The Recycling of Used Tyres as an Insulation Material in Cavity Walls in a Mediterranean Climate

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Summary

This paper evaluates the potential of recycling used tyres in three different states: whole, shredded & pulverised. The study looks into the best use of the material as a form of insulation in cavity walls in Malta, with a typical Mediterranean marine (island) climate, where a greater concern for cooling has always exceeded that for heating - albeit until recently. The Maltese building industry still depends on a robust building technology, relying heavily on traditional quarried stone for load-bearing cavity walls.

An energy-awareness is also maturing towards curtailing carbon emissions, even if initially dominated by cost concerns, especially in view of the ever-soaring price of crude oil on international markets. Malta has also adopted the EU Directive on energy performance in buildings, thus making energy efficiency governed by national law.

In consideration of today's large amount of tyres being used and disposed of, the purpose of this study is to investigate the possibility of utilising recycled rubber as a building material, namely as insulation in cavity walls. This could replace new insulating materials, typically having a higher embodied energy content. The study evaluates the success/failure of such passive design strategies.

1. Introduction

Typical insulation-related measures in a building affect the energy consumption some 50-100 years into the future, and it is either very expensive or practically impossible to modify an existing non-optimal construction. Logically, it is still important for new buildings to be as energy-efficient as possible, since in the long term, they may become decisive for the energy consumption and possibly constitute a benchmark for what is obtainable when renovating the existing building stock of the day, whenever this materialises in future.

Innovative insulation materials are perhaps at the forefront of developments in building technology worldwide. Gaining particular attention are recycled or recyclable materials, particularly those that apart from their energy-saving measure, have an eco-friendly contribution to the environment. Given its high embodied energy and end of life disposal issues, rubber is but one of them. Rubber has aroused particular interest in its potential for recycling and re-use in different forms as safety floors, acoustic panels and thermal insulation among others. This paper focuses on thermal insulation in three forms, namely pulverised, shredded and solid sheets of opened out tyres.

2.0 Present Situation

Three problem scenarios are envisaged for Malta in the imminent future. Before presenting these an overview of the present situation is given, here outlined under traditional building technology, energy legislation and waste disposal, respectively mapping out the three scenarios.

2.1 Building Technology in Malta

The construction industry in Malta has always been heavily dependent on the local quarried material, namely globigerina limestone. This indigenous quarried material has its own unique properties perhaps giving it its almost unbeatable popularity among local folk as a standard building material used for over 5,000 years.[1] Its structural integrity, durability, weathering and thermal properties as well as its ease and low cost of quarrying combined with today's technology for cutting, planning and hoisting have all contributed greatly to its quasi-perpetual use in the construction industry in Malta.

Today, at the threshold of the 21st century, trends indicate that imported modern materials have superseded vernacular construction methods, where frame structures now replace block-on-block structural load-bearing walls, especially with an increasing demand towards high-rise development. Quarrying has also been limited both due to its exhaustion as a quality source and new quarries or extensions being curtailed by stricter environmental and land use control. The demand for quarried solid blocks of *Franka* stone (soft, lower coralline globigerina limestone) has dwindled, yet somehow complementary to this, the demand has increased for *Tal-Qawwi* (hard, upper coralline globigerina limestone) for hardcore aggregate in concrete casts and hollow core concrete blockwork, the latter now gradually replacing the quarried *Franka* stone, particularly in façades.

2.2 Energy Legislation and the EPBD

Thermal considerations have also been raised to a higher importance in view of a greater sensitivity to carbon emissions and EU legislation. The EU Directive 2002/91/EC, better known as the EPBD (Energy Performance of Buildings Directive) promotes energy efficiency in buildings both in construction and at operational stages. Conceptually a building is perceived to be energy conscious from the onset with a view to minimising energy losses through the envelope, particularly through heating and cooling, yet maintaining adequate thermal comfort standards for its occupants all year round.

