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Procedia Engineering 180 (2017) 1110 – 1120

Procedia Engineering

www.elsevier.com/locate/procedia

International High- Performance Built Environment Conference – A Sustainable Built Environment Conference 2016 Series (SBE16), iHBE 2016

Architecture for refugees, resilience shelter project: A case study using recycled skis

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Abstract

In emergency and post-disaster situations one of the hardest issues to deal with regards the means and materials suitable to build temporary and livable shelter. In this prospective, the following work analyze the potentiality (from technological, thermal and structural point of view) of a lightweight shelter skin composed by recycled skis, covered by a textile envelope coupled with thermal reflective multilayer insulation able to provide high-quality thermal comfort. This solution addresses different purposes: recycling high technology material, construction speed, lightness and low embodied energy. As skis are constituted by different layers of high-performances materials, that are also difficult to dismiss, their reuse reduce the CO_2 emissions and the amount of wasted material. In collaboration with the University of Grenoble, some laboratory tests have been carried out in order to investigate the mechanical properties of skis and design durable and resistant structure. The morphology of proposed shelter comes from the archetype of the Mongolian Yurt, modelled and adapted to improve energetic performances: a detailed building model has been used to perform dynamic building energy simulation. The structure is composed by 130 pair of skis with different lengths and characterized by a circular basement (6 meters of diameter) divided in 24 concentric sectors that constitute the structural axis, where are located pillars and beams made by coupling different combinations of skis. Externally two orders of circular hoops help to absorb the loads coming from the covering, and between the pillars are placed two bracing elements. At the center of the circumference a steel pillar supports the flat-roof window. A real-scale prototype has been developed in order to verify the assumptions made during the design phases. The shelter is now built and used in a humanitarian mission in Guinea Bissau.

Peer-review under responsibility of the organizing committee iHBE 2016

Keywords: Post-disaster insulation; reflective multilayer insulation; ski shelter; recycling material.

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Peer-review under responsibility of the organizing committee iHBE 2016
doi:10.1016/j.proeng.2017.04.271

1. Introduction

Many disasters exist, whether caused by natural or by human factors [1]. In the world, during the 2015, the total number of people affected by natural disasters are approximately 103 million (222.000 in Europe) [2]. In emergencies context, it is important to provide shelters to protect the population ensuring technological and psychological safety [3-4]. The massive refugee crisis that has dominated the news over the last and current year has resulted in a displaced population spread across many countries in Europe, as well as a shortage of affordable and quick-to-construct shelters. The scope of the challenge suggests the tradeoffs that arise when designing and implementing a large-scale shelter solution: how to create quick and easy buildings that are more solids and dependable than simple tents, with adequate comfort conditions. Several scientific researches concerning emergency post disaster shelter are available in literature dealing with the technological design, the adaptability and versatility of different solutions [5,9]. Only few publications focused on the reuse of recycled materials for shelter construction. The purpose of this work is to investigate the re-use of high-tech recycled materials improving thermal comfort, reducing the energy consumption with an easy assembly installation. Starting from the Ski Dome project, a geodesic dome entirely built with skis [10-11] developed by a team of researcher of the University Joseph Fourier of Grenoble, the presented work analyze the potentiality of a lightweight shelter composed by recycled skis, covered by a textile multilayer envelope. The skis are high-tech materials made up by several layers: steel plates, plastics and resins that confer high resistance and good ductility, the analysis concerning the amount of skis disposed on the Alpine Area shows approximately 1.500 tons of skis fallen into disuse every year. However, their recycle is very difficult due to the proper layers composition, the reuse option is, therefore, the achievable option. A temporary emergency shelter, called “Ski Shelter” made up by used skis and covered by a lightweight envelope composed by thermal-reflective-multilayer insulation and PVC (polyvinyl chloride) sheet, has been studied, and built in a real scale. The joint between skis has been tested, from the structural point of view, with experimental tests. The first tent prototype has been donated to the Missionaries Oblates of Mary Immaculate and it now operating in the Republic of Guinea Bissau.

