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Architecture of the Scape: Thermal Assessment of Refugee Shelter Design in the extremes Climates of Jordan, Afghanistan and South Sudan.

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ABSTRACT

In the face of the largest human displacement ever recorded in modern history more than 79.5 million persons around the world have been forced to flee their homes worldwide at the end of 2019, from which 30 million are refugees. However, most shelters lack actual capacity to provide adequate thermal control for much of the year time; whereas many are located in regions with hard weather conditions, most fail to maintain temperature and humidity within accepted human comfort levels. This fact triggers ad hoc users' responses that compromise their sense of security, privacy, and belonging, and in some cases, challenge their cultural traditions. This study evaluates the thermal performance of the three most common UNHCR's shelters design for refugees assigned to the three extreme climatic regions facing this crisis worldwide: Jordan, Afghanistan, and South Sudan and links with the regional particularities. Seasonal analyses are carried out through computer simulations contrasted with data collected in-situ. The study also tests variations of the thermal performance of each shelter type under the other climate locations seeking for potential matches. Findings show that UNHCR's shelter type A has the best regulation of humidity levels and potential for exportation, and that type C has the best performance for thermal stability although greater difficulties and application for rapid deployment. The study concludes with a detailed assessment of current designs' strengths and weaknesses that could inform future shelter designs or alterations of existing units to improve refugees' living conditions.

1. Introduction

Desertification and its consequent natural disasters threaten to change today's demographic map. According to a report by Christian Aid [1], [2], [3], by 2050, one billion people will be displaced from their homes due to climate change. Along warlike conflict, natural disasters are one of the two main reasons that force large numbers of population to leave their homes and move in search of a safer place.

This problem, which began to worsen shortly after the end of World War Two, has resulted in millions of newly displaced people every year since 1970 according to UNHCR [4]. This report also states that the year 2017 was characterized by multiple population displacements, as the number increased from 65.6 to 68.5 million since 2016; This means that on average, 31 people are forced to flee their homes every minute, either across borders or within their own country. According to the World Bank, in Sub-Saharan Africa up to 86 million people could be displaced by 2050 due to the consequences of climate change unless action is taken [5].

This population is known as "climate or environmental refugees," and in addition to displacement. they face a legal, political and social vacuum [6]. Whereas international legislation does not recognize the climate or environmental refugee status, neither does the definition of refugee includes population displaced for environmental reasons.

The challenge of climate change and consequent human displacement demands a sheltering response that provides a minimum of environmental comfort to this population [7]. This study will evaluate the environmental behavior of existing shelters in three different climates in order to define the design parameters for an adaptable and thermally responsive unit.

In addition to cultural and privacy requirements, thermal safety-comfort is a crucial factor determining inhabitability that is usually disregarded. These different dimensions are closely linked and influence each other significantly, and therefore, they cannot be fully understood separately. A disregard of cultural differences in inhabitation and shelter's management can result on the exclusion of populations[8]. For example, the lack of thermal comfort along with the need in certain cultures to cover the woman body, can cause both discomfort and privacy concerns that can only be addressed from an intersectional approach [9]. That is why the behavior and well-being of the occupants is of special attention [10][11][12].

Regarding thermal comfort, in addition to computer simulations, this study pursued interviews with refugees. Most respondents reported that thermal conditions in their shelters were unbearable in summer and freezing in winter [9]. In addition to the cultural disruptions describes above, this lack of comfort can pose health risks such as thermal stress [13], aggravation of diseases, and at worst, death [8]. Thermal stress is the sensation of discomfort caused by remaining in an environment in which the body needs to make significant effort to regulate its internal temperature [14].

In order to ensure basic environmental comfort, shelter designs have to respond to physical, psychological, cultural, and individual factors [15][16]. Environmental factors include temperature, thermal radiation, relative humidity, and ventilation among others, whereas individual factors refer to the body's metabolic consumption, behaviors, state of mind and clothing insulation. Individual factors need to be taken into account in extreme environmental conditions in order to counterbalance temperature's gains and losses and prevent thermal stress. Cold temperatures are also a source of concern in shelter design [17]. According to a 2017 UNHCR report [18], the number of deaths reached 20 people on a single cold night.

The most common current shelters' designs do not respond to extreme thermal conditions to which inhabitants are usually exposed [19][20]. One of the key issues resides in their envelope's lack of thermal mass. Their envelop without thermal inertia or capacity to store heat lead to rapid changes of temperatures inside. [21]. A solution was the adding of sand, brick, and/or insulation to the envelope [21]. Other solutions include a moisture permeable polyester lining--equivalent to covering the shelter with 30 blankets [8] --or including lining to reduce heating needs.

Another major problem that we have identified in shelters' design is their inability to guarantee proper ventilation and healthy environments through passive cooling mechanisms [9] [21] . Although shelters frequently have openings, these are usually insufficient to achieve comfort values. In addition, the design of these openings usually disregards crucial requirements in different locations. In Jordan, storm winds will bring sand into the shelters through these unprotected openings [8]. In other cases, the lack of shaders increases solar radiation and therefore the temperature inside the unit.

All the quantitative and qualitative factors described demonstrate the present urgent need to provide a temporary shelter solution capable of offering safety, privacy, and comfort, rather than mere survival [22][23]. For this reason, this research focuses on the evaluation of shelters' thermal conditions in Jordan, Afghanistan, and South Sudan. These three areas are representative of the main current populations' migration destinations, extreme climate types, and the presence of cultural traditions that have a relevant impact on thermal comfort.

In particular, this study will evaluate the thermal behavior of different shelter designs that are currently assigned to each location by the UNHCR [24] [See Appendix A]. The study will also evaluate the thermal behavior of each shelter in the other two climatic and cultural regions. This transnational strategy will generate a taxonomy of cases that cover the most vulnerable scenarios generated by this global problem.

This analysis includes measurements at different time frequencies such as periods, months, days, and hours that draw a profile of each shelter's environmental behavior for their computer simulation. The computer models were calibrated following industry standard adjustments and the ASHRAE 14-2002.

The objectives of this paper are (1) to identify the climatic conditions and cultural needs of the refugee camps analyzed; (2) to evaluate thermal conditions in the shelters of the three areas selected; (3) to analyze the results in a country other than that studied; and (4) to identify extreme periods for each season and calibrate values discriminating between day and night.

2. Data Collection and Case-Studies

2.1. Site location

The study focused on three refugee camps representing three climatic and socio-cultural environments of special significance in migratory flux: Afghanistan, Jordan, and South Sudan (Figure 1). Although there are camps and assistance to refugees in 134 countries around the world, global figures indicate that these three areas account for the largest presence of refugees worldwide, 57% of the total [25]. These sites present three different climate environments which make it possible to assess the performance of the shelters against individual types of exposure, thus allowing conclusions to be extrapolated to other similar areas. Therefore, in-depth analysis was carried out on the geographical and climate framework of each country, as well as their habits, culture, and refugee camps.

Fig 1. Location of climatic zones assessed.

2.2 Geographic and climatic information

Jordan is characterized by its arid plateau located to the east bank of the Jordan River and the Dead Sea. It's capital, Amman, presents low rainfalls, winds of up to 14.3 km/h, extremely hot summers (with temperatures exceeding 32ºC) and mild winters (between 3ºC and 11ºC, although temperatures can drop below zero on extremely cold days) [26]. This study addresses the Azraq refugee camp (Figure 2a), which presents a mid-latitude steppe and desert climate (near BWh).

Afghanistan is a landlocked mountainous country that has a relatively dry climate, which varies depending on the altitude and location [27]. The area of Sozma Qala presents very hot dry summers (exceeding 34ºC) and cold (sub-zero temperatures), dry and partly cloudy winters [26] in addition to dusty winds. This study addresses the Gulan refugee camp (Figure 2b, which presents a cold-semi arid climate.

South Sudan is located in East Africa. This research focused on Juba, where the wet season is very hot and stifling. Over the course of the year, temperatures vary from 21ºC to 39ºC. Unlike the other two countries, South Sudan has high rainfalls, with an average precipitation of 142 mm [26]. This study addresses the Ajuong Thok refugee camp (Figure 2c), which presents a tropical savanna climate.

2.3 Clothing traditions

Clothing habits varies significantly between the three locations.

In Jordan, women traditionally wear hijab and cotton tunics. Men wear light clothes, such as white cotton tunics, in order to withstand the heat.

In Afghanistan, women traditionally wear burkas and tunics, while men wear Pakols (hats), turbans, and chapans (coats).

In South Sudan, clothing traditions regarding the covering of women bodies are less strict in order to withstand high temperatures. This means that clothing habits create great variation on the thermal experience in summer and winter in this location. In summer, women wear light clothes following the minimum requirements of their religious clothing codes. However, in winter, they add additional layers supplementing their garments with jackets and sweaters (Figure 4).

Data show that females represent a significant larger percentage of the population living in refugee camps [28][29][30]. Therefore, cultural gender expectations regarding privacy, clothing, or behavior must be considered for an inclusive and realistic definition of comfort [31].

The knowledge of the camps social structure provides information on the response of the population strata as vulnerable groups (children and elderly), as well as the different adaptive response based on clothing and codes of conduct.

2.4. Refugee camps

This study focused on the Azraq refugee camp (Jordan), the Gulan camp in Khost (Afghanistan), and the Ajuong Thok camp in Yida (South Sudan).

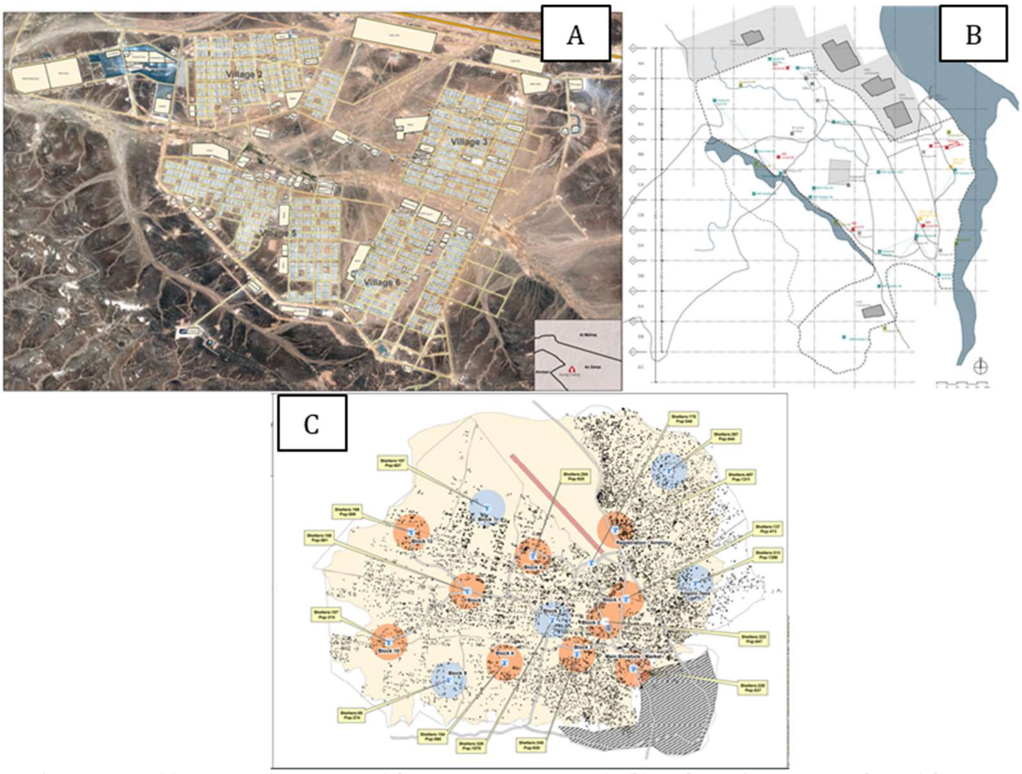


Fig 2. Refugee camps (a) Azraq refugee camp. (Photo: UNHCR, UNOSAT); (b) Gulan refugee camp, Khost, (Photo: UN High Commissioner for Refugees); (c) Ajuong Thok refugee camp. (Photo: UNHCR, ACTED & UNOSAT)

Type A

The Azraq refugee camp shelters 36,699 refugees distributed in four villages (Figure 2a). This camp can potentially be expanded towards the remaining unoccupied area to accommodate a total of 120,000 people [28].

