Thermal-reflective multilayer insulation systems in the emergency architecture: the Air Shelter Skin.

MARCO IMPERADORI¹, PUSCEDDU CRISTINA², GRAZIANO SALVALAI³

1 Department of Architecture, Built environment and Construction Engineering, Politecnico di Milano, Milano, Italy 2 Department of Architecture, Built environment and Construction Engineering, Politecnico di Milano, Milano, Italy 3 Department of Architecture, Built environment and Construction Engineering, Politecnico di Milano, Milano, Italy

ABSTRACT: It has been estimated that 14,9 million of people are forced by natural disaster to flee or leave their houses worldwide in 2011. During the emergency processes transitional shelter helps to cover the gap between the immediate temporary emergency and the time to reconstruct individual house or durable solutions. However, main difficulties of this solution are related to the assembly time, cost and to the thermal comfort conditions. A good temporary shelter need to be light, resistant, practical, modular and above have to guarantee good thermal comfort with very low or even absent supply energy. To answer to this needs a lightweight material, as a thermo-reflective multi-layer insulations (TRMI), can be coupled with a structural material ensuring high thermal features in a flexible way. This innovative insulation system, become a viable way to reduce energy consumption and thereby improve thermal comfort providing the psychological need of private space. The presented paper firstly gives an overview on the state of the art of different TRMI and secondly, describes the thermal properties and the technology of the new element called "Air shelter skin". This experimental product can be applied on each supporting type structure to improve the shelter's thermal insulation and provide waterproof protection to different house systems. *Keywords: Shelter, TRM, Lightweight, Emergency.*

INTRODUCTION

In last years the total number of people displaced in the world has remained roughly constant at approximately 15 million refugees and a further 25 million internally. [1]

Disaster-affected households should no longer be treated as liabilities. This has significant implications on recommended approaches to post-disaster shelter and to the survivors of these crises must be given every opportunity to engage in their own recovery.

SHELTER FEATURES

In the post-disaster activities it is possible recognise three major phases: Response and Relief (0-35 days), Recovery (days to months) and Reconstruction (months to years). In particular in these first and second phases it is important to stabilize the situation. Transitional shelter, therefore, is part of a process covering the spectrum from immediate temporary/emergency shelter following displacement through the time an individual's house is reconstructed or a durable solution is found. Problems in this process is that temporary solutions become, actual, permanent ones without appropriate requirement. For this reason it is important that the cultural, social and economic norms of the specific disaster-affected societies must be reflected in shelter and, therefore the design are based to rapid and cost effective solution can also be culturally acceptable to the populations. Considering these needs this temporary architectural building element have to be: Lightweight, an easy to assemble and transport shelter allow to be faster in the construction phase and react to emergency situation; Resistance, the reconstruction can take years, or decades, and transitional shelter needs to be designed to potentially last as long as the permanent solution is achieved; Ductile, the best designs allow the household to upgrade or incorporate the shelter materials into the permanent reconstruction. Allow families to return to their homes because they are mobile and flexible, or both; Practical, to minimize the distance from former and future homes and minimize the duration of displacement, allowing people to better maintain their livelihoods and protect their land, property, and possessions; Modular, to create a sense of community among displaced families at the temporary settlement(s) helps to avoid conflicts and discontent; According with culture, degree of acceptability and ownership by displaced communities determines a successful outcome of a transitional shelter program coordinated with population's participation and with local needs and customs taken into consideration. [1,2] To answer to these requests the design explore the lightweight material as a thermo reflective multilayer insulations for their high thermal features in a flexible way. The features of this materials, in fact, are totally in agreement with shelter parameters, in this way thermal, psychological and construction performance are ensured by this lightweight, resistance, ductile, practical, modular system, adaptable to different kind of structure from local culture (refer to in Fig. 1). Literature already shows example of Shelter with reflective materials, here follow same significant example of this Emergency Architecture.



Figure 1: Performance needs.

THERMAL REFLECTIVE MULTILAYER SYSTEM (TRMS)

The TRMS is an innovative insulating system, originally developed for aerospace suits, become a viable way to reduce energy consumption and thereby improve comfort and save on energy bills. It is composed by numerous thin membranes made up different materials. The reflective films, in fact, are separated by wadding layers, foam layers, polythene films, bubble films sewn together to form a thin insulating blanket. The number of layers change depending to the materials and to the thermal performance requirements. It can be three to five times thinner than traditional insulation (including air spaces) but performs to the same level and does not support the nesting of rodents because of its minimal thickness. The chosen materials are ordinarily nonirritant fibers, non-asthmatic and non-allergenic. For these reasons no protective clothing or equipment is necessary during the assembly and the insulation does not weaken over time. Installation is, furthermore, easy for the flexibility of multilayer materials sold in light rolls, easy to transport and to cut.