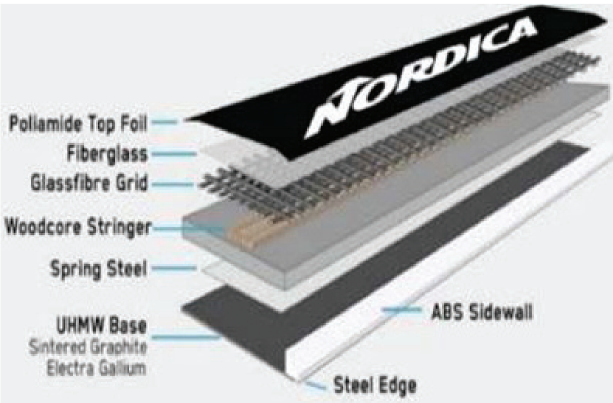
Nomenclature

R	Thermal resistance [m^2K/W]
MLI	Multi-Layer Insulator
PVC	Polyvinyl Chloride
ACH	Air Change Hour
ORT	Operative Room Temperature

1.1. Analysis of the disposal skis

In Northern Italy, the Alpine Skiing is a popular sport, the main equipment consist on skis and poles that after some season must be disposed because of delamination, splinters, cracks or other reasons. The material composition of the skis is particularly complex and they cannot be recycled easily by deconstruction: the making-up materials of a typical alpine ski are assembled in a sandwich panel, perfectly bonded together and hardly disassembled (Fig.1a). In order to get the alpine ski life-cycle data a reference ski was taken into account, which weighs 1,8 kg divided as follows: the 35% of the weight is represented by the angular steel blades, 20% by the wood core, 10% by the surface foil. The remaining 35% is mostly represented by adhesives, foams and by rubber elements [12]. Regarding the disposal, the companies take just the metal parts out, after that, the remains is shredded and burned in incinerators producing CO_2 emission. Considering the different manufactory steps the ski’s production involves a big amount of energy. The environmental impact produced by a single ski can be achieved by calculating the energy spent for each stage: processing, manufacturing, distributing, using and disposing at its end.

The Fig.1 b shows the specific profile of the Alpine Ski: the first two life cycle stages, namely raw material and manufacture, contribute most to the overall energy consumption. The distribution scenario or the use stage contribute little to the environmental impact of the product. Italy has more than 250 ski areas, with a huge amount of potential disposed skis. Most of them are located in the north of Italy i.e. in the Alps, but it is possible to go skiing in central and southern Italy too; even on Mount Etna, a volcano, which is located on the island of Sicily. Some Italian regions such as Tuscany, Emilia-Romagna and Abruzzo offer their inhabitants and tourists snow and skiing in winter. Some of the bigger ski area are located around the Alps and Lombardy region hosts the most famous location. The Fig.2 shows the number of skis sold over the period 2004-2014 in Italy: in general, the market decreased of about 50% passing from 398.189 skis of the 2004 to 182.120 skis of the 2014. The sales volume decrease with the same trend passing from 58 Million Euros to 28 Million Euros in 9 years. The amount of disposed skis remain anyway constant and around 1.500 tons every years.



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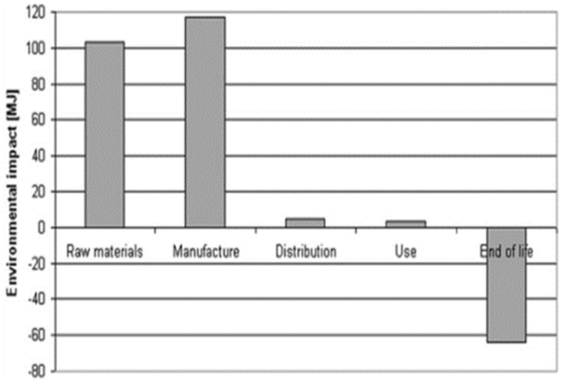


(b)

Fig. 1. (a) Sandwich Construction of a ski; (b) Environmental Impact Analysis of a ski [source: W. Wimmer, H. Ostad-Ahmad-Ghorabi, Eco-design of Alpine Skis and other Sport Equipment, Taylor & Francis Group, 2007].