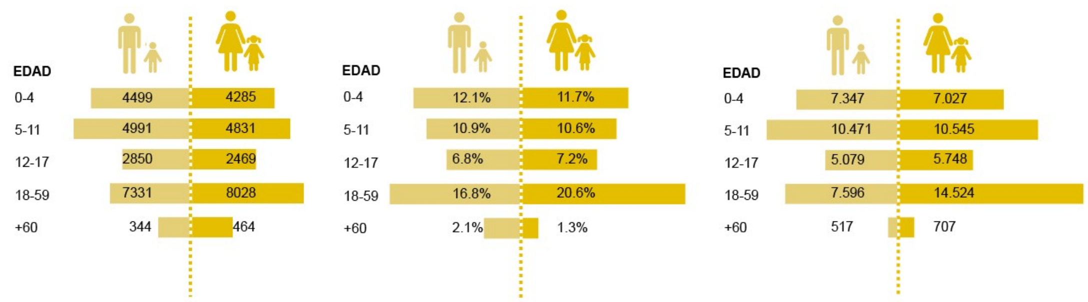
Type B

The Gulan refugee camp (Figure 2b) shelters 42,391 according to the Operational Portal for refugees [29] [32].

Type C

The Ajuong Thok refugee camp shelters 40,502 people, according to the UNHCR South Sudan Fact Sheet (Figure 2c) [30] [33][34].

The demographic distribution of each camp per gender and age is the following:



Azraq (Jordan) **Gulan, Khost (Afghanistan)** **Ajuong Thok, Yida (South Sudan)**

Fig 3. Demography of refugee camps studied (Acnur Fact Sheet, Jordan 2018 [28]; Portal operacional de refugiados Afghanistan 2018 [29]; UNHCR population statistics Ajoung Thok 2015 [30]

2.5 Shelter types

First, it was necessary to establish the type of shelters provided, by consulting the UNHCR Shelter Design Catalogue [24]. The types identified for the camps selected are Azraq T-Shelter (Type A, Figure 4a), developed in Jordan and classified as a transitional shelter; the Tent Shelter, developed in Afghanistan (Type B, Figure 4b); and the Tukul Shelter, developed in South Sudan (Type C, Figure 4c). The last two are classified as emergency shelters. In addition to these material factors this research also considered the distance between shelters and camp layout (Table 1 and Table 2). Therefore, exposure to sun and wind conditions affecting these shelter groupings was also studied.

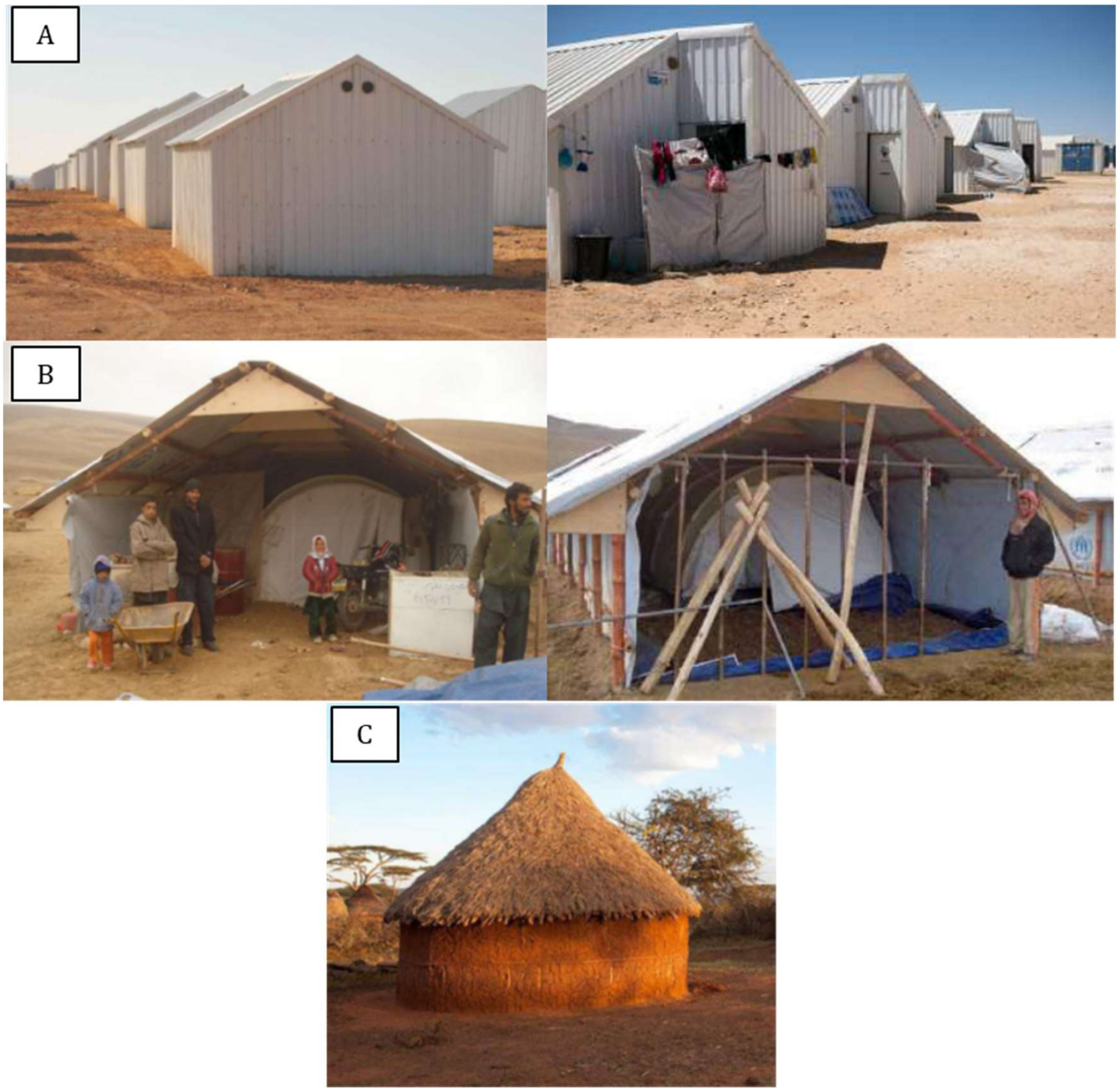


Fig 4. Shelter Types (a) View of a type A shelter (Photo: UNHCR, Shelter and Settlement Section); (b) View of a type B shelter (Photo: UNHCR, Shelter and Settlement Section); (c) View of a type C shelter (Photo: UNHCR, Shelter and Settlement Section)

Table 1. Analysis conditions in shelters

ANALYSIS CONDITIONS	SHELTER A		SHELTER B		SHELTER C	
Number and gender of people	Family of 4 (man, woman, 2 children)					
Metabolic conditions Factor (Man=1.00, Woman=0.85, Children=0.75)	0.84					
Shelter size	24 m²		38.7 m²		21.6 m²	
Density (people/ m²)	0.166		0.103		0.214	
Clothing:	winter	summer	winter	summer	winter	summer
Jordan	1	0.7	1	0.7	1	0.7
Afghanistan	1.5	1	1.5	1	1.5	1
South Sudan	0.5	0.3	0.5	0.3	0.5	0.3

*Appendix B

Table 2. Features of shelters

BUILDING ENVELOPE	SHELTER A		SHELTER B		SHELTER C	
Wall	IBR sheeting Expanded Polyethylene IBR Sheeting	0.35 mm 1.5 cm 0.35 mm	UNHCR Tarpaulin	1 cm	Adobe plastering Branches of local wooden poles Adobe plastering	2.5 cm Ø 5 cm 2 cm
Roof	IBR sheeting Expanded Polyethylene IBR Sheeting	0.35 mm 1.5 cm 0.35 mm	UNHCR Tarpaulin Bamboo structure	1 cm Ø 5 cm	Covered by thatch Branches of local wooden poles	2.5 cm Ø 5 cm
Rest zone	Door clad with flat corrugated iron sheeting and filled with expanded polyethylene insulation		UNHCR tent covered by tarpaulin 1 cm		Bamboo sticks	
Floor	Steel window frame 1 m x 1 m		Tarpaulin 1 cm		Tarpaulin 1 cm	
Infiltration	0.70 AcH		0.70 AcH		0.70 AcH	

2.6 Meteorological data

Meteorological data for modeling the shelters have been obtained through the meteorological data bases nearest to each location. TMY are derived from the datasets including the ISD (Integrated Surface Data) provided by NOAA's National Centers for Environmental Information (NCEI) [35]. Supplementary local data is available in the 2018 study by Fosas [36], which provides data from remote places that we used for the model calibration in Azraq refugee camp (Jordan).

The goal of this study is not to develop a highly accurate thermal analysis of a specific shelter, but rather, to produce approximate simulation models that can then be compared across the three climatic regions and cultures to propose improvements for shelters' design. However, through a calibration process comparing our model with onsite measurements, we confirmed the accuracy of our preliminary approximation [See section 3.2 and Appendix C].

Table 3. Meteorological data base for each location

Camp Site	Weather Date set for simulation	Linear Distance	Local height difference
Azraq (Jordan)	Hasan Air Base (JOR)	49 km (NE)	155 m (+)
Gulan (Afghanistan)	Khost Air Base (AFG)	12 km (NNE)	48 m (-)

Ajuong Thok (South Sudan)	Wau airport (SSD)	87 km (NW)	29 m (-)

3. Methods and Variables

3.1 Simulation process

Each shelter type was first assessed in its climatic area and then tested in the other two countries' climatic areas in order to determine whether there were performance improvements under different conditions. In addition, this allowed us to establish whether we could generate a single shelter model that would present a better thermal behavior in the three climatic areas despite of the results variations. For this purpose, nine analyses of the three case studies were conducted using the software EnergyPlus 8.3 (Design Builder v 4.5.0.148 as Gui).