In Malta this Directive was transposed to local legislation through LN 238/2006, where reference is made to the latest revised building regulations, particularly part F, where the technical guidance document sets minimum requirements for energy performance of new buildings. Although not yet enforced, it is intended to guide architects in their design schemes with appropriate construction detailing and design when applying for a building permit as from 02 January 2007. Perhaps foremost in controlling heat transfer through the building envelope is the type and thickness of insulation. Naturally this has its own energy implications. Ideally one should compare its embodied energy with the actual operational energy savings made and the pay back periods envisaged at today's energy costs. One strong potential for cutting back this embodied energy is the use of recycled materials for cavity insulation. Rubber is but one of them.

2.3 Waste Disposal & Land Use

Waste management has always posed an environmental problem worldwide. Malta is no exception. Considering a small Island State of 216sq.km, with a population in excess of 400,000 leading a more western lifestyle, waste disposal may be deemed as a very acute problem. A decision was taken some fifty year ago to collect all municipal and building industry waste in one national rubbish dump, close to a small rural community, *Maghtab*, today more known for its dump than for the original indigenous village.

In fact the problem became greater over the last two decades as the land take-up for waste disposal was having serious implications on the local residents, neighbouring towns and the tourist industry at large. Today waste management and the associated land use have gained more importance, where professionally managed engineered landfills are being meticulously planned and set up. A proper nation-wide waste separation educational programme is in place, identifying organic form inert waste, also separately collected at source. A greater emphasis on re-use and recycling is also made with a view to increasing longevity of materials and products ("cradle to the grave" life cycle) thus logically reducing disposal volumes and land-use demand. Apart from all other inert (possibly compacted) waste tyre disposal poses a serious concern, as its disposal takes up precious stockpile volume, considering a tyre's low mass per unit volume.It also poses a high helath risk when deteriorating or burnt, emitting toxic fumes.

Tyre recycling is typically considered when vehicles' tyres are beyond repair or rethreading. This is particularly the case with larger vehicles, especially when severely damaged or punctured. All but more particularly larger tyres present the most problematic sources of waste, due to the large volume required and their durability, thus having a slow rate of decay, if at all. These same characteristics that make disposed tyres generate such a waste problem can also be viewed positively, as it makes them one of the most re-used waste materials. Since rubber is very resilient it can also be reused in other forms and products. Examples include shoe soles, shock absorbers, road surfaces, noise absorption and thermal insulation.

In the U.S., approximately one tyre per person is discarded annually. In 2003 alone 290 million scrap tyres were generated, of which 45 million of these were re-used through re-threading.[2] With most landfills worldwide minimising their acceptance of whole tyres due to the health and environmental risks associated with stockpiling tyres, many new markets have emerged for recycling such a heavily disposed-of waste material. Established growing markets exist for a majority of scrap tyres produced every year; across Europe some of these plants are also being supported (or owned) by national authorities or local governments.

It is particularly worth investigating the LCA (Life Cycle Analysis) associated with the disposal of scrap tyres or their export out of Malta, as compared to the importation of synthetic rubber for use in various products such as road surfacing, safety mats for children's play areas and thermal insulation among others. The latter needs further investigation against other forms of insulation typically the more popular EPS (expanded polystyrene) or EPU (extruded polyurethane), both having a high embodied energy content.

Increase in public pressure in the field of waste management, deposition and internalization of environmental cost factors, has led to legislative measures, both National and European, which have resulted in a new scenery in the construction sector. The influence of an LCA approach is evident, when considering the environmental impact phase model of the entire building process.[3]

This paper however investigates the potential energy savings associated with achieving comfort standards through the use of three different types of rubber. These, in themselves, also encompass a different amount of embodied energy to produce; for example flattened tyres require less energy than machine-shredded crumbs, while the latter then demand less energy than pulverised rubber.

