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Insulated membrane kit for emergency shelters: product development and evaluation of three different concepts

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Abstract

The paper deals with the development of a novel winterized textile partition to accommodate refugees during a humanitarian crisis. The research has been developed within S(P)EEDKITS, a four year research project (March 2012 - February 2016) in which research institutes, universities, companies operating in the emergency sector and non-profit organizations have rethought shelters, medical care resources and other facilities provided in case of natural disaster and conflicts.

The S(P)EEDKITS project aimed to scrutinize materials and equipment of the Emergency Response Units (ERUs) that are currently used by humanitarian non-governmental organizations (NGOs), and to develop novel solutions which drastically reduce their deployment time, the volume and weight for transportation. Solutions needed to be clever and durable enough so that the affected population can use them also during the reconstruction phase. This dual approach - speed and seed - was crucial as the recent trend in emergency aid for organizations is not only to stimulate as early as possible the self-repair, but also to support the transitional period and the reconstruction.

Starting from a detailed analysis of the state of the art, the research group of Politecnico di Milano (POLIMI) worked on the design of innovative shelter solutions and their packages, in order to add values in terms of ease of transport and set up. Through the multidisciplinary approach that involved several partners of the collaborative project, a list of metrics scored three diverse shelter concepts; one of them was prototyped in ten units and tested by Senegal and Luxembourg Red Cross delegations.

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Keywords: Emergency; Sheltering; Winterization; Adaptability; Polyester fiber.

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1. Research field and goals

In humanitarian field, shelter products are mainly developed as ‘closed’ prefab system that work independently to other provided shelters and local materials. Prefabricated designs are developed ad hoc and their parts often require time-consuming assembling. Sometimes prefab products don’t include instructions for post-emergency use or disposal. As result, abandoned temporary shelters become common, sad reminders of the easy waste of money and resources. Moreover, the different climatic contexts require from NGOs a huge faculty of adaptation as each situation calls for a precise answer. Recent emergencies draw attention to limits of current standard tent to be adapted in all climates or in places with high daily-temperature ranges [1].

Within the collaborative project S(P)EEDKITS, for overcoming this critical aspect of current shelter kits, the development of novel solutions aimed to offer an effective winterized solution that also well works in warm and hot climates. The idea of a progressive solution was adopted according to local constraints: it wasn’t only linked to climate risk, but also dependent by local resources [2]. Adaptability was to ensure both a prompt first-time repair, that can be easily erected, and an effective protection in a medium and long-term period, so configuring the ‘core’ of a transitional dwelling.

Moreover, a novel shelter system should not only link to climate risks and local resources, but also relate to cultural identity of the affected population. The novel shelter kit has to be inserted in an affected area (urban area, improvised camp, rural region etc.) to reach as quickly as possible an acceptable post-disaster situation towards the rebuilding of economic and social life. By providing shelter kits that are adaptable to users’ practices (tribal composition, lifestyle, religious claims etc.), the rescue could be organized with a people-centered approach in which refugees enclose themselves private spaces, even inside damaged buildings. This feature can improve the acceptance level of the entire sheltering process during a disaster [3].

2. State of the art

By analyzing the state of the art (SOTA) of current shelter-materials that are currently used to protect affected persons from extreme climatic conditions in cold and hot environments, it’s possible to distinguish two different main types, as shown in Fig. 1. The first one collects all the winterization kits that are conceived for upgrading NGO-standardized tents; they are optimized to be combined with their reference products, and aren’t adaptable to other tent-structures. The second category includes all the non-food items (NFIs) that are distributed in rolls to displaced population as winter protections: blankets, mattresses, foam boards, plastic sheeting etc.; in that case, materials - often recovered from local markets - are used for insulating floors, openings of unfinished/damaged buildings and non-winterized shelters [4].

Fig. 1. (a) Winterization kit for UNHCR-IFRC Family Tent (Source: ICRC-IFRC, 2009); (b) Tuareg population uses blankets and plastic tarpaulins to cover tents of the refugee camp of Sagnioniogo (Burkina Faso), located in the sub-Saharan climate with an high daily temperature range (Source: Virgo, De Vilder, Viscuso, Roekens, 2014)

Recent crises in the Middle East region (Afghanistan, Iraq, Syria etc.) have been offering two proper examples of how families and communities have self-upgraded improvised shelters or existing dwellings by using simple raw materials, although they didn't have any skill in sheltering and construction [5]. In such regions, many families have started to seal off the unfinished or abandoned buildings by themselves using tarps, blankets, metal sheets etc. (Fig. 2 a). However, this approach doesn't permit to achieve confortable solutions with good insulating scores, due to the difficulty to erect durable and effective protections: the consequence is the low resilience of insulated dwellings and shelters, that don't offer a marked improvement to previous living conditions and vulnerability [6].