The main parameters taken into account for the simulations are the following:
The internal parameters analyzed are relative humidity (%), indoor air temperature (^{O}C), radiant temperature (^{O}C), and operative temperature (^{O}C). The external parameters are air temperature (^{O}C), wind speed (m.p.s.), atmospheric pressure (Pa) and solar radiation (kWh). In addition to internal and external temperatures, simulations also include the number of occupants, clothing, shelter size, and building materials (Tables 1, 2 and 3).

3.2 Validation and calibration process

To verify the validity of the shelters' simulation models, values are calibrated comparing them with on-site measurements. This process adjusts values in both the modeling protocols and the initial assumptions. The aim is to establish an adjustment methodology to be consistently applied to every set's unit. The characteristics of these samples are described in Tables 1 and 2. In the monitoring datasets.

A thermal performance profile was generated using the hourly measurements of real temperature in summer and autumn. A contrast model was then generated using the same operative values. By comparing measured and simulated results, the model was adjusted and calibrated using analytical optimization [37]. These adjustments were subsequently extended to the entire group of energy models.

According to ASHRAE 14-2002 evaluation criteria [38] (Appendix C), time data are used to establish the Mean Bias Error (MBE), with acceptance criteria of up to 10%, as well as the Coefficient of Variation of the Root Mean Squared Error (CVRMSE), with acceptance criteria of up to 30%. Hourly data is suitable for the calibration of these models (Appendix C).

3.3 Types of analysis

The analyses consisted on comparing on-site measurements of indoor temperature and humidity with results obtained for our simulation models in three different categories:

A first analysis comprised the measurements of both monthly and daily average values throughout a year in each shelter and climatic region.

A second analysis focused on the shelter's hourly performance variations. For this purpose, each shelter was evaluated 24 hours a day for a full year.

A third analysis focused on measuring comfort values following ASHRAE55. The goal was to identify potential aspects for the shelters' design improvement. The analysis provided information about periods when extreme values were reached in winter and in summer. In addition, the analysis compared each shelter's performance with the industry standards.

3.4 Surveys

Comfort can only be fully defined when considering users' perceptions in addition to abstract measurements. For this reason, a previous discussion was developed with families with analogous experiences. (See Appendix D). Their responses help to develop analytical design. These interviews were carried out, not for statistical purposes, but rather, for acquiring further knowledge about the average concerns and problems detected by the camp's users.

4. Quantitative Results

For each shelter and climatic region, we analyzed: the average monthly values in each climatic zone taking into account the average daily results throughout a year for each shelter and climatic region; relative humidity; and indoor operative temperature and its contrast with outdoors air temperature.

4.1 Average indoor temperatures and humidity

Shelters placed in Jordan presented hourly and monthly indoor ambient values as shown on 'Figure 5a-a'. Type C achieves the best operative temperature figures, moving in values of almost 20ºC and 25ºC, unlike shelters A and B, which normally present higher values, especially during the summer, remaining above 30 ºC in type B most of the time. However, relative humidity is high in the type C shelter, often reaching 100% during cold periods. In this regard, both shelters A and B, obtain better results as their environments are warmer. Shelter A achieve the most balanced relative humidity results between 40 and 60%. Nevertheless, shelter B levels are of 40-50%.

Shelters placed in Afghanistan presented the most extreme values as shown on Figure 5b-b'. In these shelters, interior temperatures during cold periods are in low ranges, especially for type A., Types B and C present milder temperatures although lower than what is usually understood as comfortable or healthy. Regarding hot periods, type B shows indoor temperature ranges around 40 ºC. Shelter type C offers again the most balanced response to the operative temperature, not only maintaining a mild temperature, but also showing a low variation range. However, its average relative humidity is high with frequent risk of surface condensation. There were some similarities in terms of relative humidity between type A and type B shelters, although in this case the values were relatively low (below 40%). Regarding operative temperature, the peaks in A and B remain high in the summer months. The type A shelter continues to obtain more adequate values compared to type B, where the temperature on occasion exceeds 40ºC.

Shelters placed in Sudan presents values as shown on_Figure c-c'. This location has a less extreme climate than the other two regions discussed. For indoor temperatures the results for the three shelters type are similar. However, shelter B continues to obtain higher range values. Between A and C there are differences of about 2-3ºC. Regarding relative humidity, a reduction was observed in shelter C, these values still remain high. The situation in this case is more stable for shelters A and B.

In summary, type B obtained higher temperature values in the three locations analyzed.
In contrast, type C maintains a more stable temperature. However, type C does not perform well regarding relative humidity regardless of the region where it was placed. Type A presents high temperature values but a balanced result for relative humidity in the three regions.

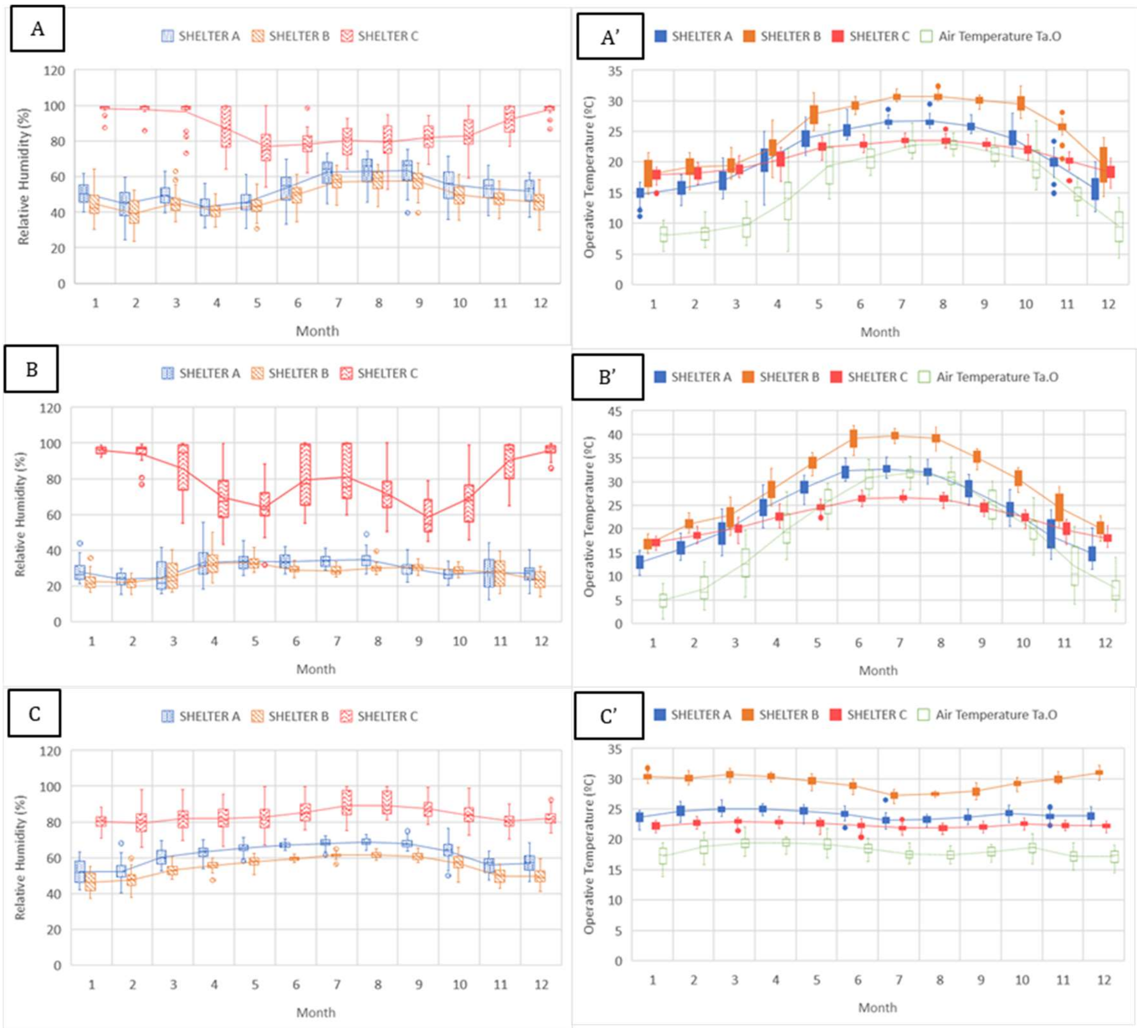


Fig 5. Monthly indoor ambient parameters distribution for shelters (a-a') Jordan; (b-b') Afghanistan; (c-c') South Sudan

4.2 Outdoor vs. indoor temperature evolution.

4.2.1. Per type

Type C is the shelter with the greatest internal stability, with the least reaction to external conditions, thus allowing greater heat conservation during cold periods and a longer delay in heating due to the higher inertia of other types. Compared to the external variation it displays the lowest dispersion of values (standard error of the estimate with respect to the linear model, varying from 0.578 to 0.499), with the least dispersion observed in Sudan.

In contrast, type B is the most reactive due to its low thermal mass and insulation. A greater dispersion of values is observed compared to the same external temperature conditions (greater than the other types for identical conditions). The higher counts of residual square overall are seen in the three locations, with an error of the estimate of around 3 times the value of type C, with the difference increasing as the weather becomes more extreme. This effect is more evident in the range of average temperatures and is more limited in extreme values given the low inertia of the shelters.

The greater dispersion of type A interior temperature values can be linked to the relationship with solar radiation and the emissivity of the materials. The situation of type A is intermediate, and accordingly the behavior is halfway between both, although generally closer to C, with estimated standard errors between 0.80 and 0.50. In all cases, a statistical significance of the operative temperature is identified with the external parameter for a confidence of 95% ($p < 0.05$ in all cases). The ANOVA analysis performed (Table 4) indicates the importance of the type of shelter when describing its behavior and allowing a causal relationship to be established between the different configurations. Two behavior patterns can be observed, basically associated with the response to the climate of this type of building.

4.2.2 Per region

In areas such as Jordan and Afghanistan, the greatest dependency appears linked to the average daily temperature (the general model presents an R2: 0.93 for $p < 0.0001$), an expected situation given the low thermal inertia of the solutions, as well as the actual daily variability of arid desert climates. Although the daily accumulated solar radiation is also relevant, it is less relevant in explaining the internal variability of the models (R2:, 54 for $p < 0.0001$), as well as a much larger associated error than the only temperature model. (RMSE: 10,085 vs. 1.37). The F-value for ANOVA is much greater for the outdoor temperature than for the cumulative radiation, due to a greater difference in means, so that a stronger relationship between the variables can be identified. In the individual trend, type C shows the least standard error, due to its lower thermal variability - it presents slightly higher internal stability than the other models, which can be associated with its greater inertia.