The definition of system comes from the need to lying the multilayers element inside two air gap of 20 mm thick per one, in order to improve thermal performance. [3] Application of this system reduces energy demand, heating and cooling needs, which translates into energy cost savings of up to 50% and reduced greenhouse gas emissions for the environment, contributing to 40% reduction of global housing consumption. In general the functioning of this insulation system is to create a barrier against the transmission of cold or heat through walls, floors or roofs. The heat is kept inside the construction during winter and rejected outside during summer.

According with the standard NEN-EN-ISO6946:2008, Annex B, heat transfer inside determinate air cavity is divide between conduction, convection and radiation, the three types of heat that affect a building.

Radiation is ensured by external reflective foils insulation extremely effective to reflecting infrared radiation back towards the source of heat (heating systems in the winter, and solar radiation in the summer). Each internal reflective foil acts as an additional barrier to thermal transfer by radiation. The amount of energy emitted from a surface, however, depends also on its surface temperature and above all depends on the value of the longwave emissivity ε . Aluminium foil in the external side of TRMLS with approximately the low emissivity of $\varepsilon \approx 0.1$ can considerably reduce the amount of heat transfer through the product, reflecting most of the incident radiation energy (up to 97%).[5]

Convection inside this system reduces thermal loss limiting the cold air infiltration in the winter, and warm air infiltration in the summer. [5]

Conduction is allowed by the layers separators with low density (wadding and foam) between the aluminium foils create insulating air gaps, which are also barriers against conduction (same principle as double glazing). To guarantee this reaction outside the multi-foil insulation it is installed between 2 air gaps which avoid the materials to be in contact with the surface to be insulated. This part of the system significantly reduces thermal transfer by conduction. Within the multilaver insulation there is a very little conduction occurs given that the foils are separated by materials. They create small air gaps which act as barriers to conduction. [5,6] This three functions enable the system to ensure efficient operation of the same according with chancing state. The TRMLS is waterproof in case water penetrates the roof area, furthermore, its thermal performance prevents any internal condensation.

Certification of this material is different from common processes for general thick insulation works to prevent heat exchange through conduction, but TRMLS works using all heat transmission, radiation rather than by conduction or convection.

STATE OF ART OF TRMS PERFORMANCES

Past studies demonstrate that this material have good thermal performance but relative to the contest and test methodologies. Anyway this small differences inside the building contest are negligible. [4]

Currently the studies produce are from FIW Munchen (Forschungsinstitut für Wärmeschutz e. V. München), NPL(National Physical Laboratory), WTCB (Belgian Building Research Institute), Fraunhofer IBP (Institute for Building Physics) analysed the material with

guarded hot box apparatus; WTCB, Fraunhofer IBP did test with guarded hot plate apparatus to determinate thermal conductivity; NPL lab measurement with flow metre apparatus; BRE (Building Research Establishment), Alba Building Sciences Ltd and University of Reunion flow metres apparatus plus thermocouples to determinate thermal resistance of built walls, roofs, floors; Sheffield Hallam University, Trada UK, WTCB, Fraunhofer IBP, SFRIMM, CSTB (The French Center for Building Science) and TNO Quality Service test it in situ, comparison with mineral fibre insulation. [3,4]

In the hot box apparatus the measurement are according to international standard NEN-EN-ISO8990:2007. Thermal resistance value tested is 1.5-2.0 m2K/W with a thickness of 20 mm. Best performance are founded in walls and attic, worse performance in the floor. The test shows that thermal value are influenced by air cavity.

In the hot plate apparatus (refer to in Fig.3) the Labs involved are the Belgin Building Research Institute BBRI/WTCB and Fraunhofer Institute of Building Physics (Fraunhofer IBP). Measurement are in agreement with the international standards ISO8302:1991. Thermal Resistance value tested is around 0.47 - 0.60 m2K/W. Lower value is because air cavity are not present and there is interference with the rubber border placed between the specimen and heated or cooled plates and for the resistance from absence of resistance surface. [4]