During the on-going crisis in Syria, the countries around this affected region are hosting a large number of emigrants in refugee camps where temperatures easily drop to 0°C and even below for two or three months a year. In that context, the current shelter solutions (e.g. UNHCR standard tents), even if provided with their winterization kits, are not particularly adapted to protect beneficiaries from low temperatures and related health hazards (Fig. 2 b). Trying to compensate the poor insulation obtained with provided materials, Syrian refugees increase heating, with the consequence to raise the risk of fire, especially when heaters are operated during night times without being safeguarded [7].

Fig. 2. (a) Plastic tarpaulins used to close openings in unfinished buildings of Iraq (Source: Morgenstern, 2015; Fowler, 2014); (b) Syrian refugee camps in summer and winter season (Source: courtesy of Mohamed Azakir and Richard Wainweight)

In more extreme climates, as for example in earthquake prone mountainous regions of central Asia (e.g. Pakistan, Nepal, Mongolia, India etc.), temperatures that need to be braved can be low than -30°C. For overcoming the insulating limits of current shelter solutions, on January 2015 the Shelter Research Unit of the International Federation of Red Cross (IFRC-SRU) spent three weeks in Mongolia - with temperatures between -15°C and -30°C - for testing: (i) the main globally-used standard tents (e.g. Turkish Red Cross tent, UNHCR-IFRC family tent etc.); (ii) the relative winterization kits (e.g. insulating floor mat, inner layers, floor protections etc.); (iii) a new prototype of inner tent, designed by SRU with the support of British and Mongolian Red Cross Societies, and consisting in a inner tent made of non-woven polyester board (thickness 40 mm) laminated on the interior side with a reflective layer (Fig. 3). The temperature tests with burning stoves were run in all tents to establish which tents could assure a minimum temperature of 15°C throughout a night time heating period. To assure appropriate air quality inside the tents with burning stoves the CO_2 and CO levels, as well as ventilation rate were recorded [8].

Data logger results of Mongolian temperature-test showed that just three tents made it over 0°C and only the SRU prototype kept an indoor mean air temperature higher than 15°C. However, the unit weight of non-woven polyester requires to reduce the thickness of material, also for obtaining a more flattened package volume; moreover, a thermal infrared analysis individuated that stitching lines creates thermal bridges, so they should be minimized [9].

Fig. 3. (a) Non-woven polyester internally laminated with reflective layer, used to manufacture the inner tent for the SRU Mongolian test in 2015; (b) Burning stoves used to achieve an indoor mean air temperature of 15°C; (c) Detail of the door (Source: Virgo, 2015; Ledesma, 2015)

3. Designing and selecting concepts

The concept generation aimed to transfer the practical users' needs in a set of shelter concepts. In extreme climate conditions, the first basic need is to protect the displaced population against external agents. On these fields, the lack of insulation of standard tents and damaged building is more critical than the request of structural elements (timber or steel) and blocks, which are easily recoverable from local markets. Thus, potential novel shelters should mainly provide flexible panelling systems to adequately winterize beneficiaries; they might be compatible with standard tent structures and locally available structures (frames, simple poles, trees etc.); finally, they could be adaptable to diverse functions depending on needs (e.g. the roofs after a hurricane, floors during flooding, etc.).

Requirements and inputs coming from S(P)EEDKITS partners (IFRC-SRU, SIOEN Industries and CENTEXBEL) were translated in a list of metrics. The list reflected as directly as possible the degree that new concepts had to approximate for satisfying emergency needs and production skills. In product design area, requirements are generally expressed in the 'language of the customer'. As sketched in Fig. 4, in product design the workflow usually starts establishing a set of specifications, which spells out in precise, measurable detail what the product has to do [10]. For instance, in contrast to the user need of 'lightness', the corresponding specification might be that 'the weight of packages has not to overcome the limit point of 30 kg per person'. A specification consists of a metric and a value: 'weight of packages' is a metric, while 'until 30 kg per person' is the value of this metric. Together, the metric and value form a specification. The relationship between needs and metrics was central to the entire design process in the S(P)EEDKITS research: a matrix represented connections between these ones: rows of the matrix corresponded to the users' needs, and the columns to metrics.