In the case of South Sudan, representing tropical savanna climates, the daily thermal oscillation is much lower than in previous cases, with radiation gaining prominence due to its greater annual intensity and number of hours of sunshine. This is reflected in the general linear models with very similar F-values for temperature and solar radiation, which identifies strong relationships between the variables, as well as very close error values (RMSE: 0.874 vs. 0.824), with R2 greater than 9 in both cases for a significance p-value <0.0001. For individual type trends, the cumulative radiation has somewhat tighter standard errors (Std. err factor 0.016 -0.029) than those of air temperature (Std. err factor 0.0183 - 0.0496) due to a greater dispersion of the values, although in any case, the trend is equally significant ($p < 0.05$ for all cases). In individual types type C presents the clearest relationship with radiation, which can be attributed to a greater absorbency of the material, compared to a slightly higher emissivity and reflectivity of types A and B, an aspect that stands out when the exchanges through the walls are lower due to the lower thermal differential. The results in Figure 6 show the different behavioral dynamics between A and B in relation to C. As already mentioned, the climatic conditions of the three areas studied account for the difference in behavior between shelters. However, the behavior of type C displayed the least change, successfully establishing a balance with the outside temperature. This can be verified in Jordan (Figure 6a), where the indoor temperature exceeds 30°C when the outdoor temperature exceeds 40°C. This balance did not occur in the other two cases, as temperatures were shown to be the same or reduced by only one degree. Therefore, as in the study of averages, shelter C stands out for its behavior in terms of temperature stability.

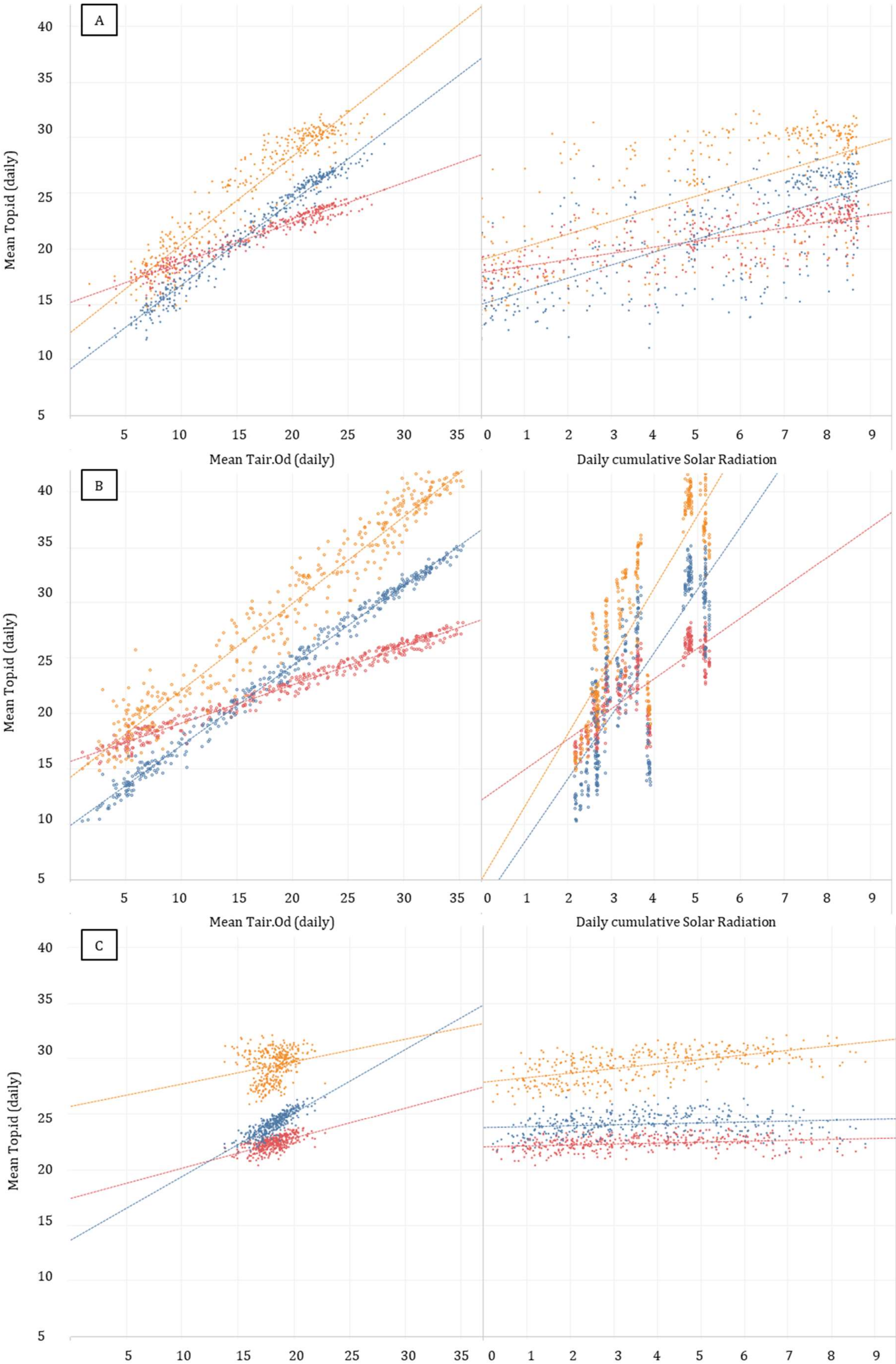


Fig 6. Analysis of indoor and outdoor temperature in shelters with climatic conditions in (a) Jordan (b) Afghanistan; (c) South Sudan

Table 4. Trend models

LOCATION	JORDAN						AFGHANISTAN						SOUTH SUDAN					
	Linear Mean Tair Outdoor			Linear Daily Cumulative Radiation			Linear Mean Tair outdoor			Linear Daily Cumulative Radiation			Linear Mean Tair outdoor			Linear Daily Cumulative Radiation		
SCE	1492.68			10982.5			1423			15192.2			832.118			898.065		
MSE	1.370			10.0849			1.306			13.950			0.764			0.824		
R square	0.937			0.540			0.974			0.732			0.924			0.918		
Standard error	1.170			3.175			1.143			3.735			0.874			0.908		
p-value	< 0.0001			< 0.0001			< 0.0001			< 0.0001			< 0.0001			< 0.0001		
ANOVA																		
DF	4			4			4			4			4			4		
SSE	5622.90			4709.09			14012.77			13004.82			9876.26			9919.26		
MSE	1405.73			1177.27			3503.19			3251.21			2469.07			2479.82		
F	1025.56			116.736			2680.93			233.051			3231.29			3007.04		
p-value	< 0.0001			< 0.0001			< 0.0001			< 0.0001			< 0.0001			< 0.0001		
Individual trend lines																		
Shelter	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Definition	Prom. Ta O / Intercept			SR / Intercept			Prom. Ta O / Intercept			SR / Intercept			Prom. Ta O / Intercept			SR / Intercept		
Value	0.3593	0.792	0.755	0.573	1.152	1.176	0.345	0.784	0.721	2.740	6.583	5.702	0.271	0.201	0.572	0.083	0.408	0.083
	15.185	12.476	9.197	17.884	19.028	15.023	15.682	14.242	9.905	12.18	4.994	2.702	17.42	25.733	13.664	22.062	27.910	23.791
StdErr	0.004	0.015	0.006	0.029	0.074	0.062	0.002	0.009	0.003	0.106	0.224	0.219	0.018	0.049	0.018	0.016	0.029	0.025
	0.084	0.258	0.118	0.180	0.453	0.375	0.059	0.203	0.073	0.406	0.859	0.839	0.335	0.907	0.343	0.066	0.122	0.104
t-value	73.014	52.736	109.85	19.156	15.378	18.943	126.13	83.110	212.89	25.823	29.295	26.001	14.776	4.057	30.479	5.1608	13.874	3.3394
	179.636	48.323	77.848	98.856	42.001	39.990	265.422	69.860	135.31	30.018	5.8079	3.2207	51.912	28.356	39.804	330.068	228.205	228.72
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0092
	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.013	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

4.3 Adaptive Comfort Range

In order to establish the acceptable thermal conditions for occupants in shelters, ASHRAE Standard 55 [39] was used to quantify hours outside an established range and to measure the potential of each shelter. Given that shelters function as passive buildings, ASHRAE 55 establishes the method based on the adaptive comfort equation developed by de Dear. The CONFADAPT-ASH55 tool was used to compare the adaptive comfort criteria to hourly forecast results.

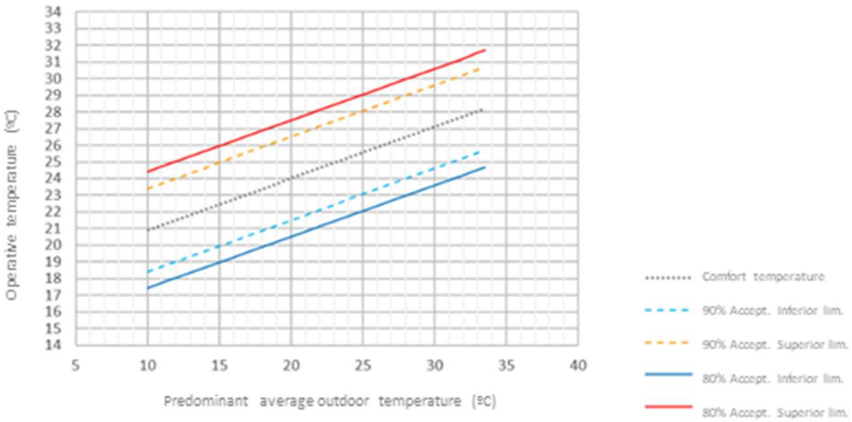


Fig 7. Acceptable operating temperatures for passive buildings, according to ASHRAE Standard 55

The annual and hourly behavior of type A, B and C in the three climatic zones can be observed on Figures 8, 9, and 10. Type B shelter is the one with the worst results in all cases. Most of its values fall outside the comfort area defined, which can cause high levels of thermal stress to the occupants. However, the situation changes with type A and C. Both provide interesting results and although many hours fall outside the range, the balance in all three situations is more suitable. Althouhg, type A shelter concentrates more hours within the comfort range than the Type C, especially in the climatic situations of Jordan and Afghanistan. Type C tends to accumulate more hours in the range of 80% acceptability, which is closer to 90% in the case of type A. The most favorable situation for the Type C is in the simulation with climatic conditions in South Sudan, concentrating most hours between adaptive comfort limits. Table 5 shows the development of these measured hours.