3.0 Experiment Methodology

3.1 Thermal Conductivity Theory and Codes of Practice

The ultimate aim of this paper was to determine and compare the U-values for two double skin cavity wall systems, one made of GLS (globigerina limestone) and another in HCB (hollow core concrete blockwork), both tested for three different types of rubber as cavity infill, compared to air. Independent of heating or cooling, the composite U-value is calculated theoretically assuming linear heat flow perpendicular to plane, parallel layers or skins of wall of uniform thicknesses. However in reality, all building components have irregularities, such as mortar joints, lateral cold bridges through corner bond stones, etc. These result in non-uniform transverse heat transfer, thus affecting the aggregate heat transfer through the element. Therefore this needs to be allowed for when determining the U-value of the composite element.

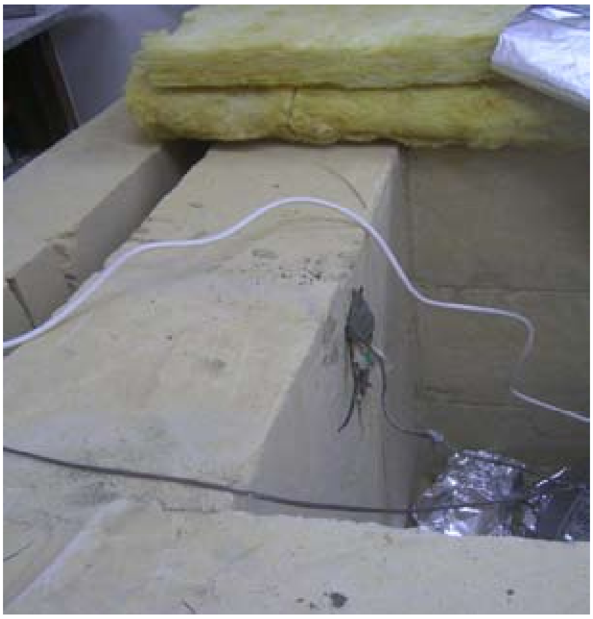
In general for such U-value calculations simplified methods are used where they are deemed appropriate for the element concerned. British Standards (BS) and other calculation methods define the scope of validity of the methods they describe. The method defined in BS EN ISO 6946 is often acceptable. This is known as the *Combined Method* since it involves the calculation of the upper and lower limits of thermal resistance of the element. Any non-uniform layer is to be treated as a bridged layer when using this method. The Standard calculates the U-value of the component from the arithmetic mean of these two limits. Hence its name, the *Combined Method*. However Anderson[4] points out that equal weighting can be an imperfect approximation when the difference is large, even though the true result always lies within the same upper and lower limits.

Finite element analysis is typically used for an accurate calculation of the thermal resistance of an element or single material in a composite part of the building envelope (wall or roof system). For routine calculations the Parallel Heat flow or Parallel Isotherm Method is used. The former overestimates the thermal resistance while the latter underestimates it hence it is for these reasons that the Combined Method takes their average. Based on empirical calculations of thermal conductivity of materials, the U-values were worked out for the different composite elements, representing wall construction in Malta, as per current practice in the building industry. These are later compared to physical testing out of similar test cells, as per current standards, namely BS EN ISO 6946. On the other hand EN ISO 8990:2003 uses the calibrated hot-box to find the steady state thermal transmission properties. This suggests using Q=UADS, but taking into account the emissivity factor, mean radiant temperature, radiant and convection coefficients.[5]