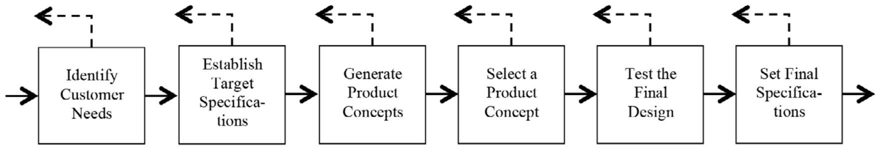


Fig. 4. Workflow in S(P)EEDKITS shelter design (Source: Ulrich, Eppinger, 2011)

Diverse examples of SOTA represented the benchmark cases for establishing a list of ideal values to achieve through the generation of novel concepts. The goal was to consider the strength point of current competitive products, and get over limits due to their rigid prefabrication, that is not often accepted by locals. This methodology also offered a mechanism to guide in the thorough exploration of alternatives, for demonstrating that it's passible obtain more significant achievements by providing on the field partial solutions (e.g. separate components that can used independently or also combined each other to set a complete shelter).

An example of comparison matrix is displayed in Table 1. In 2010 IKEA, the Swedish company notable for its user-friendly set-up and mass production, begun a cooperation with the UNHCR (BetterShelter.org) to design a portable Refugee Housing Unit (RHU). In this novel transitional shelter, a series of lightweight polymer boards, laminated with thermal insulation, composes the envelope to be fixed on the steel frame. The panelling kit can be also used independently to its original structure, e.g. to clad other shelter frames, or to protect damaged clinics and schools [11]. The matrix allowed setting values to reach (e.g. a better insulation) without loosing the important goals achieved by the IKEA product (such as cheapness). Once applied to main existing market products, the comparisons gathered information from many disparate sources and reduced the risk of failure of entire design process.

Table 1. Matrix showing the relationship between requirements (columns), metrics (rows) and values (bold cells) in a competitive product (left) and in the new design (right)

<table>
<tr><td rowspan="12">Reference product: RHU Panel kit (BetterShelter.org)</td><td>Lightness</td><td>Portability</td><td>Simplicity</td><td>Cheapness</td><td>Adaptability</td><td>Reliability</td><td>Durability</td><td>Sustainability</td><td>Safety</td></tr>
<tr><td colspan="2">4,857 Kg/m^2</td><td colspan="7">Weight / Footprint Area 17,5 m^2 (5 persons)</td></tr>
<tr><td></td><td colspan="2">0,8 m^3</td><td colspan="6">Packaging Volume</td></tr>
<tr><td colspan="2"></td><td colspan="2">3 h by 2 p.</td><td colspan="5">Assembly Time</td></tr>
<tr><td colspan="3"></td><td>500 €</td><td colspan="5">Production Cost</td></tr>
<tr><td colspan="3"></td><td colspan="2">High</td><td colspan="4">Industrial finishing level</td></tr>
<tr><td colspan="4">Thermal Conductivity</td><td colspan="2">0,209 W/mK</td><td colspan="3"></td></tr>
<tr><td colspan="5">Water Absorption</td><td colspan="2">0,01%</td><td colspan="2"></td></tr>
<tr><td colspan="6">Life Span</td><td colspan="2">3 years</td><td></td></tr>
<tr><td colspan="6">Disposal Use</td><td colspan="2">Recyclable</td><td></td></tr>
<tr><td colspan="7">Ventilation Openings</td><td colspan="2">3720 cm^2</td></tr>
<tr><td colspan="8">Fire Resistance (EN13501-1)</td><td>D s2 d0</td></tr>
</table>