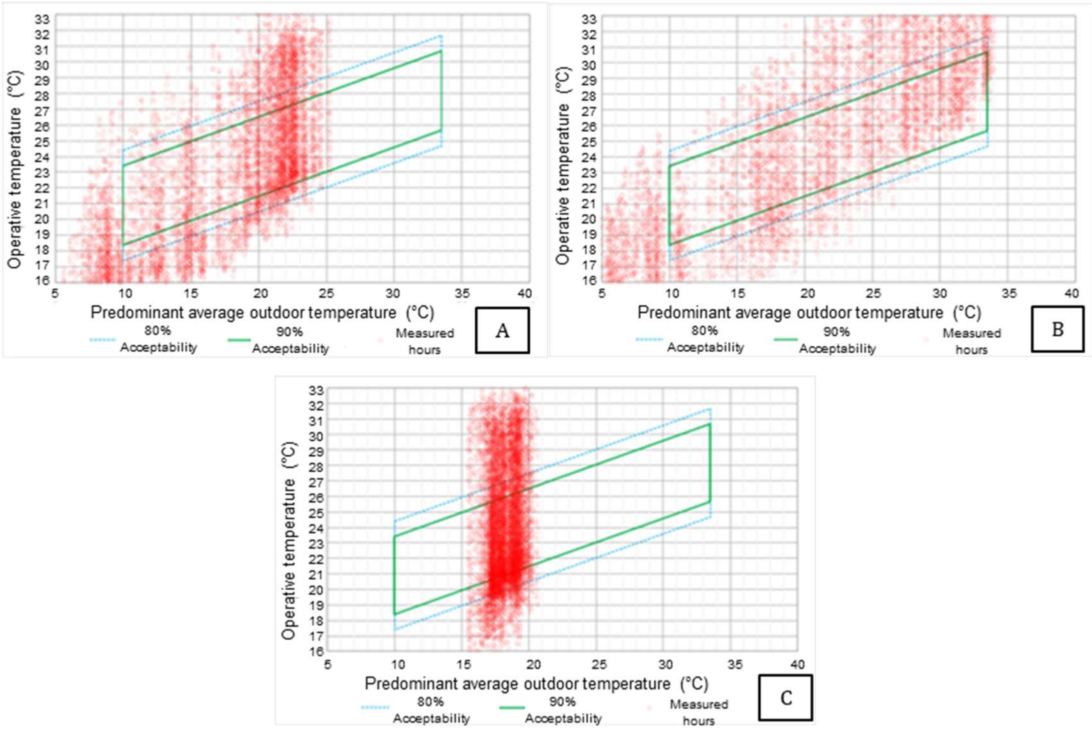


Fig 8. Adaptive Comfort Range Type A shelter. (a) Jordan, (b) Afghanistan, (c) South Sudan

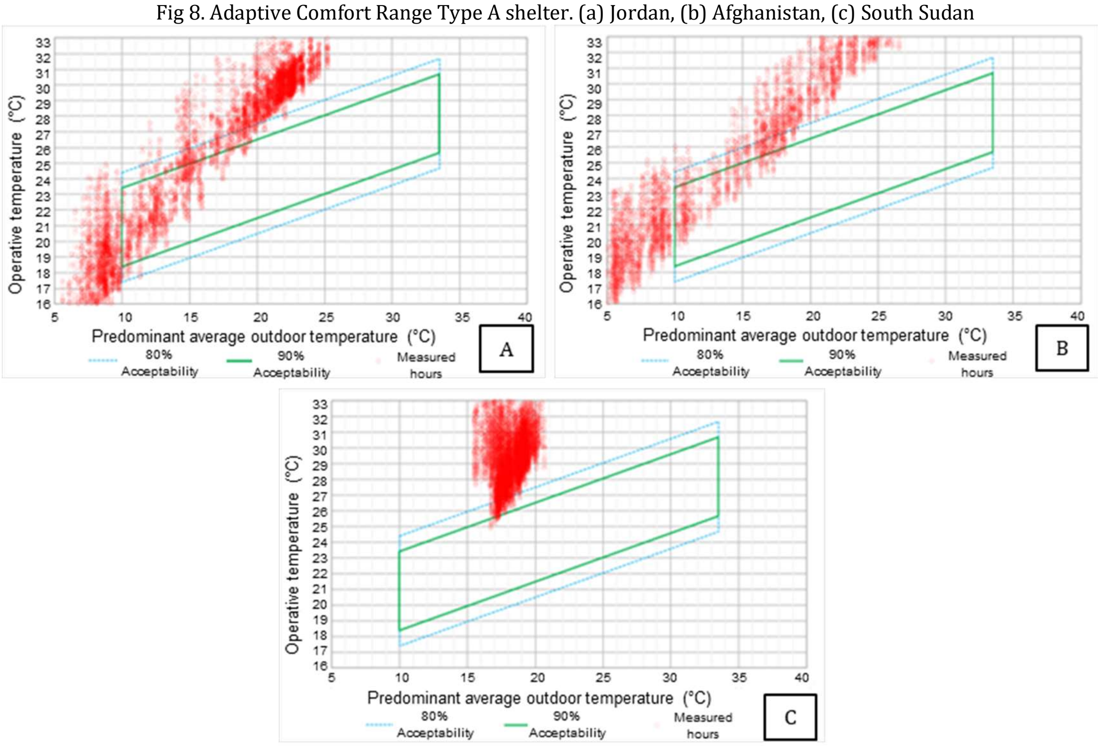


Fig 9. Adaptive Comfort Range Type B shelter in (a) Jordan, (b) Afghanistan, (c) South Sudan

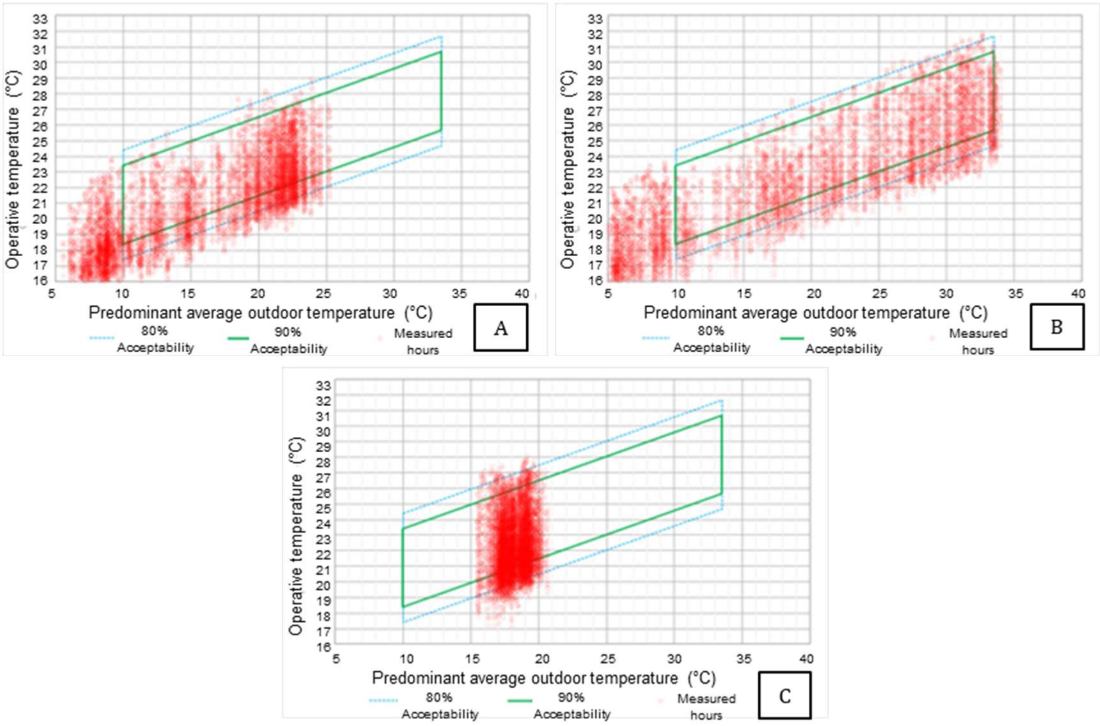


Fig 10. Adaptive Comfort Range Type C shelter in (a) Jordan, (b) Afghanistan, (c) South Sudan

Table 5. Adaptive comfort results according to ASHRAE 55-2017 standard

LOCATION	JORDAN			AFGHANISTAN			SOUTH SUDAN		
TYPE SHELTER	A	B	C	A	B	C	A	B	C
Out-of-range hours as ASHRAE 55.17		2329 h			2644 h			5 h	
In range hours		2329 h			2644 h			8755 h	
Total measured hours	8760 h	8760 h	8760 h	8760 h	8760 h	8760 h	8760 h	8760 h	8760 h
Hours within 90% acceptability	43.32%	22.79%	60.92%	38.29%	10.86%	62.95%	45.87%	0.35%	70.42%
Hours out of 90% acceptability	56.68%	77.21%	39.08%	61.71%	89.14%	37.05%	54.13%	99.65%	29.58%
Hours out of 90% acceptability: HEAT	26.56%	76.55%	1.23%	44.21%	89.14%	4.46%	31.42%	99.65%	4.64%
Hours out of 90% acceptability: COLD	30.12%	0.65%	37.85%	17.50%	0.00%	32.59%	22.71%	0.00%	24.95%
Hours within 80% acceptability	58.47%	31.55%	84.11%	50.76%	17.38%	84.86%	63.80%	5.64%	92.97%
Hours out of 80% acceptability	41.53%	68.45%	15.89%	49.24%	82.62%	15.14%	36.20%	94.36%	7.03%
Hours out 80% acceptability: HEAT	20.20%	68.41%	0.20%	37.02%	82.62%	0.69%	25.12%	94.36%	0.81%
Hours out of 80% acceptability: COLD	21.33%	0.05%	15.69%	12.22%	0.00%	14.45%	11.08%	0.00%	6.22%

Once these hours outside an established range were identified, it was possible to recognize and classify the results obtained outside these limits as extreme values. A study of the performance of each of the types of shelters applied to the different climates was carried out for the days when the most extreme values for interior temperature were reached, both in winter and summer, in each shelter and climatic situation. After studying the weeks with extreme winter and summer conditions in each of the locations, an analysis was carried out on the results of that week and the days that reached the most extreme values of operative temperature in the shelter were selected.
These extreme values are shown below, as along with the dates of the days when those values were analyzed (Figure 11).

4.3.1 Per type

In the case of the extreme values of Shelter A, we found that - as expected - the worst results are obtained for both summer and winter in Afghanistan, with 41ºC and 6ºC respectively (Figure 11). The performance in Jordan is also poor with values far from the comfort range, with values of up to 8ºC in winter and 35ºC in summer. A better performance is shown in South Sudan, with an operative temperature of 20ºC, which is hardly surprising as the winter is rather mild. This is not the case in summer, when temperature peaks of up to 32ºC are reached inside.

In the case of Shelter B, worse extremes are again observed in the climatic conditions of Afghanistan, with 13ºC and 43ºC in winter and summer. The situation improves slightly in Jordan, where the operative temperatures are 14ºC and 34ºC.

In South Sudan, the extreme results of the previous case remain practically the same.