Figure 3: Hot plate apparatus values

The "In situ and lab measurement with heat flow metre" are from the Building Research Establishment, Alba Building Sciences and the University of Reunion, Eindhoven University of Technology. They were performed by National Physics Laboratory according with standard ASTM C-518. The results are an underestimates effective R-value of materials of products that include radiation shield in combination with wide air cavities (more than 25 mm) because of non-uniform flows in these cavities. [3] The thermal resistance value in the same order of hot box measurement with a value of 1.0 and 1.9 m²K/W, in relation with heat flow direction and separate value for TRM and non-ventilated cavities. In this case the

difference between test in situ and hot box apparatus are environmental conditions, which are controlled in the second case. The thermal resistance, in fact, increases adding reflective foils between the layers of polyester foils and outside. Test repeated with polyethylene film instead of reflective layers whit less performance than the first one with four layers of reflective barrier. [4]

In the comparative measurements with test houses the laboratories involved are TRADA UK, WTCB, Fraunhofer IBP, SFRIMM, CSTB TNO Q&S. Tests included the use of two identical test houses, first insulated with 200 mm mineral fiber insulation with noted R value of 5.0 m^2 K/W, and the second insulated with TRMS. The weather condition are supposed identical, in the real or simulated conditions, and energy demand for maintaining a constant indoor temperature is monitored and finally compared between the two solutions. By reason of identical energy demand from the two houses is supposed to have the same thermal resistance between TRMS and 200mm of mineral fiber insulation, or if the energy demand of TRMS define a value x higher or lover, then the R value is x higher or lower than mineral fiber insulation. The measurement implemented, however is not uniform because of air tightness of both test houses, of ventilated and nonventilated air cavities and influence of thermal bridges.:

WTCB, Fraunohofer IBP(2007/2008) and CSTBresults are slightly higher than hot box measurement, in order of 1.5-2.5 m²K/W; Studies by Sheffield Hallam University, TRADA UK, Fraunhofer IBP(2005/2007), SFRIMM and TNO Q&S found thermal resistance value of 6.1 m²K/W with the same method. [4]

In the thin, non- ventilated or weakly ventilated cavities convection can be neglected and the significant measurement is from the sum of conductive and radiate heat transfer. In the wide cavities, differently, conduction is not unimportant, and the sum are between convective and radiate heat transfer. [6]

POLITECNICO TEST

Aims of the test is to verify thermal performance of TRM and its changing with air layers. The measurements are from guarded hot plate box, to valuate air contribution in the static condition, with high level of precision. Test involves the Measurement Laboratory Of Politecnico di Milano. Tests are from two different temperature state ($40^{\circ}C/60^{\circ}C$), with or without air layers from 10 mm at atmospheric pressure.

The instrument have a central electric heater with an electrical resistance. This structure allows to know exactly the electrical power (W) use during the test, process monitored and registered by Agilent 34970A data acquisition units (Tension V and Current A).

To reach the right thermal balance inside electrical resistance and ensure an unilateral heat flow, necessary for the measurement, there are an guarded ring surrounding the central. The two components, in fact, have a heater elements to obtain a zero temperature gradient in the horizontal direction as a Fourier's Law requires to have zero heat transfer. In this condition the thermal power measurement can indicate the right value of thermal flow inside the insulating material. This system, electrical resistance and guarded ring, is assembled between two layers of studied materials and, in turn, they are placed between the two external cooler elements. Two different thermocouples are positioned between the two external discs and the central heater, to provide temperature data from Alluminum external disc (TA), Copper external Disc (TC) and electrical internal resistance (Tcd) (refer to in Fig.4).



Figure 4: Hot plate apparatus section.

GUARDED HOT PLATE APPARATUS SET UP

The tests are guide by guarded ring method with two insulation test.

The system have two identical aluminium discs (League EN 1050 H24) Of 1.5 mm thick and 97 mm of diameter, where is located the electrical heater. According with ISO 8302 standard, there are two rings from the same material surrounding guarded ring, with another electrical heater, independent from the central one. The dimensions are 220 mm for external diameter and 101 mm for the internal and the design allow a internal gap of 2mm (less than 5% of central disc) between the two aluminium bodies. Both electrical heater, by MINCO, are connected to the system with supporting by insulating material as Kapton, ensuring the mutual locking of the heaters. They are, furthermore, isolated by circular resistance of silicone-rubber, a robust, flexible elastomer, with excellent thermal properties. General dimensions for central body are 86.4 mm of diameter, with an electrical resistance of $13.9 \pm 5 \Omega$; for the external ring 109.7 mm of internal diameter and 209.6 mm of external diameter with a resistance of $23.3 \pm 5 \Omega$. Maximum current support from both electrical heater are 7.5 A, thereby, the higher value sustenance are 104.5 V (782 W)for the first and, 174.75 V (1311 W) for the second. This layer is between two test of insulating material, TRM, which are involved between two disc, one above of Aluminium and one below of copper. All the systems are inside of a circular box of metal, which is the cooling unit to help to minimize the temperature gradient between the TRM and the two external disc, in agreement with the law standard (refer to in Fig.5).



