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Air Shelter House technology and its application to shelter units: the case of Scaffold House and Cardboard Shelter installations.

Marco Imperadori[a], Graziano Salvalai[a], Cristina Pusceddu[a]*

[a]*Politecnico di Milano, Via Ponzio 31, Milano 20133, Italy*

Abstract

Lightweight insulations, as a Thermal Reflective Multi-layer System (TRMS), are a fast and useful answer for temporary shelter. Developed from a space suit and with a conductivity of 0,038 W/mK, this system can ensure high thermal performance in combination with an easy transport, assembly and modular design. The present paper highlight the potential of the use of this material in different experimental shelter, as building component: the case of the Scaffold House and Cardboard Shelters. The combination of TRMS building elements is a technological skin, which is constitute from modular panels made by TRM, polyester and vulcanized rubber, called Air Shelter House (ASH). The Scaffold House is made by scaffold, traditional TRMS and sandwich panels. It is a modular system easy to assembly thanks to the simple technology used, which can help the self-construction and maintenance by the users. To improve the processes of housing installation, ensuring thermal performance, the envelope is changing with a new composition of ASH system and sandwich panels. In this way, it is possible to increase the construction processes and deconstruction, in agreement with internal comfort, modularity of units, transport and possible reuse of the shelter in different contest. The plurality of plants functions (as a private house or as a public use), already studied for the internal disposition of the different modules, are still guaranteed from the small thickness of 65 mm of the ASH technology. The system, moreover, it is study in combination with cardboard shelter. This unit is designed with this economical materials used in an innovative way, assembling different layers of paper, compressed by steel bars and coated with gypsum plaster. This new envelope is closed on the top by ASH panel roof, which is lightweight, waterproof and thermal resistance in the same time. Modularity of wall and ASH panels guarantee the construction of flexible plants to adapt in different contest. The results are both a thermal, waterproof and resistance housing system which is optimized to have a faster assembly, disassembly, transport, and a large number of modularity combination, according with response phase after disaster, and shelter features.

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* Corresponding author. *Email address*: cristina.pusceddu@polimi.it

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1. Introduction

The Thermal Reflective Multilayer System (TRMS) is an insulation method developed from aerospace suit as explained by Li and Cheng (2006).

TRMS is the result of the combination between Thermal Reflective Multilayer insulation (TRM) and air layers, located in both material sides. TRM is composed from different types of films, which alternates aluminum foils with different materials as a polyethylene, foam, wadding or sheep wool (Fig.1).

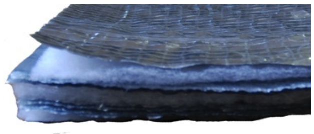

Fig. 1. TRM insulation composition.

When TRMS is installed in building cavities, it traps air and reduces heat flow by convection, thus addressing all three modes of heat transfer. RIMA-I (2002) suggests that reflective insulation is a non-toxic, user and building owner and environmentally safe building material. In addition, the products are typically recyclable and thus can be termed a Green Building Material. Another advantage is that the reflective insulation can also serve as a high performance and thus effective vapor barrier. The system works by holding the heat inside the building during the winter, and preventing internal heating during the summer, with a thermal conductivity of 0,038 W/mk, as is reported by Imperadori et al. (2013). Guo et al. (2012) state that especially during the summer is performances are better; it can roughly be derived that the annual air-conditioning saving is about 5,8 kWh/(m^2-months). These performances are in according with Transitional Shelter (TS) properties.

TS is an housing solution which "provides a habitable covered living space and a secure, healthy living environment, with privacy and dignity, to those within it, during the period between a conflict or natural disaster and the achievement of a durable shelter solution." Corseillis & Vitale (2005) explain as in the definition. Considering the data from EM-DATA (2013), and iDMC (2013), the number of disasters which are hitting the worldwide is around 8314, and the estimated number of displaced people is 143,9 million, from 2008 to 2012, in 125 countries worldwide. These numbers indicate that design of appropriates TS became a priority. Technologies, de fact, could be a suitable instrument to ensure an appropriate design for response and recovery phases.

TS, indeed, should be durable enough to last the entire transition period, should be able to be upgraded or relocated to different sites, and should use simple techniques and rapid construction methods appropriate to the environment and community with which it is being implemented (Shelter Centre 2009).

In the same way, TRMS could provide a durability around 10 years, a modularity implement to be adapt to different size and structure, lightweight and flexibility to be easy transport and assembly.

Thermal performance, moreover, may contribute to decrease energy demand from building, which is significant at the global level; in the U.S. space heating and cooling, which combined account for 54% of site energy consumption and 43% of primary energy consumption, drive residential energy demand. U.S. (Department of Energy 2012).