Finally, for Shelter C, the operative temperature is more favorable in all cases, both in winter and in summer.

4.3.2 Per region

In Afghanistan, 14ºC are reached in winter and 31ºC in summer, that is, up to 4ºC less than in the first case. Equally, in Jordan, on the day of extreme heat value of 28ºC is reached, and 13ºC in winter. It was found that in the case of shelter C, a more favorable temperature was obtained for all three climatic conditions, although outside the range of adaptive comfort.

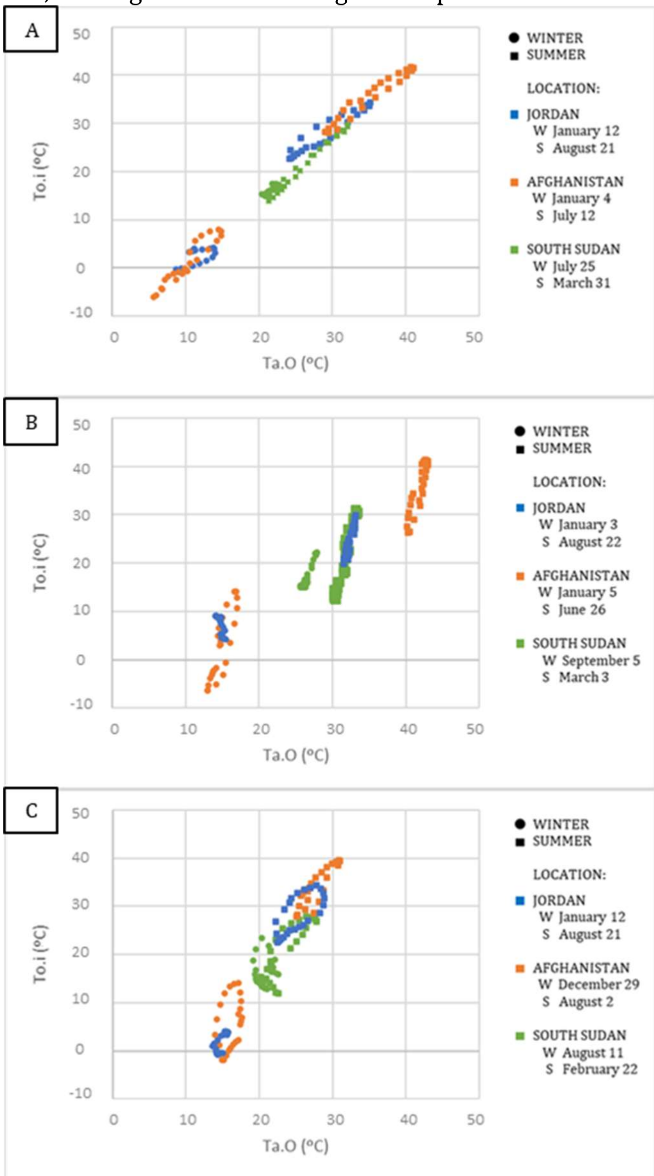


Fig 11. Extreme days (cold and warm period) analysis in Shelters Types A (a), B (b) and C (c). Caption: Ta.O : Outdoor temperature To.i Indoor temperature

5. Qualitative results

An overview of the most relevant aspects is shown in the Figure 12.

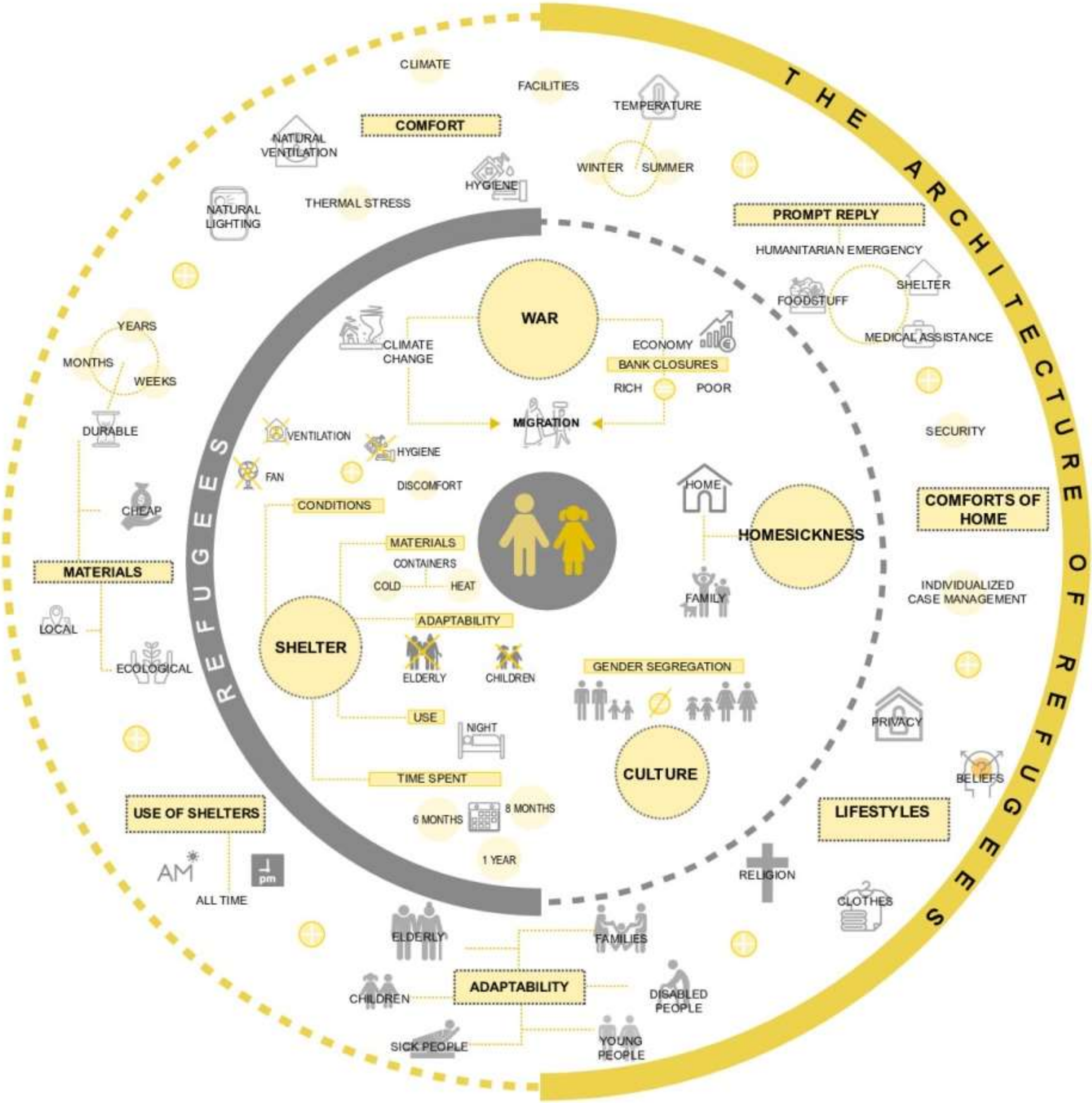


Fig 12. Overview of qualitative results

This study pursued survey questions (Appendix D) to refugees in order to consider qualitative and experiential observations in addition to the quantitative data. Most respondents agree on the lack of thermal comfort and believe that this is due to the fact that the shelters are not designed to be in constant use [40]. In particular, they questioned shelters envelopes' materials, what they believe was the main reason why high temperatures are reached. They report that indoor temperatures usually and greatly exceeded outdoor temperatures, and therefore, they can only use the shelter for sleeping in at night, but not during the daytime. As a result, they are continually exposed to situations of thermal stress and a sense of homelessness [41][42]. This is fundamental given the fact that most respondents describe a feeling of disorientation and confusion in the new settlement and longing of their previous homes.

Respondents also describe feelings of insecurity and lack of physical protection in inhabiting shelters. This common perception has a significant impact on how shelters are used and experienced, and surprisingly, on the level of thermal comfort. Some users shut down ventilation openings for achieving a sense of control and protection from the outside, however, affecting radically the thermal behavior of the unit and its possibility of being naturally ventilated. A comparison was carried out between these interviews and the data obtained from the interviews by Albadra [37]. This comparison was particularly useful in calibrating the type A shelter that presents further difficulties preventing ventilation. In this region, dusty winds easily bring sand into the shelter through the ventilation holes. Users tended to cover these holes with different materials, however, preventing air circulation for thermal comfort and air quality.

Other responses addresse the difficulty to reconciliate cultural expectations with living in a refugee's shelter. In particular, females usually mentioned the lack of separation between the shelter and the public realm but also the lack of privacy within the unit when coinhabiting with family members. In many cases, cultural expectations demand the clear separation of females from others that cannot be met in the available design layouts and shelters.

6. Discussion

Type C shelters demonstrate the best average performance as a whole when adaptive strategies can be developed (for an acceptable indoor ambient). Under this envelope the type has capacity for a greater number hours a year within moderate indoor temperature ranges. The type also presents stable values regarding operative temperature that ranges between 20ºC and 30ºC in all three climatic scenarios.

However, this type presents a lower performance in controlling the level of relative humidity that is usually exceeding 60%. The use of shelters such as type C built with local resources such has important benefits in terms of the ecological footprint and cost, and above all, the thermal performance against most climates. The response of these types usually entails a higher relative humidity for a greater number of hours than other cases, indicating the need to control this aspect in order to limit the possible formation of surface condensation; this control can be done primarily through ventilation. This aspect is of importance considering the construction and characteristics of the materials and interior surfaces of type C, given that greater hygroscopicity and difficulty for cleaning can promote the growth of mold inside. Some aspects of this typology are:

- It does not allow an easy implementation of technological construction measures such as reflective / absorbent coatings and requires the development of other potential approaches.
- They require a process of re-study and optimization of their design to be able to improve ventilation without compromising constructive and technological simplicity, while allowing the control of privacy and limitation of entry by external agents.

Regarding economic considerations, this shelter (Type C) would be the cheapest option (See Appendix E). On the one hand, since the shelter is locally produced, transportation and manufacturing costs and operations are considerably reduced resulting in a more sustainable building process. On the other hand, production is highly constrained by the availability of adequate local materials, what can be crucial given the high demands of shelters and unpredictability of humanitarian crises. In addition, this type of shelter is perceived as more permanent and consolidated building rather than a temporary construction. According to the UNHCR Catalogue [24], this perception results in longer periods of inhabitation worsening the constant lack of space in refugee camps. On the contrary, shelter A is optimized for prefabrication and transportation to the site, and therefore independent of the availability of local material or labor. Shelter B combines prefabrication with a local design character. However, it responds poorly to inhabitants' privacy needs, what disproportionally affect the comfort of women. In addition, the lack of material availability in arid climates limits the production of this shelter.