3.2 Test Cell set-up and Methodology

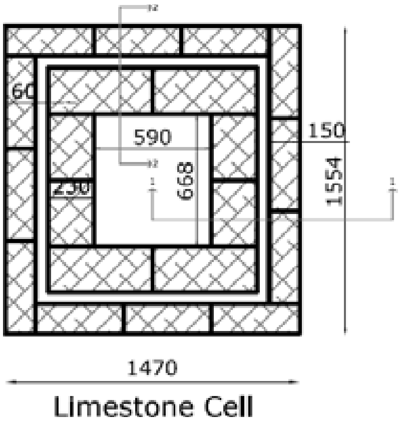
The experimental procedure involved the setting up of two test cells, as per EN ISO 8990:2000.[6] The principal difference between the cells was in their construction system. One was built using the local quarried material, *globigerina limestone*, composed of two skins of 230mm and 180mm, while the second test cell was similarly composed of two skins of 230mm and 180mm, but in HCB (hollow concrete blockwork). In both instances the thicker skin was deemed to be more effective for its thermal mass when placed on the inside.[7] A consistent cavity of 60mm was ensured throughout. The blockwork cell was plastered up to 5mm both sides, while the limestone walls were pointed both sides, both as per standard local building practice. Such cells were placed on an isolating pallet, to minimise ground cooling, yet built directly on glass wool as an insulating material. Top level capping was achieved with a similar layer of insulation, both 100mm thick; both floor and ceiling of insulation panels of the cells were lined up with aluminium foil for maximum reflectivity.

Pictures 1, 2 illustrate the experimental set up while drawings 1, 2 show the corresponding test cell dimensions and thermocouple set-up. The data logging device (not shown here) connects all thermocouples to a special card inserted in a PC, carefully navigated by moving around altogether on a trolley on castors.

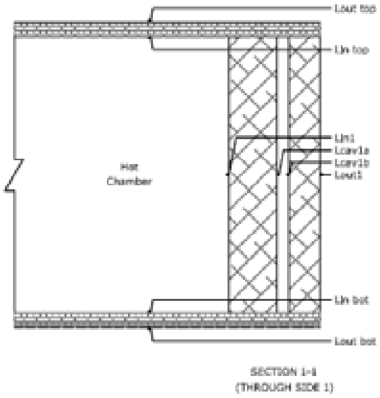


Picture 1 GLS cavity wall test cell

Picture 2 Insulation with aluminium foil lining



Drawing 1 Plan of test cell for GLS



Drawing 2 Section through test cell

Four rates of heat transfer were tested, namely with a void cavity, solid opened out tyres (sheets), shredded morsel (10-15mm) and pulverised rubber (1-3mm). The test cell facility was set up inside an environmental laboratory, behind a double door chamber to ensure a stable indoor environment. An electric heating element of a constant 1000W intensity was placed inside each test rig. A series of thermocouples were attached to the respective faces of the cell walls, interconnected to a robust data logger, previously calibrated, all set up as per MSA standards.[8] Although monitoring was initiated immediately, steady state conditions were allowed for until formal data logging was noted to be fairly stable, with a steady rate of heat transfer through the different test cells. Output results were charted and analysed for observations.