1.1. Air Shelter House building element

The Air Shelter House (ASH) is a housing unit composed by building modular elements. These panels are made using the TRMS, ensembles with rubber and polyester membrane, which are common, lightweight and low cost materials. Air gaps inside TRMS are around 20 mm thick, in fact, a thickness larger than 25 mm may cause convective mote, as indicated in the studies of Seriacaroupin et al. (2007). Polyester contains the two air gaps, which is insufflated through valves placed in each panel. The ASH can be used as a:

- Shelter or emergency tent, with an adequate pipe structure (Fig. 2a);
- Internal/external thermal skin, to adapt to different kind of structure, and in combination with other envelope technologies (both according to local traditions), or to improve performance of single buildings elements as roof, floor, walls, etc. (Fig. 2b).

a b

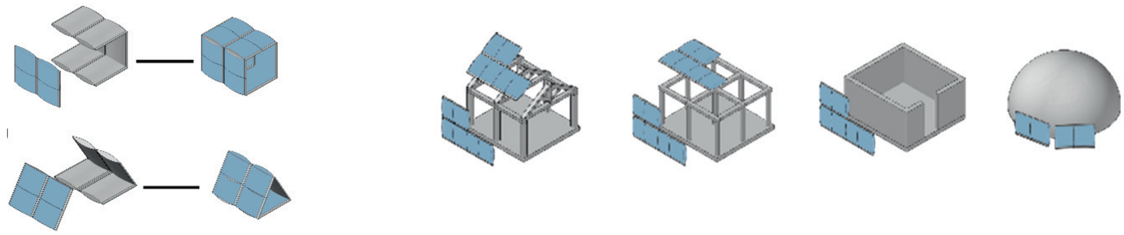

Fig. 2. (a) Tent application; (b) Thermal skin application.

The standard panel dimensions of 0,80 x 1,35 x 0,65 m is chosen in agreement with ISO 6346:1995 concerning containers code, size and type for intermodal shipping containers. Thus, general building element could be package for an easy transport.

Anyway, modularity of panel component allows adapting the element size to different situation, according to the project parameters. The adaptability of the element are ensured by the modularity of the joints too. As shown in the Fig.3 the panel could be connected with different kind of structure, in the horizontal and vertical way, through common technologies in a flexible way.

a b

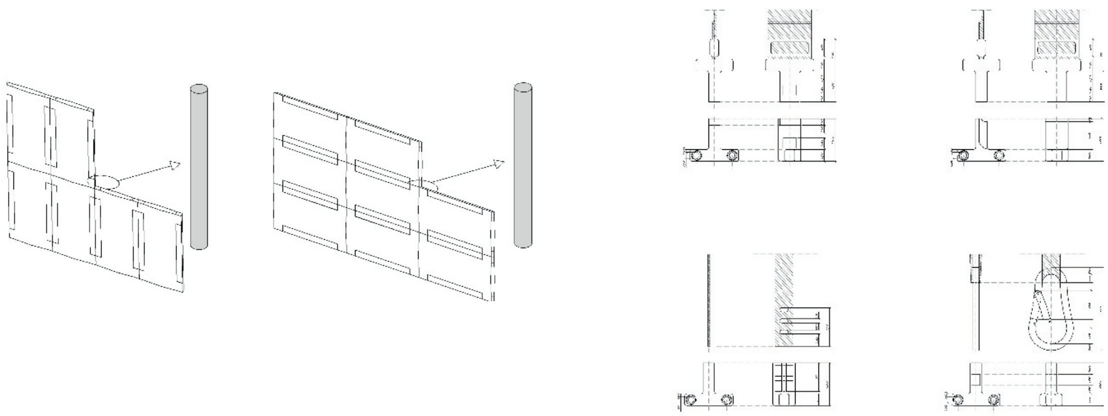

Fig. 3. (a) Vertical/Horizontal application; (b) Nylon joints with structure.

The simplicity of the systems allows a fast assembly of ASH technology, by also no skilled workers.

Rubber, nylon and polyester materials design joints. Connection with the structure are ensured through nylon element connected with elastic bands. Polyester joints between panels are secured through strips of 100 mm, and zippers or snaps connection.

In the traditional application, as shown in the guideline ACTIS(2010), TRMS is mounted inside or external the bearing structure with the support of wooden posts with staples or galvanized steel around 14 mm /20 mm overlapping the foils for 50–100mm. In this way, TRMS requires a skilled labor and some days for the application.