An all-around compromise model bearing on mind deployment capacity may be the type A shelter, developed in Jordan for this study, as it displays acceptable performance in all climatic scenarios. This type exhibits better stability, bearing in mind the full limitations already discussed, and on average it may provide some degree of limited comfort for its users. Figure 13 shows the results obtained by the type A shelter for all three climatic scenarios.

Regarding the climatic regions, due to climatic conditions South Sudan is the most favorable location, with an average operative temperature of 20ºC throughout the year, with no influence of cold periods. In Jordan and Afghanistan, where the weather conditions are more extreme, especially in the latter, indoor operative temperature exceeds 35ºC. The figures for relative humidity are usually high in South Sudan, where values often exceed 70%. In contrast, average indoor values in Jordan range between 40 and 60%.

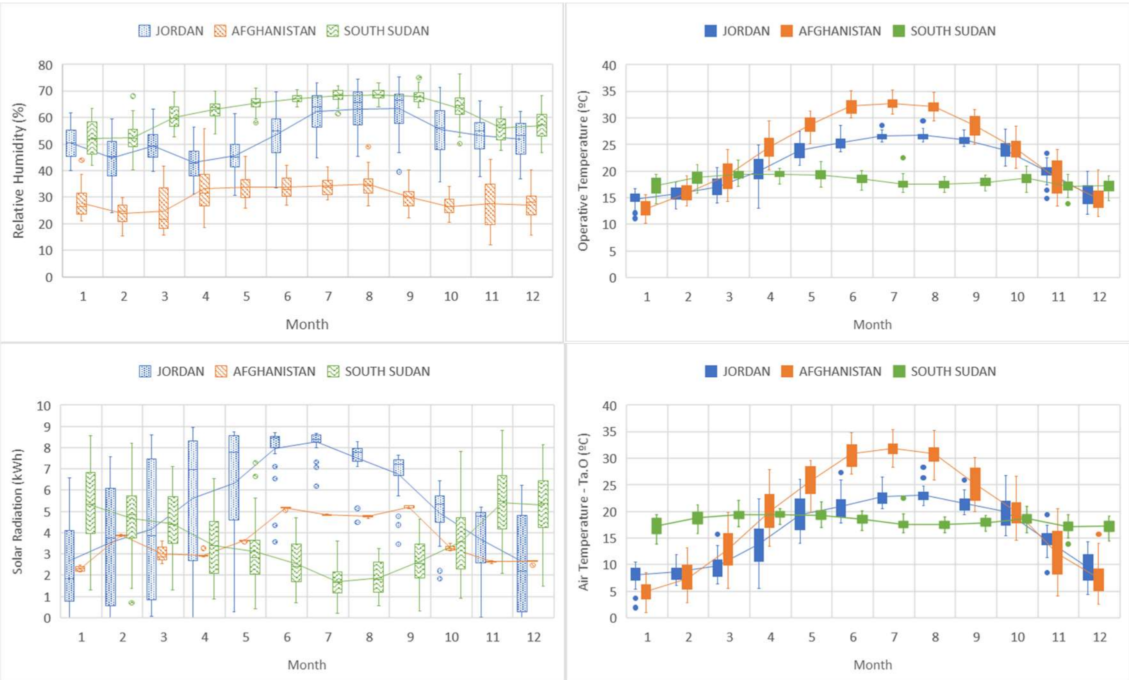


Fig 13. Average results obtained by the type A shelter in the three climatic zones

Type B shelters are those that offer the lowest environmental shelter capacity with the fewest hours in acceptable indoor thermal ranges in all cases. Their inadequate behavior in heat conditions is highlighted, as is the higher frequency in overheating situations. The potential for thermal stress of these types of shelter must be understood as linked to their nature and composition, despite their low cost and speed of construction, their use must take into account these critical aspects in order to ensure occupant health. Poor behavior in warm situations with high levels of radiation is especially relevant, making it advisable to use other types whenever feasible. In general, these type B shelters should be chosen only when immediacy and speed of installation is a critical factor, ensuring that their use is as temporary as possible, bearing in mind the circumstances and capacities of the area.

7. Conclusions

There is a significant difference in the performance of shelters used in arid or desert climates (temperate or extremes) and those in tropical or humid areas.

Type C shelters demonstrate the best average performance as a whole. This shelter type maintains a moderate temperature for the greater number of hours a year when adaptive design strategies can be deployed. The type also presents stable values regarding operative temperature that ranges between 20ºC and 30ºC in all three climatic scenarios. However, this type presents lower control of relative humidity, usually exceeding 60% concentration. The use of shelters such as type C built with local resources has important benefits regarding its ecological footprint and production cost, in addition to presenting the best thermal performance against most climates compared to the other types.

Types A and B are the shelters which are better suited to fast deployment and simpler installation. They presents acceptable thermal performance in dry climates with marked daily oscillations, in particular type A. This is less noticeable in warm-humid climates areas, where they are subject to considerable overheating.

Although shelters built using local-natural materials show good overall thermal performance, due to the lack of available materials neither rapid deployment nor use in arid or desert regions are possible. Their poorest performance is observed in cold weather, where lower solar absorption tends to lead to lower indoor temperatures.

The key points are:

- In the daily average results, the shelters built using traditional techniques and hut-morphology, like type C, usually show a more acceptable temperature range, unlike prefabricated models and shelters made of lightweight materials. Although this is to be expected given the physical configurations, the differences are notable in terms of tolerable ranges, and especially operative temperature.

- The type C shelter performs with a more favorable temperature in all three climatic situations, although these generally fall outside the usual ranges for comfort.

- In addition, its construction has a lower ecological footprint, providing there are materials available. Its greatest drawback is the need for accessible building resources, and the additional construction time and specialized labor needed.

- Light tent-type shelters like type B show extreme operative temperatures both in total figures and daily oscillation. This also corresponds to a configuration with hardly any thermal mass or actual insulating materials. This type offers the most basic refuge capacity, with very limited performance in terms of indoor thermal ambient envelope. However, lightweight cabins such as shelter type A present a more stable behavior with lower extreme values, although far from having an acceptable comfort envelope.

- Consequently, types A and B present strong shifts between day and night with fast hourly variations. Type C shelters display a different trend with specific dynamics and a smoother response curve, compared to more reactive lighter systems, something which is more evident in warmer climates.

- Under the adaptive criterion Type C displays a reasonable performance, followed by type A, although many hours fall outside the range of comfort conditions. Type B shelters account for the most hours outside the specifications for potential thermal comfort for all the climates.

It would be interesting to research additional aspects in order to lengthen the periods when shelters allow comfort through personal adaptation.

The use of type B shelters should be limited, inasmuch as possible, to situations requiring fast and urgent deployment when no other solutions are available, given the limited environmental control performance of this shelter type. The system presents significant control issues in hot and high solar radiation environments. Although its semi-open characteristics may improve ventilation and partially mitigate its performance, they lead to diminished protection from sand and dust, and also compromise privacy. This factor can invalidate its suitable use, worsening interior conditions and placing occupants, especially groups of women, elderly and the sick, at risk.

Acknowledgment

The authors want to thank to Department of Architecture & Civil Engineering, University of Bath for the open access to their comprehensive field-database, to the research group USE-TEP 130 Architecture, Heritage, and Sustainability and to the "VI Plan Propio de Investigación (University of Seville)".

Appendix A. Tables

Type A. Shelter developed in Jordan

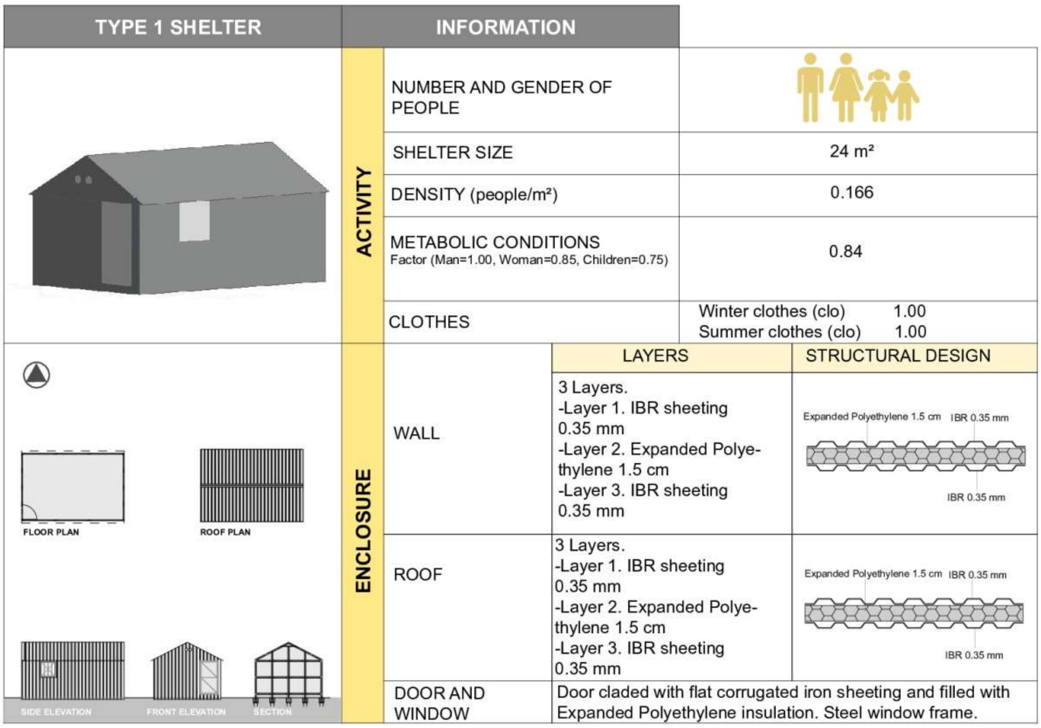


Fig A1. Features and considerations in type A shelter.