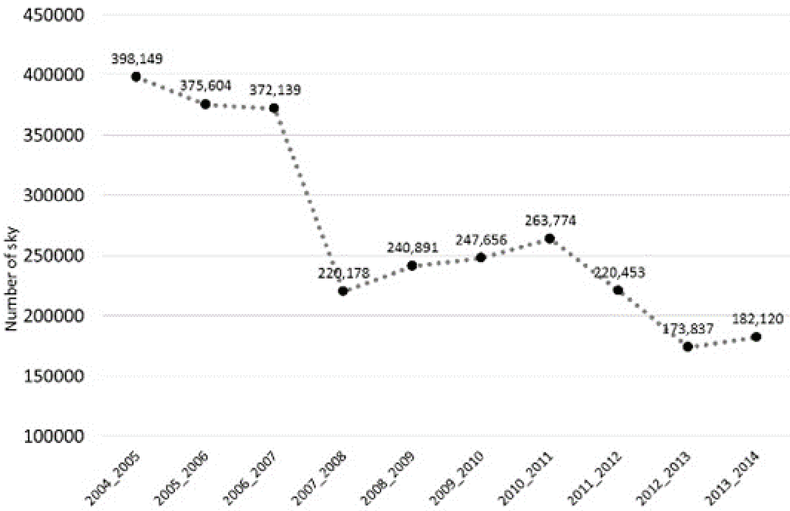


Fig. 2. Analysis of the skis sold from 2004 to 2014 [source: Pool Sci Italia [Online]. Available: http://www.poolsciitalia.com]

The prevalent part of the market is share between the Norther Alpine ski areas. In detail, the Tab. 1 summarizes the data collected through a research, carried out by the authors with questionnaire and direct interview, between March and April 2014 in five different sky area located in Lombardy Alpine area.

The interviews involved 23 ski's shop with the aims to analyze the local ski's market, the technical life of the skis and the amount of the disposal equipment. From the data collected, about 2100 skis, approximately 3 tons of high-tech material have been disposed only during the 2014 winter season. In this scenario, supported also by the environmental impact analysis, the reuses at the end of their life span represent an interesting opportunity. Furthermore, considering the high performance characteristic concerning both, the geometrical and the structural resistance, the skis can be efficiently used as structural component in the emergency shelter design.

Table 1. Analysis of ski disposal in Lombardy (Italy) [source: surveys carried out by the authors between March and April 2014].

Place (Province)	Number of ski's shop interview	Skis disposed per year
Livigno (SO)	2	900
Bormio (SO)	1	300
Ponte di Legno (BS)	3	200
Madesimo (SO)	2	200
Valle Seriana (BG)	15	500
Total	-	2100

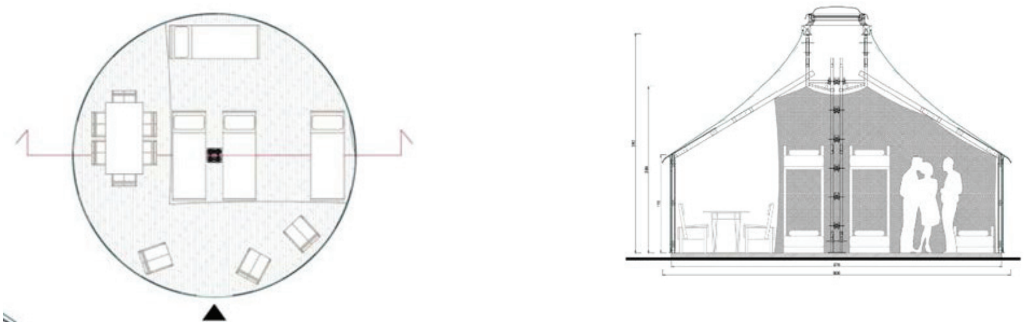
2. The Ski Shelter description

The Ski Shelter project aims to develop a tent prototype characterized by an easy assembly method, lightweight and reused materials, with the ability to maintain acceptable internal thermal comfort conditions. The basic design started from the archetype of the Mongolian yurt, revised in some aspects in order to optimize the use and the connection of the specific materials: the skis and the multi-layers envelope. A regular grid composes the architectural scheme: 24 concentric axes, represented by beams and pillars, divide the circular base. At the center of the room, a pillar composed by reused standard steel elements for building scaffolding supports the openable 80,0 x 80,0 cm skylight. Linear assembly of several skis constitutes the beams and pillars, the tips of each skis have been previously modified, according to the structural design. The skis have been assembled together to create composite beams and pillars, increasing the inertia and stability, local and global. The joints between skis were reinforced with wood spacer elements.