Figure 5: Guarded Hot Plate apparatus metal box; Aluminium above disc; TRM test.

A thermopile take the measurement of the temperature differences between the two heaters and it is composed by five different copper constantan thermocouple, connected with data unit acquisition. Temperature differences different of each system component are gauged by thermo resistances type Pt100 with four wire, also connected to the multiplexer Agilent34970 A. The advantage to use a thermopile with different thermocouple is a greater awareness for the superior ratio result between the incoming and outgoing data. The TRM tester, ACTIS Triso Super 10 test, are 0.025 mm thick and 0.16 x 0.16 mm, and it is compose by 19 layer: 8 reflective foils; 2 metallic films with reinforcing grid (ground surface: 600 g/m^2); 3 types of wadding (30 mm thick); 8 foam layers; 6 intermediate reflective films. The TRMS tester are a combination of TRM, 0.16 x0.16 x0.025, with neoprene spacers to guarantee air layer, 0.14 x 0.01x0.01 mm, and polyester membrane to close all the system.

TEST PROCESSES

The test agrees with the method and with the standard ISO 6947:2007(Thermal resistance and thermal transmittance: calculation method). Set point of temperature was fix from three different solutions, considering the material TRM or TRMS. Following the thermal balance between the two central electrical resistance, the unilateral thermal flow are guaranteed. In this condition, when the thermal power reach output value under the 50μ V the system goes in full speed, further down this value the error measurement are under 2%, according to ISO standard. This means that Temperature changing are less than 1 C°, stable Δ T and unilateral flow are ensure.

In order with this consideration the data analyse are from the last 30 values from 10 test for each set point. This numbers have been recorded when the system was going full speed and thermopile voltage imbalance between the two extremity was are under $100\mu V$.

From the experience of Measurement Laboratory of Politecnico di Milano the electrical control are by a software which use LabView DSC graphic interface and allow the storage for the data collection. To enable the development of the control, all the measuring devices were connected to the multiplexer with two cards data acquisition. With the data recorded, value of thermal power from different three temperature set point are calculated.

The data are presented in simple interface where electrical resistance tension, thermopile value, and temperature are shown.

Through the use of this software, realized by Measurement Laboratory, time for each test are decreased and the value results are stabilized.

Measurement of voltage (V) current (A) and temperature (T) allow to calculate the TRM/TRMS conductibility by the formula:

Formula 1:
$$\lambda = \frac{W}{A} \times \frac{t}{((T_R - T_A) + (T_R - T_C))}$$

Where:

 λ = Conductibility of TRM and TRMS; W= Thermal power from V x A ; A= Area of central heat disc; t = Insulating material thickness; T_R = Temperature of the central resistance; T_A = Temperature of aluminium external disc; T_C = Temperature of Copper external disc. The dimension of two tester are according with internal electrical resistance, to have all the disc cover by the insulating material, and not contact between neoprene and internal aluminium disc, to guarantee any interference with heat flow. Distance of air layer in TRMS tester are 0.010 mm but internal pressure condition of the box can change this value. Uncertainty of this data lead the measurement to consider another formula to express thermal capacity of this value, where the thickness are not certain value:

Where:

U= Transmittance of TRM and TRMS; W= Thermal power from V x A; A= Area of central heat disc; T_R = Temperature of the central resistance; T_A = Temperature of aluminium external disc; T_C = Temperature of Copper external disc.

Formula 2: $U = \frac{W}{A} \times \frac{1}{((T_R - T_A) + (T_R - T_C))}$

R air value of 0,15 m²K/W are added per layer in the set point with TRM + Air. The R value are chosen considering descent and ascent flow inside air cavities, equivalent value considering 0.010 mm air layers thickness.

RESULTS

This formula is used for all the 10 tests inside 3 set point. The results are collected in one table, considering the average value counting with the last 30 value per test. In particular, 40 C° set point for TRM and TRMS are considering for final value. Set point at 60 C°, in fact, just show the lower performance whit high temperature according with physics law and to indicate the accuracy of the calculations.

In the set point with air cavities According with the UNI CEIENV 13005:2000 (Guide to the expression of

uncertainty in measurement), this result are valuated in order with measurement uncertainty, a non-negative parameter characterizing the dispersion of the values attributed to a measured quantity. Measurements are concerning Set point at 40 C°, whit TRM and TRMS testers, which are the condition closer to the real performance.