ASH panel allows application of the system as a normal insulation panel. The support structure for TRMS is inside the panel, and can be apply only with simple joints.

Packages also could be applied only by 5 easy steps, where movable nylon joint and air are removed, and the panel is rolled to have a cylinder of 0,26 x 1,15 x 0,21 m, easy to transport.

Two case studies are showing to demonstrate possible application of ASH system. The use as a thermal skin it is described in the case study of "Scaffold House". It is a modular house unit made by scaffold for emergency and development areas, where the ASH technology is applied as an internal insulation.

The application as a single panel, to improve thermal performance of single building element, is presented in the second case, the "Cardboard Shelter". ASH panel is used in combination with recyclable and common material, used in an innovative way (cardboard) to improve technological performance of the roof.

Both cases are the example as the new building component could enhance the assembly, transport of the units, according with users, psychological and technological performances

2. Case study 1: Scaffold House

The Scaffold House is a housing unit projected with materials already present in the market, but used in an innovative way.

The design comes from a final project from Politecnico di Milano students, Azzolini et al. (2012), afterwards it was has been most thoroughly investigated in collaboration with companies, though also workshop experience presented in the Fig.3a.

a **b**

Fig. 3. (a) Scaffold House Workshop; (b) Visual Scaffold House. Azzolini et al (2012)

The scaffold multy-level system design the units, which have single module of 17,50 m^2. The frame is repeated any 1,140 m and is anchored to the ground through precast concrete plinths, which guarantee stability. Any modules could be coordinated each other, the assembly of the structure was verified during the workshop, and is composed of simple steps. The mounting is possible with simple tools, readily available, and by 10 persons for one day, as the process shown in Fig. 4.

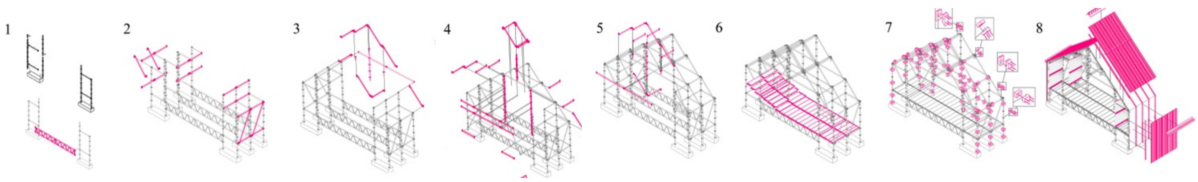

Fig. 4. Scaffold House assembly process.

Considering possible internal function, the envelope is studied to guarantee thermal performance, to ensure internal comfort for users, and energy saving according with energy future consumption and a sustainable development.

In the first study, the envelope was designed with various layers, generally compose by twice: external coating, TRMS applied in the traditional way, and OSB panel, with the tubes structure in the middle.

During the prototype construction process, a sandwich panel envelope was experienced, as a faster and flexible new solution. Considering positive performance of the panel as envelope technology to use, the design proceeded with a design where there are externally a sandwich panel skin, and internally the ASH system. The insulation system, in this way became easy to assembly and compose by only two different elements; four less of the original version, as show in the Fig.5.

a b

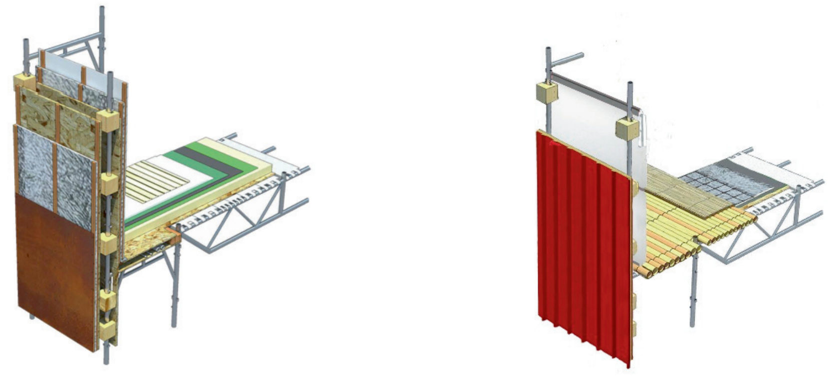

Fig. 5. (a) First envelope design. Azzolini et al. 2012); (b) New envelope design.

Panel sandwich has a polyurethane insulation and an external steel coating. It has a weight of 12, 92 kg/m^2 and a thermal conductivity of 0,17 W/m^{2}K. (Marcegaglia, 2012).