4.0 Results & Discussion

4.1 Charted Output: Building Materials comparison

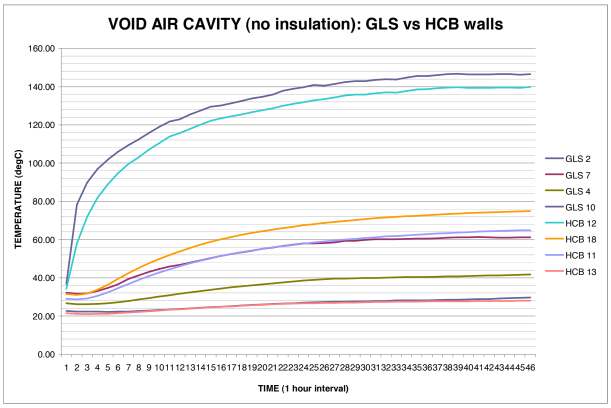


Figure 1 Void Air Cavity - GLS vs HCB

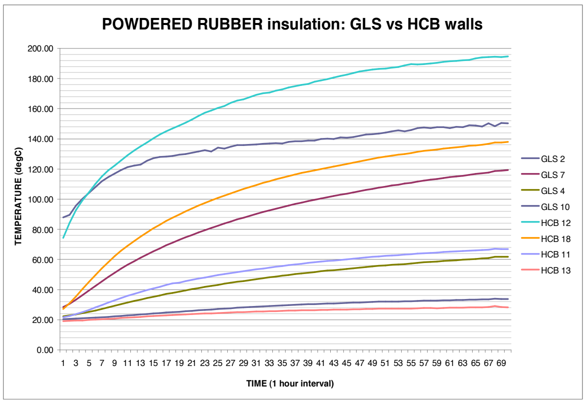


Figure 2 Powdered Rubber - GLS vs HCB

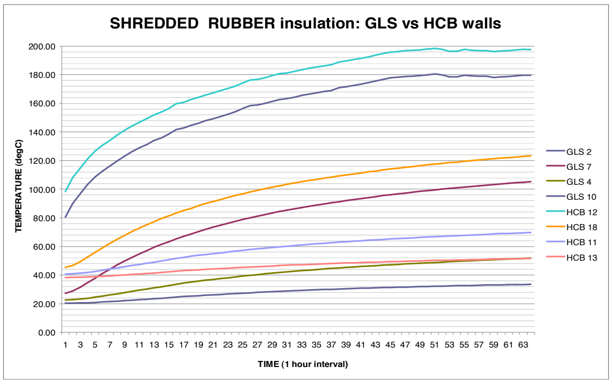


Figure 3 Shredded Rubber - GLS vs HCB

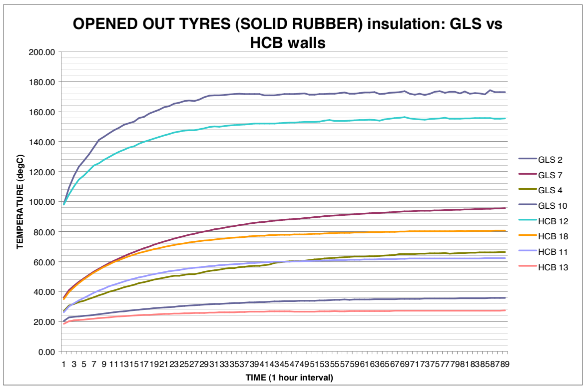


Figure 4 Solid Rubber Tyres - GLS vs HCB

From the above charts, figs 1,2,3,4 the four scenarios compare the different thermal performance of the two distinctly different building materials, GLS (Globigerina Limestone) and HCB (hollow core blockwork), the former naturally occurring and quarried, while the latter man-made, composed of hard-core aggregate, sand and cement. Both materials shave considerably high embodied energy, not calculated in this paper.

Fig.1: Void air cavity: It is noted that for both GLS & HCB heat transfer generally stabilises after 65 hourly readings. While GLS reaches 140℃ in 48 hours, HCB reaches the same temperature after 57 hours. The difference of 9 hours is attributed to the 100mm cast cavity within the HCB and possibly its lower porosity. Both GLS and HCB outer cell surface temperatures rose marginally from 26℃ to 28℃ over the same period.

Fig.2: Powdered rubber: Heat transfer stabilises after 60 hours for both cells. HCB inner surface temperature reaches 195℃ after 70 hours, while GLS reaches 150 ℃ over the same time frame. HCB cavity surface temperatures rose steeper than GLS from the onset. This may be due to the fact that GLS was probably still wet internally as typical for most freshly quarried stone. Although water is a better conductor of heat than air, the moisture content itself must have been cooler than capillary pores, thus lowering the kick-off temperatures. Hence the slow rise detected by the thermocouples on the GLS.

Fig.3: Shredded rubber: Both HCB and GLS rose steeply over the first 24 hours but rate of heat transfer slowed down to stabilise at 198℃ and 180℃ respectively. Outer surface reached equilibrium after 63 hours with HCB rising to 52℃ and GLS lower by 17℃ at 35 ℃. It is also worth noting that cells' inner surface temperatures experienced minor non-uniform fluctuations in temperature readings. This is possibly due to variations in the mains current supplied to the heaters since both HCB and GLS experienced consistent congruent dents in their temperature logging.