<table>
<tr><td rowspan="12">S(P)EEDKITS Design Process (Ideal Values)</td><td>Lightness</td><td>Portability</td><td>Simplicity</td><td>Cheapness</td><td>Adaptability</td><td>Reliability</td><td>Durability</td><td>Sustainability</td><td>Safety</td></tr>
<tr><td colspan="2">5 Kg/m^2</td><td colspan="7">Weight / Footprint Area 17,5 m^2 (5 persons)</td></tr>
<tr><td></td><td colspan="2">0,8 m^3</td><td colspan="6">Packaging Volume</td></tr>
<tr><td colspan="2"></td><td colspan="2">1 h by 2 p.</td><td colspan="5">Assembly Time</td></tr>
<tr><td colspan="3"></td><td>800 €</td><td colspan="5">Production Cost</td></tr>
<tr><td colspan="3"></td><td colspan="2">Medium</td><td colspan="4">Industrial finishing level</td></tr>
<tr><td colspan="4">Thermal Conductivity</td><td colspan="2">0,050 W/mK</td><td colspan="3"></td></tr>
<tr><td colspan="5">Water Absorption</td><td colspan="2">0,01%</td><td colspan="2"></td></tr>
<tr><td colspan="6">Life Span</td><td colspan="2">2 years</td><td></td></tr>
<tr><td colspan="6">Disposal Use</td><td colspan="2">Recyclable</td><td></td></tr>
<tr><td colspan="7">Ventilation Openings</td><td colspan="2">5000 cm^2</td></tr>
<tr><td colspan="8">Fire Resistance (EN13501-1)</td><td>E, B</td></tr>
</table>

Taking advantage of support given by the industrial partner SIOEN, specially for identifying the cheaper production technologies currently in use in the humanitarian market sector, the concept design of novel insulating shelter-components presented three different levels of industrial finishing, corresponding to three diverse products and ways for using them: i) a self standing foam panel coated with textiles on both sides, conceived for configuring any home layout when anchored to existing supports or stiffened with local materials; ii) a semi-opened foam module, coated with textiles, that can configure a closed box if combined with an other one; iii) a closed box made of non-woven polyester and coated textiles, that is ready to be hanged to structural beams and ceilings of damaged/unfinished buildings, or to any structural element [12]. The generation of three gradual finishing levels was crucial to balance production costs with the aim to provide a unique, adaptable shelter component.

The first concept represented the base product delivered on roll and configurable with diverse paths. For this development, POLIMI designed several internal configurations for erecting a transitional home. By using the roll panels to enclose home layouts, one or more tarpaulins can cover wall layouts, while the poles used to tension roof membrane also stiffen the corners or walls. On May 2014, the POLIMI research group tested foam panels (thickness 40 mm) in combination with the membrane and relative structure of an other kit (named 'Clever Roof') that has been developed by VUB University within the S(P)EEDKITS project [13]. As shown in drawings of Fig. 5, vertical and diagonal foam board cuttings could be used for reinforcing panel directly on the field (e.g. with small timber profiles and bars).

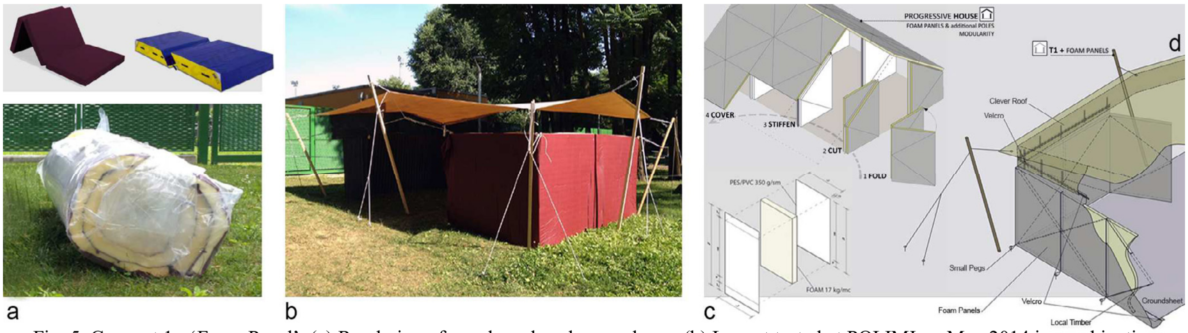


Fig. 5. Concept 1 - 'Foam Panel': (a) Rendering of panels and package volume; (b) Layout tested at POLIMI on May 2014 in combination with the Clever Roof kit (structural design by VUB University); (c) Shelter layout erected with locally available materials; (d) Shelter layout connected to the Clever Roof

The second concept was a semi-opened, tridimensional module suitable to be combined each other in a completely insulated shelter. Three sides of textile-coated foam boards (thickness 40 mm) were attached together with a polyethylene groundsheet to close the bottom part. This solution was conceived during the S(P)EEDKITS Workshop organized in Milan on July 2014. During the meeting, POLIMI, VUB and SRU fabricated and tested a first mock-up, verifying its usability below the Clever Roof also to winterize the ground when rotated of 90° (Fig. 6).