Table 2. Geometry description of a standard module Ski Shelter.

Diameter of the plan	6,00 m
Total floor area	28,26 m^2
Minimum internal height	2,63 m
Maximum external height	2,97 m
External height	4,91 m
Total storage volume	62,36 m^2
Skis used	260,00

The total structure has a diameter of 6,0 m, which covers an area of approximately 30,0 m^2 (Fig. 3 a,b). The internal height is equal to 1,70 m at the lowest point and 3,80 m in the center of the building area. The shelter is modular and the number of units are potentially implementable according to emergency situation requirements: the coupling of multiple Sky Shelter allows a variation of the spaces reaching variable housing dimensions. The pitched roof has been designed with a modification of the classic yurt tent in order to maximize the "chimney effect" and improve natural ventilation effect with increased thermal comfort. The building envelope has been made by textile material coupled with different functional layers (Fig 4 a, b). In particular, the envelope system is composed by a multilayer technology that consists in a double PVC layer, both outside and inside, with thermo-reflective insulation system interposed in between. The materials used are readily available on the market, characterized by high performance, lightweight and easily recyclable at the end of their life span.



(a) (b)

Fig. 3. (a) Horizontal section of a standard Ski Shelter; (b) Vertical section of a standard Ski Shelter.

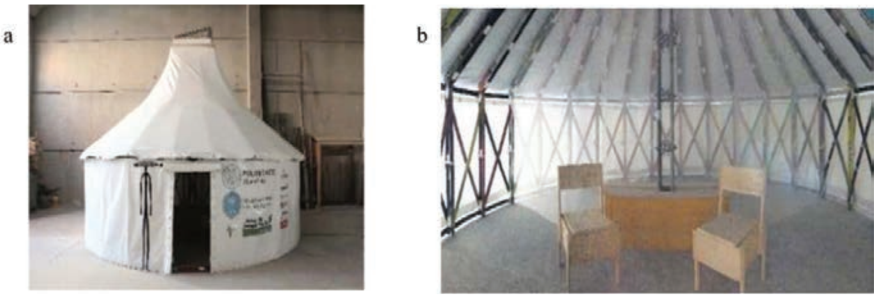


Fig. 4. (a) Photo of the full-scale prototype of the Ski Shelter; (b) Photo of the interior of the Ski Shelter.

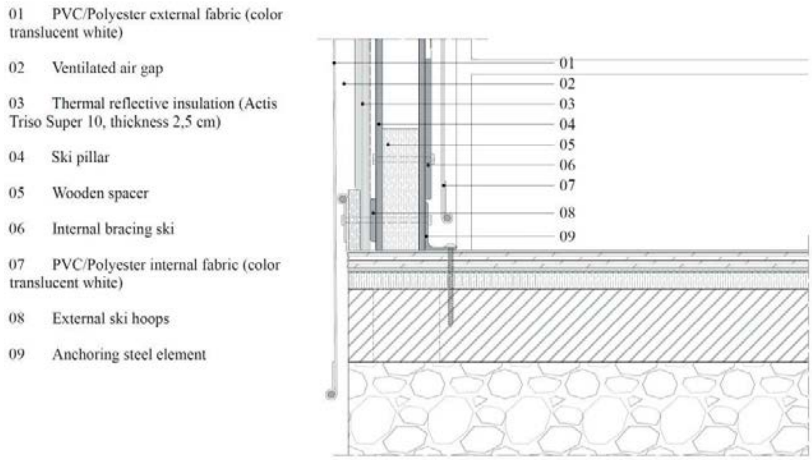
2.1. Technological design and materials

As mentioned in the previous section the envelope of the Ski Shelter is composed by several layers, each one with its specific functionality in order to ensure good internal comfort conditions reducing the fuel consumption during the winter season. The technological solutions of the Ski Shelter do not require special a in situ, and respect the requirements typical of the emergency structure, such as flexibility, portability, lightness, quick installation process and durability. The superficial layer has been made up from a polyester/PVC material, which is characterized by a translucency value of about 0,8 to 4,0 % and with high resistance. This material has good fire resistance and low specific weight (1450,0 g/m^2). Currently polyester/PVC is the material most commonly used in architecture since it provides a good balance between cost, performance and durability (the average life span is between 7 and 15 years). The textile material also has high strength and good elasticity; the main characteristics are summarized in the following Table 3 [13].