Fig.4: Solid Rubber: Inner surface temperature for both GLS and HCB rose steadily from around 96℃, possibly due to the thermal inertia of the stone from previous experiments. [This was the last test performed, and although a period of five days was allowed for cooling, the inner mass may have still been warm enough]. Its is also worth noting that both GLS and HCB temperature profiles are now experiencing more

erratic changes, yet retaining a steady flow overall. Both curves reach fairly stable values of 172℃ and 154℃ after only 33 hours of data logging. Cavity's inner surface inside the GLS cell stands at 96℃ while that for HCB is at 80℃. In this instance GLS cavity temperatures are circa 14℃ warmer than the HCB cavity (unlike the former three scenarios). This is only attributed to the now dry globigerina limestone, after the earlier three experiments. Outermost surface temperatures are equally different by about 8℃ with GLS still the higher of the two cells. It is worth noting that while GLS was only pointed along its bedding joints, the HCB cell had a plastered surface composed of a sand+cement mortar of circa 5mm overall. This may have helped to dampen thermal losses overall, even if marginally. [Such surface finishes were applied to simulate current practice for typical Maltese building construction finishes].

4.2 Charted Output: Temperature Profile comparison

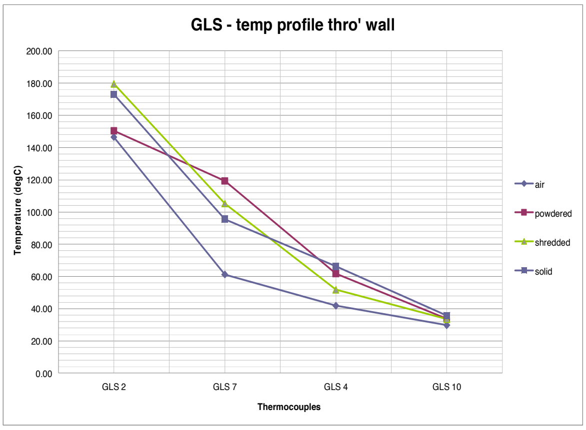


Figure 5 Temperature Profile for GLS

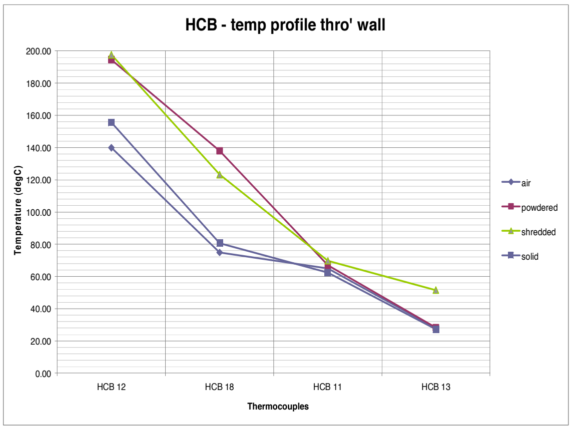


Figure 6 Temperature Profile for HCB

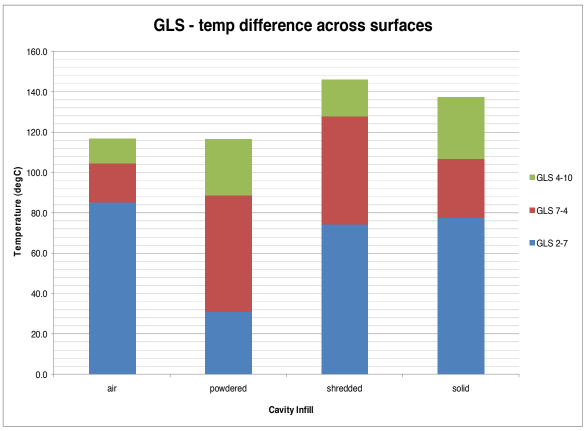


Figure 7 Four Insulation types for GLS

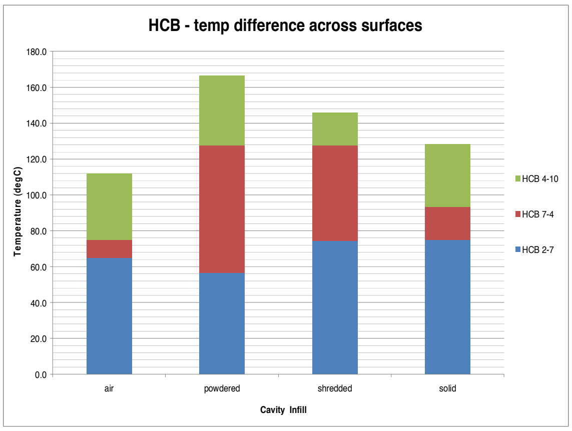


Figure 8 Four Insulation types for HCB

Figures 5 and 6 depict the 4 in 1 temperature profiles through the *two* different materials, while figures 7 and 8 represent the effect of each cavity infill (insulation type) for the same two materials, namely globigerina limestone (GLS) and hollow core blockwork (HCB).

Figures 5 and 6 indicate that while an empty (air) cavity and a solid rubber infill (opened out tyres) have a similar gradient of 72℃ and 40℃ across the inner skin and the cavity respectively, they converge to the same point at 28℃ externally. However, shredded and pulverised rubber infill insulation behave quite differently: both GLS and HCB experience a greater resistance to heat losses through their inner skin wall of circa 30℃ and 70℃ respectively. The steeper gradient of the temperature profile for powdered rubber also indicates that it performs best of all three rubber types.