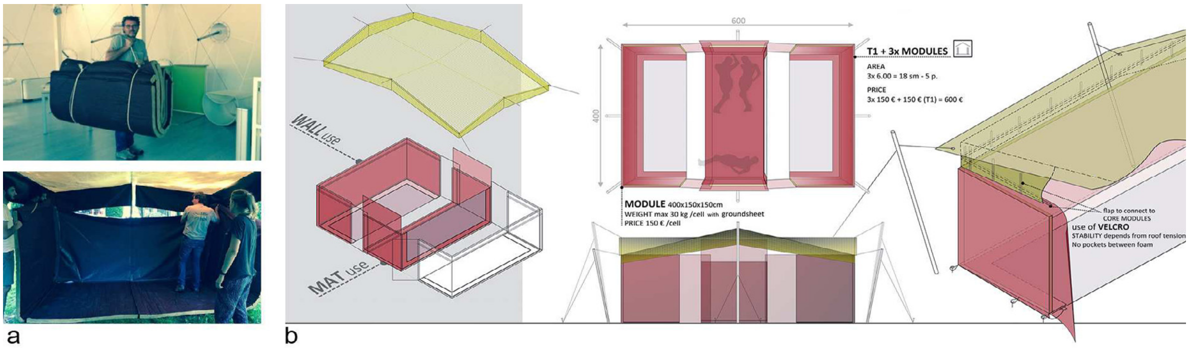


Fig. 6. Concept 2 - 'Foam Module': (a) Mock-up tested during the S(P)EEDKITS WP2 Meeting at POLIMI on July 2014); (b) Shelter layout (17,5 sm) connected to the Clever Roof by using with three modules

Following a progressive finishing level, the last concept consisted in a complete living accommodation fixed onto whatever structural element by means of polyester belts. It allows crating a confined, winterized space to assure intimacy and protection. The amount of material needed oriented towards more lightweight insulating materials instead to foam boards, such as a non-woven polyester fabric with thickness of 20 mm (Fig. 7).

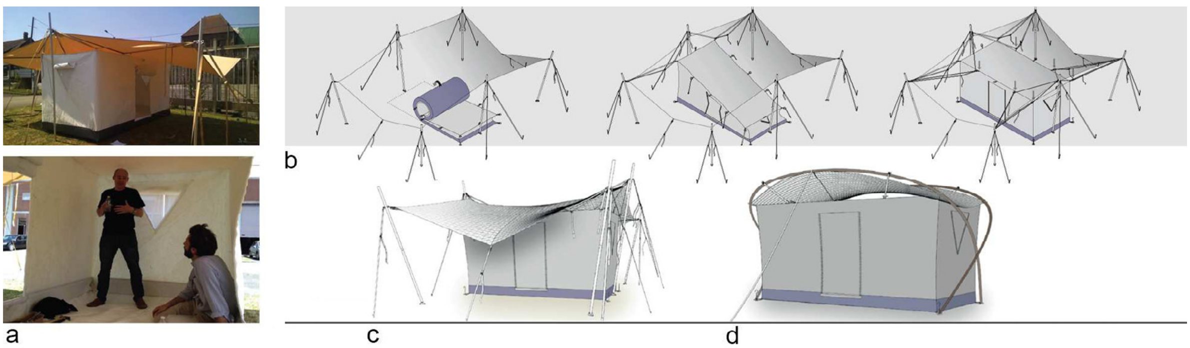


Fig.7. Concept 3 - 'Non-woven Cocoon': (a) Mock-up tested during the S(P)EEDKITS WP2 Meeting at SIOEN-Saint Frères on July 2015; (b) Assembly stage under the Clever Roof; (c) Complete shelter Cocoon + Clever Roof; (d) Cocoon hung from local bending timber

Concepts were evaluated trough a set of scores given for each specification (Tab.2). Insulating materials are not easily available in local market, especially after a disaster. For this reason, the main purpose of the concept development was to provide a quickly, winterized pannelling that can be useful for all the emergency time. Sheltering literature demonstrates that structural components (timber, steel profiles modules, bamboo etc.) and plastic tarpaulins are largely recoverable in local markets and their use is directly linked to traditional construction practices. Thus the concept generation defined solutions that protect inhabitants against external agents, even requiring structural elements and at least an upper layer that protects it against rain and snow.

All the obtained concepts presented a high connectivity score with both structures provided into other shelter-kits due to rings that permit to pretension textiles. They were also connectable to the 'Clever Roof' kit, which works as shade net in hot climates. Moreover, it was verified the aptitude of each concept to adapt itself to local buildings or wherever existing structural elements permit to hang the panelling by means of few accessories (e.g. ropes and small anchors) provided within the relative kits. Finally, they could also configuring winter rooms in collective tents, hospitals and warehouses.