Type B. Shelter developed in Afghanistan

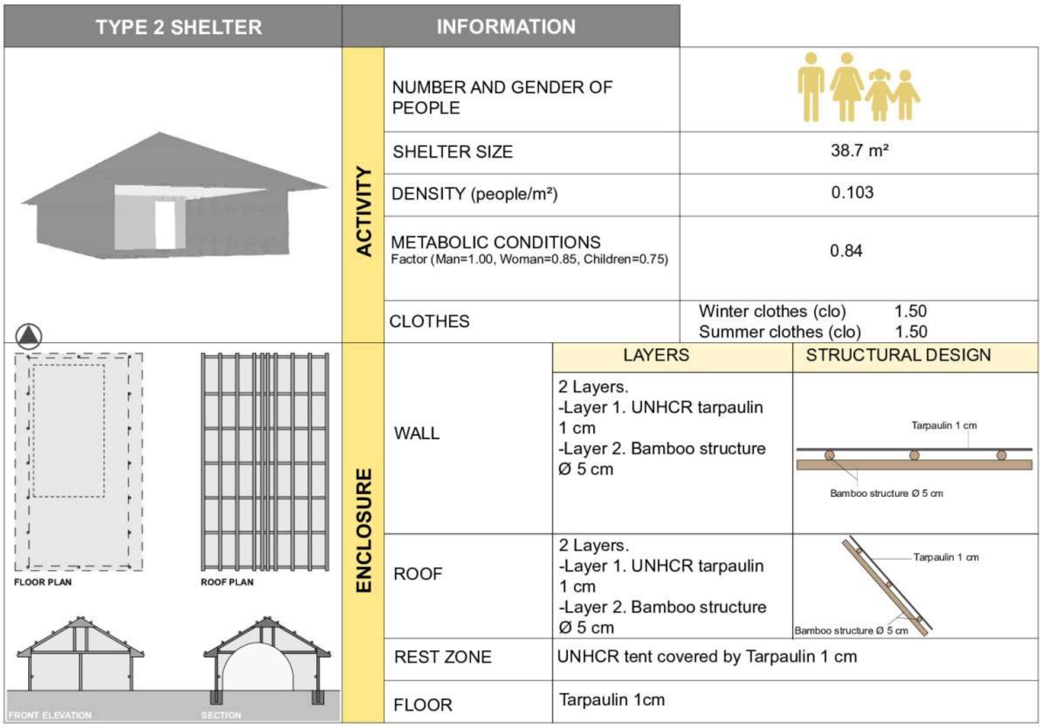


Fig A2. Features and considerations in type B shelter.

Type C. Shelter developed in South Sudan

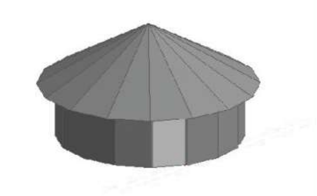
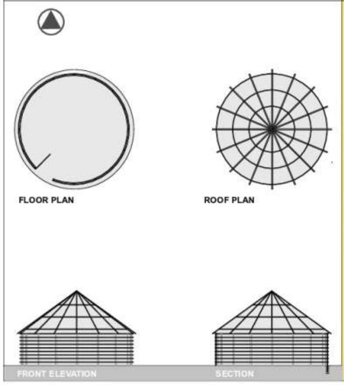
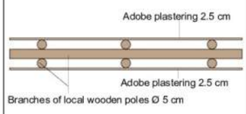
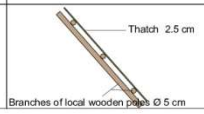
TYPE 3 SHELTER		INFORMATION		
	ACTIVITY	NUMBER AND GENDER OF PEOPLE		
		SHELTER SIZE	21.6 m²	
		DENSITY (people/m²)	0.214	
		METABOLIC CONDITIONS Factor (Man=1.00, Woman=0.85, Children=0.75)	0.84	
		CLOTHES	Winter clothes (clo) 0.50 Summer clothes (clo) 0.50	
 	ENCLOSURE		LAYERS	STRUCTURAL DESIGN
		WALL	3 Layers. -Layer 1. Adobe plastering technology 2.5 cm -Layer 2. Branches of local wooden poles Ø 5 cm -Layer 3. Adobe plastering technology 2.5 cm	
		ROOF	2 Layers. -Layer 1. Covered by thatch 2.5 cm -Layer 2. Branches of local wooden poles Ø 5 cm	
		DOOR	Bamboo sticks	
		FLOOR	Tarpaulin 1cm	

Fig A3. Features and considerations in type C shelter.

Appendix B. Clothing

The publication in 1970 of the work "Thermal Comfort" by P.O. Fanger constituted a major advance in terms of the assessment of the variables influencing man-environment heat exchanges. These variables correspond to activity level, clothing characteristics, dry temperature, relative humidity, average radiant temperature, and air speed.

The influence and thermal characteristics of clothing are measured in a unit called "clo", equivalent to a thermal resistance of 0.18 m^2 hr ° C / Kcal. The most common types of clothing are defined by NTP 74 [43], as well as UNE -EN ISO 15831:2004 [31] and UNE-EN ISO 9920-2009 [44].

Table B1. Thermal insulation (clo). UNE-EN ISO 9920 and Alberto Viti Corsi standard

Type of clothing	Thermal Insulation (Clo)
Nude	0.0
Shorts	0.1
Tropical clothing: shorts, short-sleeved shirt and sandals	0.3
Light summer clothing: Light long pants, short sleeve shirt, light socks and shoes	0.5
Work attire	0.7
Light winter clothing: long-sleeved shirt, thick pants, sweater, thick socks, shoes	1.0
Winter clothing	1.5

After analyzing these values, the specific values for each country were selected, based on the cultural study of their religious practices to adapt these to each different situation.

Appendix C. Calibration evaluation criteria according to ASHRAE 14-2002

Table C1. Calibration evaluation criteria according to ASHRAE 14-2002

Evaluation Indices		Equation	Acceptance Criteria (hourly data) [18]
Mean Bias Error	$MBE = \frac{\sum_{i=1}^{N_s}(y_i - \hat{y}_i)}{\sum_{i=1}^{N_s} y_i}$	[1]	<10%
	$\hat{Y}_S = \frac{\sum_{i=1}^{N_s} y_i}{N_s}$	[2]	
Coefficient of Variation of the Root Mean Squared Error	$CVRMSE_{(S)} = \frac{\sqrt{\sum_{i=1}^{N_s} \frac{(y_i - \hat{y}_i)^2}{N_s}}}{\hat{Y}_S}$	[3]	<30%

- y_i: monitored data
- $\hat{y}_i$: simulated data
- N_s: sample size
- $\hat{Y}_S$: sample mean of monitored data

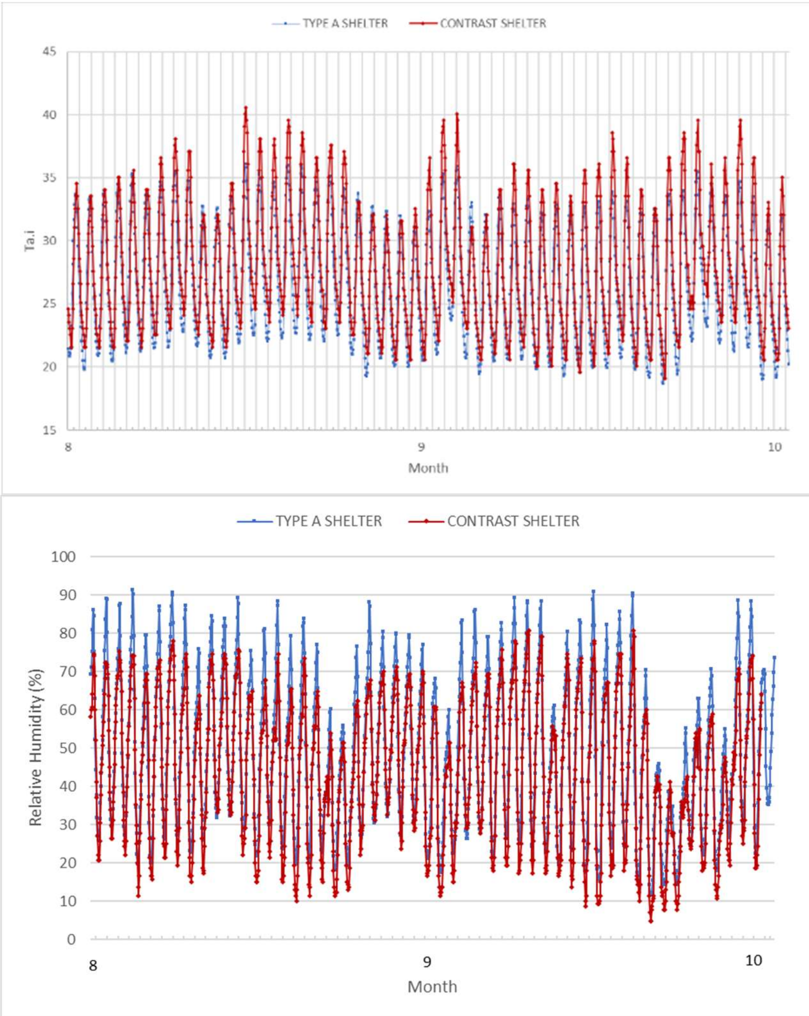


Fig C1. Contrast of results between type A shelter and the model with field data

The type A shelter was validated following a calibration procedure which contrasted it with the data set from Albadra, Coley and Hart of the University of Bath [21], analyzed in the Azraq camp [37].

In this study, the environmental monitoring data (temperature and relative humidity) was collected by Fosas [21] using buttons type I (temperature and humidity recorder DS1923-F5) in five shelters per camp in winter and summer. Half-hourly measurements were taken with placing the buttons at a 1.5m height in the shelter's center. These on-site data collections were carried out between August 17 and October 7 [18]. By comparing measured and simulated results, this model was adjusted through a GOF procedure [45] which provided a more accurate representation of the actual behavior of the refuge under study.

The simulation of the models provided results similar to the on-site measurements throughout multiple iterations, obtaining a reliable shelter's performance profile. Figure 9 shows the comparison of the data collected on-site and the simulated model measuring indoor temperatures and relative humidity.

The results show that the differences for indoor temperature are mostly minimal, with only slight differences in peak values. This is mainly due to the effect of radiation that is lowered by the model. Regarding relative humidity, the offset range is slightly higher but still acceptable. Slight humidity variations are usually unperceivable for the users and therefore will not have a significant effect in our study. In addition, the calibration is compliant with the ranges permitted by the ASHRAE 14-2002, the calibration is complying with the standards:

$$MBE = 3.57\ \% < 10\ \%$$
$$CVRMSE = 8.58\ \% < 30\ \%$$

Appendix D. Survey questions

1. Could you describe what how was your life like before you had to leave your country? Can you describe how was your home like?

2. Could you tell us the reason why you had to leave your country?

3. Did droughts, torrential rains or extreme temperatures influence your decision?

4. How did your life change once you began leaving in a refugee camp? What changes were more important for you?

5. Could you describe the conditions of living in the refugee camp where you were? What kind of resources were made available for you?

6. Could you describe the shelter in which you had to live during your time in a refugee camp? What do you think of it? Could you draw it?

7. When you were inside the shelter, did you feel safe and comfortable? What would you change in that regard?

8. Do you think they were suitable for vulnerable population such as children, elders, or sick population? Do you think the quality of shelters may have been the cause of sickness or dead?

9. Do you think that shelters were more suitable for children, adults or elders?

10. Does your gender or age particularly affect your life in a shelter? What problems did you encounter because of your gender or age? Did you have to change your customs or behaviors?

Appendix E. Costs of shelters based on a Shelter Design Catalogue UNHCR.

UNHCR Catalogue [24] shelter production estimated costs considering the three studies types:

Tabla E1. Estimated costs of shelters based on a Shelter Design Catalogue UNHCR.

	Shelter type A	Shelter type B	Shelter type C
Sub total	2374 $	560,8 $	172 $
Transport cost 15%	356 $	84 $	26 $
Labour cost 30%	712 $	168,2 $	52 $
Total estimated cost	3442 $	813 $	250 $

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