Table 3. Technical features of Polyester/PVC [9].

Technical features of Polyester/PVC	
Useful life	7-15 years
Resistance	9800 N/cm
Elongation at break	20-30%
Translucency	8-25%
Flash	Class C
Toxicity	Yes, emission of toxic fumes
Material cost	40€/m^2

The thermal resistance to the heat transfer is given by the presence of the reflective multilayer insulation (MLI), material already tested by different research study [14, 16]. This material is a thermal insulation composed by multiple layers of thin sheets developed mainly for spacecraft. It is commonly used on satellites and other applications in vacuum where conduction and convection are much less significant and radiation dominates. In general, the material consist of a series of reflective films covered by a material with low emissivity such as aluminum films and reflective plastic films. Since about 30 years, these materials have been introduced in the building, where they are able to effectively solve, and in an innovative manner the problem of thermal insulation, acting in all the heat transfer directions. The MLI used in the present study is the ACTIS TRISO Super 10 multilayer [17]. It is composed by synthetic material such as wadding sheets or plastic material; and natural fibers, such as wool of sheep. The combination of these thin materials, arranged in succession to one another, gives great results in terms of thermal performances: in winter, it prevents the heat flow from inside to outside and in summer, when the radiative component of the external thermal load is bigger than the conductive and convective one, it reduce the heat flow from outside. The Fig. 5 shows the technological details of the Ski Shelter: the connection between ground and skis and between vertical wall and roof structure.



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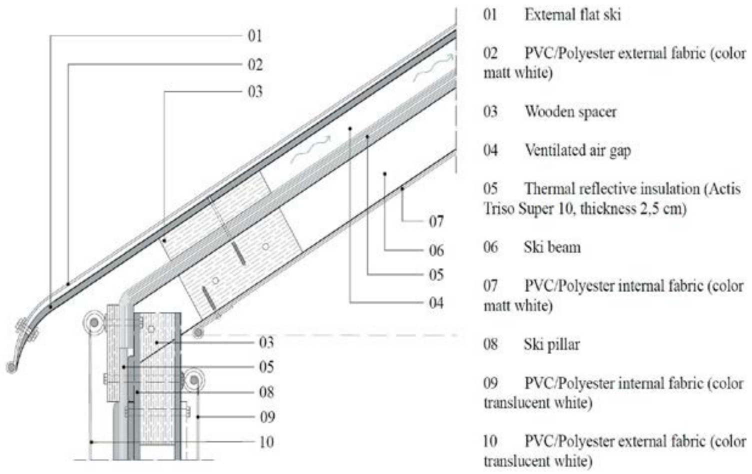
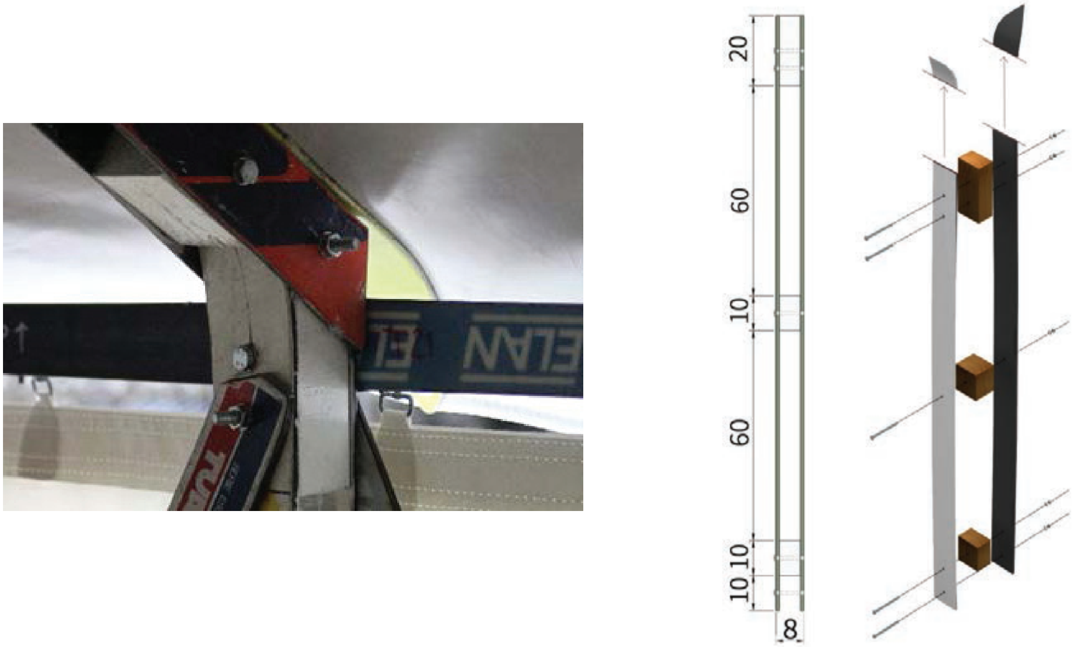