Experimental tests verified that the panelling system should not too much divided in modular parts for simplifying the set-up by untrained beneficiaries. In sheltering sector, a quickly set-up is crucial according to NGO needs: a large amount of parts and connections can require more time and specific skills to involved persons. Considering the substantial parity of weight and packaging volume between the generated concepts, the variation of the needs' rating allowed to better fit the evaluation to real needs of emergency fields: the high weighting of metrics 'Assembly Time' and 'Thermal Conductivity' scored the third solution - named 'Cocoon' - as the best performative solution between the proposed ones.

Table 2. Concepts' score obtained as the product between raw values (tested or expected for each concept: + Much worse than the Ideal Value; ++ Worse than the Ideal Value; +++ Same than the Ideal Value; ++++ Better than the Ideal Value; +++++ Much better than the Ideal Value) and relative metrics' weighting

		$Score\ (S_j) = \sum_{i=1}^{n} r_{ij}\, w_i$ r_{ij}= raw value of concept *j* for the *i* metric; w_i = weighting for *i* metric; n = number of metrics					
Metrics	**Weighting (w_i)**	**1 - Foam Panel (30 m roll - Tot. 17,5 m^2)**		**2 - Foam Module (3 modules - Tot. 18,0 m^2)**		**3 - Non-woven Cocoon (3 modules - Tot. 19,5 m^2)**	
	Rating 1-5	r_{ij}	S_j	r_{ij}	S_j	r_{ij}	S_j
Weight / Footprint Area 17,5 m^2 (5 persons)	4	3,45 Kg/m^2 ++++	160	3,03 Kg/m^2 ++++	160	5,14 Kg/ m^2 +++	120
Pack Volume	3	2 m^3 +	30	1,5 m^3 ++	60	1 Kg/sm +++	90
Assembly Time	5	3 Hours +++	150	1,5 Hours ++++	200	0,5 Hour +++++	250
Production Cost (Asian Manufacturer)	3	600 € ++++	120	825 € +++	90	1050 € ++	60
Industrial finishing level	2	Low +	20	Medium +++	60	Medium-High ++++	80
Thermal Conductivity	5	0,050 W/mK +++	150	0,050 W/mK +++	150	0,035 W/mK ++++	200
Water Absorption (F) Foam; (P) N-W PES; (T) PES/PVC	4	(F)90% (T)0,01% ++	80	(F)90% (T)0,01% ++	80	(P)50% (T)0,01% ++	80
Life Span	3	12 Months +	30	18 Months ++	60	24 Months +++	90
Disposal Use N-Rec: not recyclable; P-Rec: partially rec.	2	(F)N-Rec (T)P-Rec +	20	(F)N-Rec (T)P-Rec +	20	(P)Rec (T)P-Rec ++	40
Ventilation Openings (with door closed)	3	Not defined +	30	Not defined +	30	5500 cm^2 +++	90
Fire Resistance B1, E, F: EN13501-1 classes	4	(F)F (T)B1 ++	80	(F)F (T)B1 ++	80	(P)E (T)B1 +++	120
	Total Score		**870 pt.**		**990 pt.**		**1220 pt.**
	Continue to develop (Y/N)?		**N**		**N**		**Y**

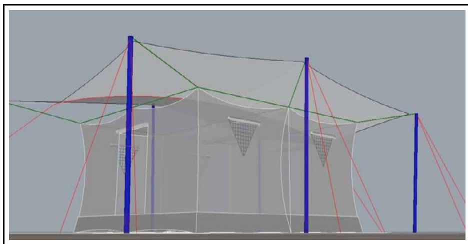
4. Evaluating and testing the final design

Once selected most promising concept, the final design of Cocoon developed practical details for achieving a good internal comfort in diverse contexts. Referring to its thermal performance, in the case of use with low outdoor temperatures the non-woven polyester well insulates the shelter; on the contrary, in hot and warm climates the cross ventilation decreases the indoor temperature, while the covering layer (the Clever Roof or simple plastic tarpaulins) reduces the solar radiation. A thermal analysis was achieved by using the energy modeling plug-in ArchSim for Rhinoceros Grasshopper, which is operable with the energy simulation software EnergyPlus (Tab 3).