The ASH has a weight of 0,562 kg/m2 and a thermal conductivity around 0, 67 W/m^{2}K, in the section where there is the TRMS. Both skin can ensure a high thermal performance in a practice way. Easy connection and lightweight of ASH can be in agreement with the timing recorded during the workshop, and with the features to be assembly without specific tools. Design flexibility of the panel and joints allows adapting the system to this already design structure, optimizing the building process to be in agreement with the emergency needs of a fast and easy assembly; and internal comfort, as indicates to the Shelter Centre (2009).

Scaffold House is an example where the ASH could be a shelter inside a shelter, which should be disassembled at any time, without compromise the all system and reuse in another contest. Adaptability also allow the use with recyclable materials as scaffold, supporting the use in an innovative way.

The system made by panels, moreover, ensure to tie the envelope to the structure strengthening the all wall, in case of quake (ISDR et al., 2007). In this way the ASH technology, used as a internal shelter, ensure an safer system, which is tied into the column and lightweight. Probability that the wall panel could move away it is lower, and lightweight ensure to have damages content, in case of failure.

3. Case study 2: Cardboard House

Cardboard House (CH) is an emergency shelter designed by a team of students of Politecnico di Milano for an academic project. The work-study, presently, is still ongoing in collaboration with several companies.

The purpose of this research is to provide a new shelter prototype with a medium/short lifetime, which allows being resilient, for this purpose, the cardboard was chosen as a good compromise between sustainability of its production process, and its lifetime. The structural technology of this shelter can be analyzed in two main components: walls and roof. The cardboard of each component is used in a specific way, because of the different properties and performances on target. Walls are made by overlapping cardboard layers cut in different dimensions, this technique helps to avoid the establishment of linear ruts: each layer is disposed between two slabs of wood, and totally crossed by steel rods. This system generates compression on the cardboard layers between the wood slabs creating a single homogeneous volume globally solid and rigid. Cardboard panels on the roof, taking advantage of their rigidity, are located slots in an orthogonal position; they work as framework and create a volume globally solid.

All the shapes, used for walls and roof (Fig.6), are optimized to be cut in the easiest way from a cardboard sheet with a dimension of 250 x 180 cm.

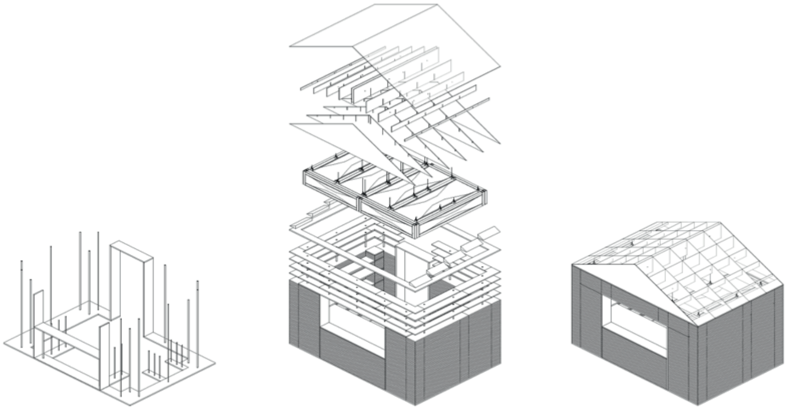

Fig. 6. Cardboard shelter structure process.

The different system on the roof cannot use the air in the cardboard as insulation component, because of the framework and not massive structure. In order to improve the thermal performance, therefore, the ASH panel was added on the internal side of the roof. Because of the different lifetimes between CH structure and

ASH panel a reversible system of assembling was studied, and the ASH panels are disposed as a soft false ceiling hanging by nylon treads and metal clips.

In the CH walls systems, in the contrary, the first transmittance estimated is around 0,25 W/m^2K, for 25 cm of thickness: the insulation performance is totally on the halted air between the cardboard waves. Thermal performance suggests to do not use ASH technology for the vertical components too, saving internal space for users. A thermic analysis realized by the finite element method is shown in Fig.7.

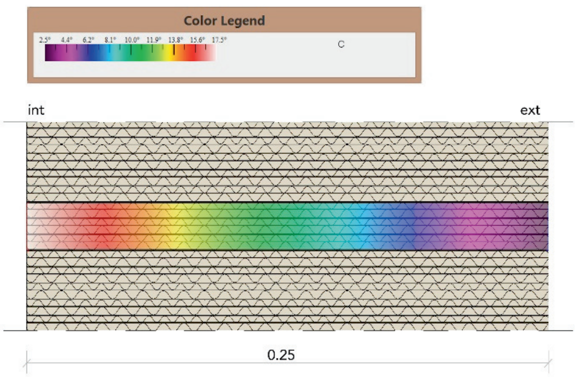

Fig. 7. Thermal perform analysis with temperature profile.