(b)

Fig. 5. (a) Constructive detail of the connection to ground; (b) Constructive detail of the connection of the wall-roof.

2.2. Structural design and testing procedure

The Sky shelter geometry confers a great mechanical resistance to elements that holds limited dimensions. As mentioned in the Section 2 the single unit Ski Shelter is built on the basis of a circular divided into 24 concentric and equidistant axes following an angle of 15°. In the center the pillar sustains a sort of “crown” which acts as a support for the roof window and the other structural elements that converge on it. To each axis corresponds a composite “ski beam” tilted by 30°, which is anchored to the “crown” at the top and to the “ski pillar edge” at the bottom (Fig.6). At both points, the type of joint does not transfer shearing actions or bending moment (hinge behavior). Different diagonal skis contribute to withstand the horizontal forces. In the end, the horizontal stress coming from the beams are absorbed by two orders of “ski hoops” placed one on the top and one on at the base of the pillars edge. Again, these joints are discretized as three-dimensional hinges. All the nodes of the structure has been connected together by threaded steel bolts.

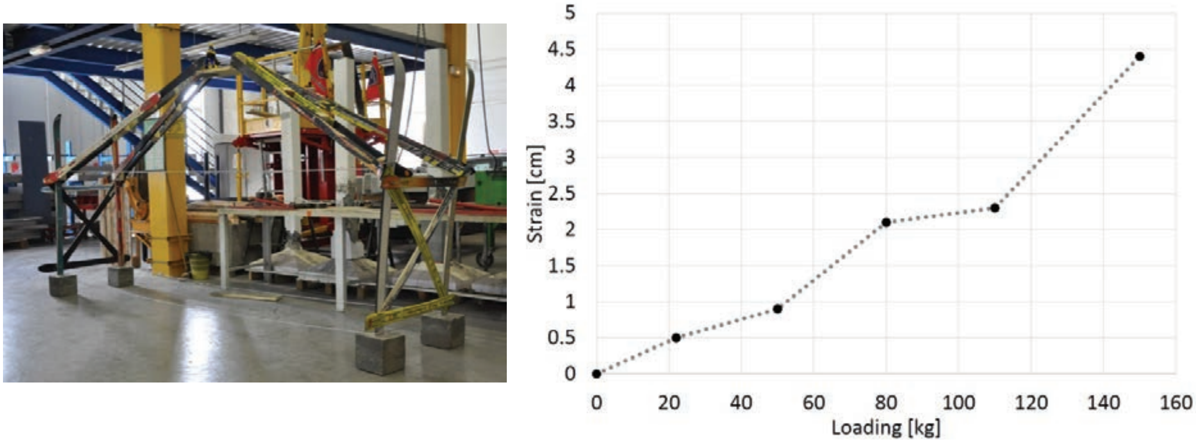


(a) (b)

Fig. 6. (a) Assembly of the connections beam-pillar; (b) Assembly scheme of the pillar.

In 2015, together with Politecnico di Milano, Italy and Joseph Fourier University of Grenoble, France, the laboratory load tests were performed in a real scale model, which reproduces a section of the structure composed by 4 beams and 4 pillars arranged in a specular way (Fig. 7 a-b). In order to test the most stressed configuration the central pillar has not been applied in the tested sample.