Simulations were related to weather data of Ulaanbaatar (Mongolia), Tabriz (Iran), Damascus (Syria) and Dakar (Senegal). For the first two climatic zones, the analysis focused on the coldest month, with a outdoor air temperature range between -33°C and 3,5°C; for the remaining areas, it considered the hottest period, with an average high of 37,4°C and low of 19,1°C. In three modules with dimension of 360x180x180 cm (total footprint area of 17,5 sm per 5 persons) made of non-woven polyester laminated with PES/PVC coated fabrics (thickness 20 mm), the software estimates the indoor air temperature between 15,4°C and 28°C; burning stoves were applied only for Mongolian simulation (with heating capacity of 40 W/sm), while the shade net and the cross ventilation contributed to improve the internal comfort in Syria and Senegal simulations. The World Health Organization recommends a minimum indoor temperature of 18°C, and ideally 21°C if babies or elderly people live in the house. If house temperatures fall below 15°C, the risk of respiratory illness increases. This is because cold houses are also usually damp, which can lead to respiratory symptoms [14].

However, the insulating material has been analyzed in its optimal conditions, without moisture or damages. If simulations also considered the humidity level of polyester, the thermal conductivity of the whole partition system would increase and change the indoor temperature value.

Table 3. Thermal Analysis achieved by the plug-in ArchSim for Rhinoceros Grasshopper, which directly links 3D models with the energy simulation software EnergyPlus. By analyzing diverse climatic contexts, the obtained data verified that modules allows maintaining the indoor mean air temperature in step with WHO standards

		**(3x) Non-woven Cocoons** Footprint area: 19,5 m^2 5 persons (3,9 m^2/p.) Volume: 35,0 m^3 Connectivity: 'Clever Roof' structure Openings (doors and windows): (A) closed - (B) open			
		Ulaanbaatar (Mongolia)	**Tabriz (Iran)**	**Damascus (Syria)**	**Dakar (Senegal)**
Climate data	Analyzed period (coldest month)	January (A)	December (A)	-	-
	Analyzed period (hottest month)	-	-	July (B)	October (B)
	Daily temperature range (°C)	-33,0 ÷ -19,0	-5,3 ÷ 3,5	19,1 ÷ 37,4	25,1 ÷ 31,0
	Daily relative humidity range (%)	61 ÷ 80	51 ÷ 87	14 ÷ 90	56 ÷ 95
Design data	People density (p/m^2)	0,26	0,26	0,26	0,26
	Heating set-point temperature (°C)	10,0	-	-	-
	Heating capacity (W/m^2)	40,0	-	-	-
	Ventilation (ACH)	1,00	0,33	20,00	20,00
Outputs	Daily indoor mean air temperature range (°C)	15,4 ÷ 18,3	15,0 ÷ 20,7	17,6 ÷ 28,0	22,9 ÷ 27,2
	Daily indoor air relative humidity range (%)	38 ÷ 72	54 ÷ 80	20 ÷ 80	60 ÷ 90

Following the thermal analysis, a set of manufacturing specifications contributed to reduce as possible the cutting pattern of blueprints and minimize production costs, without loosing in terms of performances: the final design avoided extra thermal bridges due to not essential seams and opening surfaces, while the non-woven polyester was laminated on both sides with PVC-coated textiles only for groundsheet, in order to well insulate and protect the basement without increasing the final price (Fig. 8 a) [15]. With the support of SRU, on July 2015 partners POLIMI (designer) and SIOEN (manufacturer) tested the first prototype at SIOEN-Saint Frères Confection, sited in Flixecourt (France). During this experimental test, the Cocoon was hanged to the metal poles of the ‘Clever Roof’ by means of simple polyester belts. It was also verified the feasible configurations of belts for hanging modules from diverse anchoring points (Fig. 8 b-c).

On December 2015, partners shipped ten Cocoons to Senegal for a field test in Ntiagar, a tribal village close to Dakar. Taking into account packaging guidelines developed within a specific Work-package of the research [16], modules were wrapped with thermoplastic film in a kit including eight polyester belts provided with tensioners, four pegs and the instruction manual. Once arrived on site, the weight of the whole bale (30 kg approx.) allowed a carry-on local transport (1 person per bag). The Luxemburg Red Cross used the modules together with poles provided into 10 Clever Roofs. Products were observed during a 3-month’s period, characterized by low temperatures (that sometimes lowered to 12/12°C during the night) and very strong winds (Harmattan winds) with forces often superior to 60 km/h and heavily charged with dust. This represented an important test element since the illnesses due to dust and wind in the winter Saharan season are widespread (Fig. 8 d).

