag and superadobe structures. Materials and Design, 96 (2016), 270-282

[24] S. Viscuso and A. Zanelli, Insulated membrane kit for emergency shelters: product development and evaluation of three different concepts. Procedia Engineering 155 (2016), 342-351

[25] P. Russell, 3-D printed earthen architecture: A sustainable housing solution for displaced populations, master dissertation. Aston University (2015).

[26] P. Manfield, J.Ashmore, T. Corsellis, Design of humanitarian tents for use in cold climates. Building research and information, 32 (2004), 368-378

[27] C. Crawford, P. Manfield, A. McRobie, Assessing the thermal performance of an emergency shelter system. Energy and Buildings 37 (2005), 471-483.

[28] C. Cornaro, D. Sapori, F. Bucci, M. Pierro, C. Giammanco, Thermal performance analysis of an emergency shelter using dynamic building simulation. Energy and Buildings, 88 (2015), 122-134

[29] F.J. Martinez-Martin and A.P. Thrall, Honeycomb core sandwich panels for origami-inspired deployable shelters: Multi-objective optimization for minimum weight and maximum energy efficiency. Engineering Structures, 69 (2014) 158-167.

[30] C.P. Quaglia, N. Yu, A.P. Thrall, S. Paolucci, Blancing energy efficiency and structural performance through multi-objective shape optimization: Case study of a rapidly deployable origami-inspired shelter. Energy and Buildings 82 (2014), 733-745

https://doi.org/10.1080/13602365.2018.1424227

[31] Y. Yu, E.Long, Y. Shen, H, Yang, Assessing the thermal performance of temporary shelters, Procedia Engineering 159 (2016), 174-178

[32] E.Z. Escamilla and G. Habert, Global or local construction materials for post-disaster reconstruction? Sustainability assessment of twenty post-disaster shelter designs, 92 (2015), 692-702.

[33] Y. Song, N. Mithraratne, H.Zhang, Life-time performance of post-disaster temporary housing: A case study in Nanjing. Energy and Buildings 126 (2016) 394-404.

[34] Reach, Azraq camp shelter assessment: assessment report January 2015. UNHCR, Jordan, 2015.

[35] H. Arslan and N. Cosgun, Reuse and recycle potentials of the temporary houses after occupancy: Example of Duzce, Turkey. Building and Environment 43 (20080, 702-709.

[36] J, Ashmore, E. Babister, T. Corsellis, J. Fowler, I. Kelman, A. McRobie, P. Manfield, R. Spence, A. Vitale, R. Battilana, K. Crawford, Diversity and adaptation of shelters in transitional settlement for IDPs in Afghanistan. Disasters, 27 (2003), 273-287

[37] L.L. Barbosa, Capacity building through design innovation with vegetable fibres for temporary shelters. Procedia Economics and Finance 18 (2014), 230-237.

[38] S. Saleh and M. Gadi, An investigation into thermal comfort if shelters in refugee camps in Palestine using questionnaire and computer simulation, IUG Journal of natural and engineering studies, 20 (2012), 127-152

[39] M. Kottek, J. Grieser, C. Beck, B. Rudolf, F. Rubel, World map of the Köppen-Geiger climate classification updated, Meteorol Z. 15 (2006), 259–263

[40] UNHCR data portal, Syria Regional Refugee Response: Inter-agency Information Sharing Portal. http://data.unhcr.org/syrianrefugees/regional.php (accessed on 14 April 2017)

[41] Food and Agriculture Organization of the United Nations FAO 2017, CLIMWAT 2.0 software, available online from http://www.fao.org/land-water/databases-and-software/climwat-for-cropwat/en/ (accessed on 14 April 2017)

[42] IFRC, UN-HABITAT and UNHCR, Shelter projects 2013-2014. ShelterCaseStudies 2014 Available online from www.sheltercasestudies.org