One of the advantages to adapt ASH panels are design and lightness ensure by the system, which allows to assemble the entire layer before to be matched to the roof: in this case, the laying starts from the central axis, goes on until the intersection between wall and roof and then goes down alongside of walls for 37 cm. Here the panels are bottomed up to the wall in a hermetic way (Fig. 8).

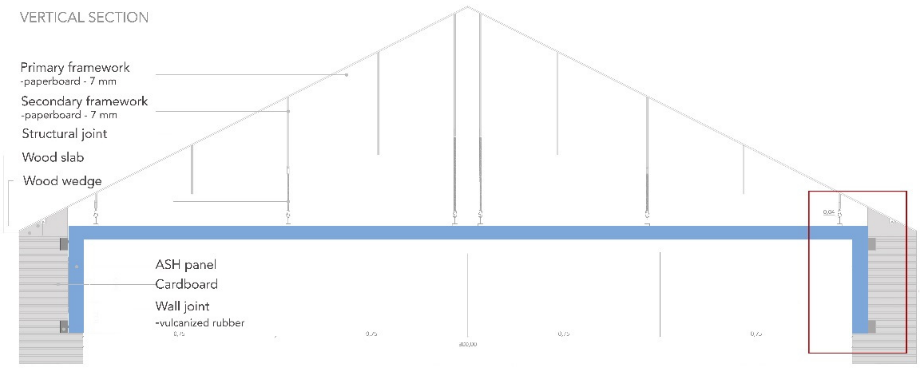

Fig. 8. Technological section of the roof.

This solution considers the idea of disassemble the ASH panel once Cardboard structure has to be dismantle for recycling and reused without any maintenances in others or new contexts. The application of the AHS system optimizes thermal performance of the shelter, and internal comfort too, without compromise the internal space in a safe way.

The use of ASH panel provides thermal performances to the shelter roof in a flexible way.

A traditional rigid insulation would produce several conditions in term of global rigidity of the structure and vibration's transmission: the lightness of the system is properly apt to a light structure as the Cardboard House one assuring a good behavior also in earthquake situations.

Furthermore, has to be considered that ASH layers are made by recycled and recyclables materials, so that they can be disassembled and reused in other different context, according to the different performances required.

In this context the ASH panel comply the characteristic of adaptability from a simple shelter to a technological element of permanent buildings, as designated by Shelter Centre (2009), and Temporary Shelter definition by Corseillis and Vitale (2005).

4. Conclusion

Twice cases of ASH panel application show the ability of the building component to adapt to different structure, location and function, in agreement with shelter features.

The first case of Scaffold House present the use of the system as a "shelter inside a shelter", improving thermal and structure performance of the unit. The envelope is modified using the ASH as internal coating. Thermal performance of the envelope are still guarantee, supported with sandwich panels in the external side. New envelope became more flexible and easy to apply. Building application, in fact, is reduce to the simple practice of connection between the components, through polyester and rubber joints; and between panels and structure thanks to the nylon links. Variability of panels dimensions allows important features to adapt to the structure already designed, and lightweight ensure an easy transport which is stated by Shelter Centre (2009). These last characteristics, moreover, guarantee to tie the envelope to the columns, preventing division during earthquake as it is described from ISDR et all (2007); and to limit damage in case of failure.

In the second case of Cardboard Shelter, the ASH is decomposed, and the single panels is used to optimized thermal performance of single building components as the roof.

Design, as an independent system of ASH panel insulation for the roof, enables to assemble and disassemble the scheme with a wide degree of freedom, important features for the maintenance phases. Modularity and simplicity of the panels and the joints allows an easy assembly of the elements, without specific tools and by unskilled workers, as in the case of Scaffold House too. A weight of 0,562 kg/m^2 of elements is in agreement with the structure material, cardboard, ensuring a lightweight system, which should be safer during quake. This second case is an example where ASH could be also a part of different or permanent housing system, to guarantee a complete life cycle, in agreement always with Shelter Centre (2009).

Starting from the shelter definition of Corseillis & Vitale (2005), the ASH confirms the design of a habitable covered living space and a secure, healthy living location with privacy and dignity, thanks to the thermal performance and lightweight of the system. Modularity and simply connection between the different components guarantee an easy transport, assembly and maintenance by local people and without specific tools. These characteristics, moreover, are in agreement with the need to adapt shelters to different culture, local tradition, function and to achieve or to support a durable shelter solution in the future.

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