Both shelter types achieved good evaluations from humanitarian operators that valuated the mounting as very simple and intuitive and appreciated the simplicity. After a quick demonstration of the mounting, the local people were able to perform the mounting by themselves, without making mistakes. The use of tensioner-provided belts also allowed a solid and quick assembling and adjustment of the tension.

After a three months’ use, the shelters are still used by beneficiaries: they are in the same state as they were when mounted, without any sign of deterioration. Users also observed that the shelters are cleanable and maintainable in a good state. The internal temperatures are acceptable thanks to the shade nets during the day and the insulation has allowed maintaining a good temperature during the night. Moreover, the mosquito net layers avoided the entrance of sand or dust inside the shelter notwithstanding Harmattan winds.

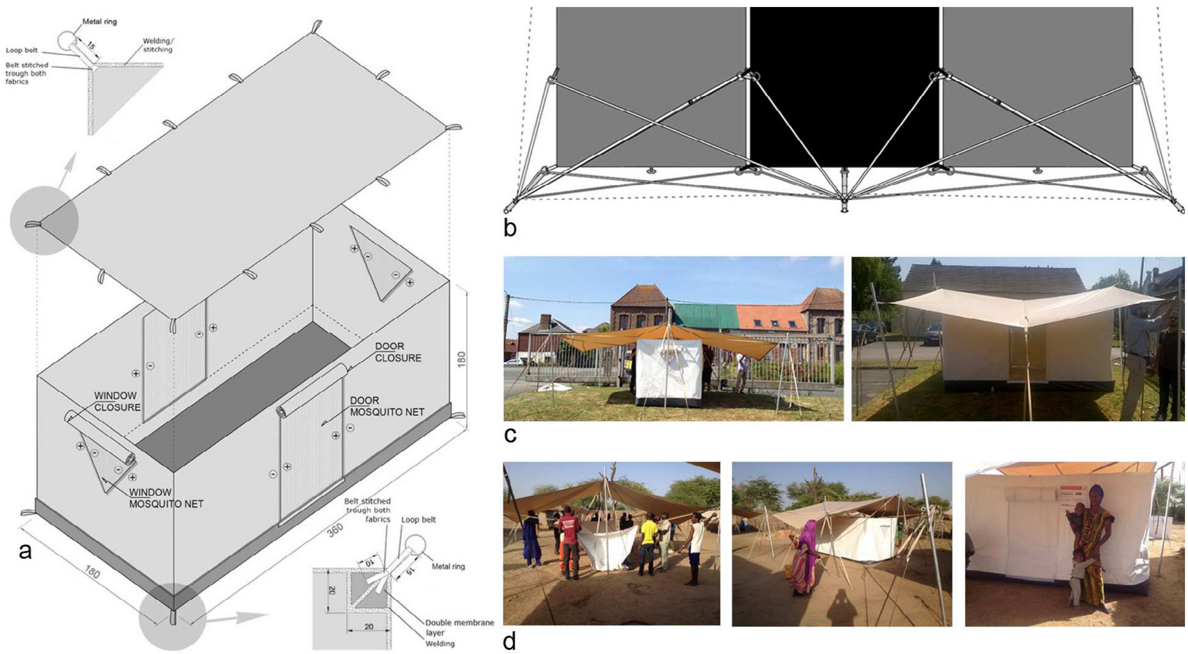


Fig.8. (a) Isometric view of final design of Cocoon; (b) belts’ layout to hang three modules; (c) Test during the S(P)EEDKITS WP2 Meeting at SIOEN-Saint Frères (July 2015); (d) S(P)EEDKITS field test in Ntiagar (Senegal)

5. Conclusion

This paper is intended to describe the design process of an adaptable shelter component for the humanitarian sector. This work is a key part of the S(P)EEDKITS research project. Within S(P)EEDKITS, POLIMI know-how in Industrial design and Architectural Technology contributed to the envisioning of a new kind of ultra-lightweight shelter and relative packaging.

For achieving the fixed goals (above all the adaptability to diverse climates and local technologies), the analysis of current literature supported the concept generation and the material selection. Moreover, the research identified a set of requirements coming from users' needs. Within the S(P)EEDKITS project, the collaboration with NGOs and manufacturers allowed to include in the design process both the real needs on the field and the current technologies in sheltering production. Metrics coming from requirements permitted a selection between diverse design concepts; finally, the most effective one was prototyped and tested on the field.

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