The different structural elements were connected using galvanized steel bolts having M10 diameter. The load was applied by hanging gradually, at the center of the structure, different concrete specimens up to a maximum of 1.5 kN. Before reaching the situation of breakage, it was also measured the deformation of the different elements, in particular the horizontal displacement of the top of the pillars (Fig.7). The graph of Fig. 7b shows the elastic behavior of the tested sample: removing the load the whole model returned into its initial position. The structure, subjected to a maximum load of 150 kg, shows a bent equal to 4.5 cm for each side.



(a) (b)

Fig. 7. (a) Photo of the load tests on a scale model of the Ski Shelter in the University of Grenoble. (b) Chart about the test on load and strain of Ski Shelter structure [source: K. Jalesse, R. Wauthy, A. Diagne, Innovation et Développement Durable dans les formations GC: Conception collaborative et normative pour l'habitat d'urgence, réalisation d'une yurte en skis usages, Grenoble: Joseph Fourier University, 2015].

3. Building energy simulation

3.1. Simulation model description

The tent prototype has been also analyzed by dynamic thermal analyses performed with Trnsys v.17 Environment [18]. The geometrical model (Fig.8) has been modeled in Trnsys3d [18], plugin for Google ScktechUp by referring to the dimension indicated in and Table 4.

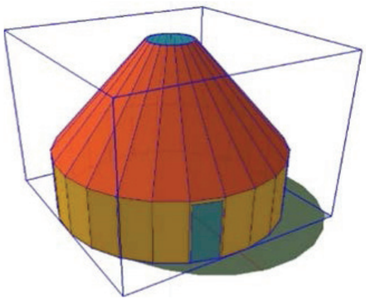


Fig. 8. Three-dimensional model used for the simulation, consisting of a single thermal zone that represents the total external volume of the construction.

Because of the simple geometry of the Sky Shelter, the internal space has been modelled as a homogenous thermal zone with a total volume of 83.15 m^3. The "wall" and "roof" are implemented in the type 56 considering a solar absorbance coefficient of 0.4 (clear colour) and the convective heat transfer coefficients has been set equal to 3,0 W/(m^2 °C) for internal surfaces and 17,8 W/(m^2 °C) for the external ones. The ground floor has been model considering the direct contact between ground and the internal zone. The model allow predicting the internal temperature for free-running operation and the ideal heating/cooling demand to maintain an internal temperature respectively of 19°C and 26°C. The simulation has been performed considering the climate of Palermo, Sicily characterized by high ambient air temperature in summer with high solar heat gains. The thermal performance of the fabric conductance materials used in the simulation model are summarized in the Table 5.

Table 4. Geometric characteristics of the model simulated through the software TRNSYS v.17.

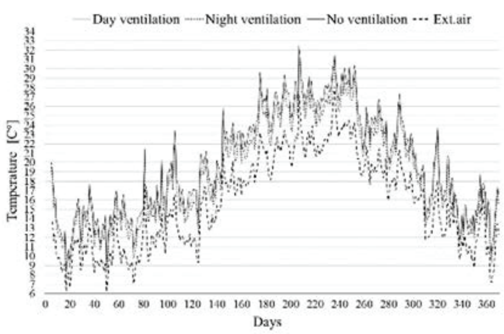
	Area [m^2]	Volume [m^3]
Floor area/volume	26,85	83,15
Vertical surface	33,84	-
Oblique surface	43,15	-
Transparent surface	2,26	-

3.2. Simulation results

The Fig. 9a and Fig. 9b shows the Sky Shelter room temperature level considering different ventilation strategies and the presence of four user during the nighttime (8:00 pm to 8:00 am) and one user during the daytime (10:00 am 14:00 pm). Changing from day ventilation (3 ach from 8:00 am to 8:00 pm) to night ventilation (3 ach from 10:00 pm to 8:00 am) there is no a relevant reduction of the temperature level mainly due to the low thermal inertia of the structure. In general, intensive ventilation strategies allow increasing the internal comfort conditions.

Table 5. Features of the elements that make up the multilayer technology.