The value achieved are not a direct calculation of the system, in order with this the method adopted is the Indirect Measurement Uncertain, indicated as a Type B. Instrument errors are counting and random errors are totalling. Propagation of distribution are considering to attain the range where thermal coefficient are included.



Figure 6: Politecnico di Milano λ value with or without errors.

Value found are according to the standard ISO 6947:2007 and UNI CEI ENV 13005:2000. Thermal conductivity λ results are around 0.0331 and 0.0448 W/mK. Especially considering measurement uncertain, show the different between test with or without area whit rising value only with 0.01 m of double air cavities (refer to in Fig.6).

These results underlines that the combination between TRM and Air cavity can ensure high thermal performance and can well be applied in lightweight, flexible and modular units. This lightweight skin, is part of Air Shelter House. This architectural concept, developed by the authors can be used as model for emergency architecture and alpine contest to guarantee internal comfort, safety and psychological needs.

AIR SHELTER HOUSE

The project involve the design of innovative and flexible building element, in principle with shelter feature, the state of art and the new technologies.

Thermal performance of the TRM, improved by air layers suggests the design of a technological system where this material and the air cavity are combined. The system can be used as external building shell itself or applied on existing structure to improve inside microarchitectures as shelters. The thermal-reflective multilayer combined with the air gap between two polyester membranes, which is contained, ensure the thermal insulation. The lightweight and flexibility of TRM material allows an easy assembly and the feature to adapt the envelope to the different structure shapes.



Figure 7: Air Shelter House module.

The Air Shelter House will be composed by different elements which can help to ensure thermal comfort and waterproof protection already guaranteed from TRM. An example of these application is shown in the Fig.7,8. (refer to in Fig.7,8).

External envelope: is made by Polyester waterproof membrane. Internal insulation are of TRM, foil of thermal reflective multilayers insulation type ISO Super 10. Joints Profiles are made by vulcanized rubber and/or neoprene. Others important component are air cavities of 20 mm to don't generate convective mote and insufflate air valve to inflate the air inside each module.



Figure 8: Example of Shelter House skin reconstruction configuration.

CONCLUSION

The first post-disaster emergency shelter as normally a tend or other temporary structures built with the priority to save people. Starting from this the authors analyse the integration of innovative technology in normal shelter in order to ensure protection and comfort in one time, answering to the needs of emergency architecture:

Lightweight considering the use of TRMS combined whit polyester membranes. The use of this lightweight materials allow a light product easy to transport and assembly for the users. Furthermore it can guarantee safety during earthquake events.

Resistance by the polyester membranes which is contained and the profiles of vulcanized rubber make the cover. This feature is important considering the hostile environment where this units are going to be located.

Ductile is allowed by the flexibility of materials ensure the ductility of the product which can be used in different combination and to always adapt in different solutions, inside permanent construction too.

Practical for the adaptability of this element to different sub-structure allow the disposition of the shelter in numerous contest ensuring the practicality of the system. Through these features it will be possible to build the shelter near the displaced people's homes.

Modular because elements consist in a modular system which allow the ability to adapt the product to different sub-structure.

According with durable solution, in fact, after reconstruction they can be easy dismissed and reused in another contest.

According with culture by adaptability of the cover to any kind of structure, ensuring the use of local material for the self-beams system, agreeing with culture and tradition of the country.

REFERENCES

1.UNHABITAT (2008). Shelter projects 2008, *IASC Emergency Shelter Cluster*, UNHABITAT, UNCHR.

2. Fengler, W., Leitmann, J., Jones, B., Bettencourt, S., Cohen, P., Scawthorn, C., Peterson, C., Arnold, M., Vishwanath, T.(2011). Earthquake reconstruction, *GFDRR Knowledge Notes Global Facility (Global Facility for Disaster Reduction and Recovery)*, The World Bank.

3. Seriacaroupin, J., Miranville, F., Braga, D., Duran, M.

(2007). Experimental evaluation of the thermal performance of a building roof including a multireflective radiant barrier. 5th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamic SJ7, Sun City, SAF, 1-4 July.

4. Tenpierik, Hasselaar(2012). Reflective multi-foil insulations for buildings: A review. *Energy Buildings* 56 p. 233-243

5. Pastory, Z., Peralta, P.N., Peszlen, I. (2011), multi-layer heat insulation system for frame construction buildings, *Energy Buildings*, 43 (2-3) p.713-717

6. Bergman (2011). Fundamentals of heat and mass transfer, 7ed. *Hoboken*, NJ : Wiley.