	Thickness [mm]	R [m^2K/W]
WALL/ROOF (R_{tot} = 5,538 m^2K/W)		
R_{si}		0,131
Internal envelope in Polyester/Pvc	1,20	0,006
Air gap	60	0,182
Insulation ACTIS TRISO SUPER 10	25	5
External envelope in Polyester/Pvc	30	0,176
R_{se}		0,038
BASEMENT (R_{tot} = 3,768 m^2K/W)		
R_{si}		0,171
Internal envelope in Polyester/Pvc	1,20	0,006
Background slab	25	0,834
Insulation ACTIS TRISO SOLS	7	2,5
OSB Panel	28	0,215
R_{se}		0,038



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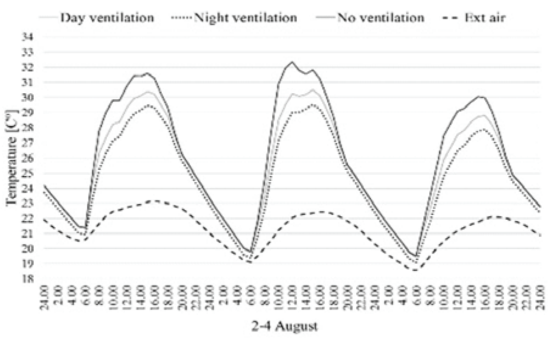
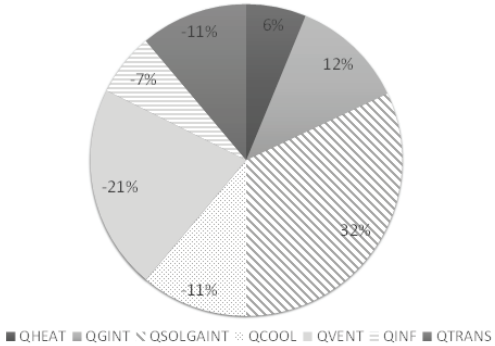


(b)

Fig. 9. (a) Annual profile of the average daily temperatures. (b) Hourly temperatures profile during between two and four August.



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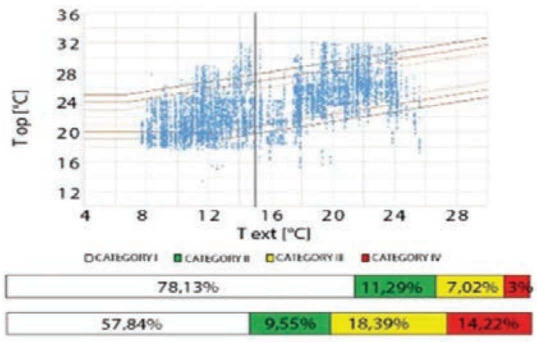

(b)

Fig. 10. (a) Annual energy balance [kWh]. (b) Annual thermal comfort expectation according to EN ISO 15251.

4. Conclusions

The presented work demonstrate how disposed sky can be reused for emergency architectures, in agreement with the emergency shelter features: the Sky Shelter confirm the design of a habitable covered living space, secure, comfortable and healthy. Modularity and simply connection between different components guarantee an easy transport, assembly and maintenance by local people without specific tools. These characteristics, moreover, are in agreement with the need to adapt shelters to different culture, local tradition, function and achieve or to support a durable shelter solution in the future. Between July and September 2015 took place the construction of a full-scale prototype of the Ski Shelter's structure. The construction took 4 working days in the month of July to the assembly of the skis for the individual structural elements, such as beams and corner pillars. Then, it was required additional 5 days in September to assembly the whole structure. The working team was composed of an average of four people, two of them skilled workers and two students. The shelter was then taken apart in half a day, packed and loaded in a container ready for the Guinea Bissau. There has been rebuilt, by the local population, as a base camp for the new mission center for the Village of Cacine coordinated by the Oblate Fathers of Mary Immaculate [21] (Fig. 11 a, b). The first objective of the research was to demonstrate the ability to effectively reuse skis for the shelter construction units. The second was to demonstrate, with a real scale test, the quick and easy assembly method. Moreover throughout structural tests has been verify how the prototype is more solid and dependable than simple tents.

a

b

Fig. 11. (a) (b) Construction stages of the Ski Shelter in the village of Cacine in Guinea Bissau. [Source: Umanitarian Mission of Oblate Fathers of Mary Immaculate].

The building simulation shows also acceptable internal comfort conditions in hot climate. The presented project is a starting point for further improvement mainly on the envelope optimization.

Acknowledgements

The authors want to thank the students and the professors of the ESPE, School of building construction of Lecco, Italy for hosting and helping the research team during the installation tests.

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