Figures 7 and 8 expresses temperature differences as bar charts. These further demonstrate that pulverised rubber offers the greatest resistance to the passage of heat, followed by shredded rubber.

4.2 Output Results and Discussion

After working through each cavity option case scenario for the two different materials, the following U-values were obtained, as summarised in table 1:

Table 1 U-values for different cavity insulation types

Cavity infill [60mm]	***U-value for GLS wall [w/m^2K]***	***U-value for HCB wall [w/m^2K]***
AIR	2.78	2.68
POWDERED rubber	2.21	1.65
SHEDDED rubber	1.91	1.77
SOLID rubber	2.03	2.19
*EPS	1.00	1.00
*EPU	0.76	0.78
*Glasswool	1.42	1.09
*Stonewool	**1.08**	**0.91**

**Note: These values were obtained through similar experiments carried out by Abela.*[9]

Comparing theoretical calculations with the experimental values inserted in Fourier's Law of thermodynamics U-values compared favourably. Table 1 illustrates all experimental values obtained. Once more it is evident that pulverised recycled rubber gives the optimum thermal performance out of the three types tested, followed by shredded rubber - both in hollow core blockwork.

However when compared with modern conventional purposely manufactured insulating materials, these performed marginally less. It is worth pointing out however that the embodied energy of both the new material, as well as the recycled rubber, did not feature in the overall energy balance equation.A holistic LCA would have been justified in this case for a true overall comparison, including embodied energy of both types.

4.3 Potential Shortcomings

To be precise, the solid rubber is actually an opened out tyre of circa 10-15mm thickness, including steel mesh. [Rim lining was deliberately stripped out to avoid steel conductivity]. The two factors that may have influenced readings are the percentage of steel content - albeit even if very low, as well as the remaining air void between the solid tyre and the cavity walls. These may have (marginally) distorted the readings for the opened out tyres. Naturally if the full 60mm cavity was packed with layers of solid tyres, the results would have been quite different for this case.

The heat source of a known intensity of 1000W was assumed to be divided between the four walls of the cell. Since the ceiling and floor of the two cells were heavily insulated with 150mm of glasswool internally lined with an aluminium foil, it was assumed that there was no absorbtion and no heat was conducted out of these two planes in theory. In reality however, the roof did warm up even if marginally. Ths may have contributed towards a margin of error when assuming the 1000W source to be divided into 250W for each side.

Initial kick-off of inner surface temperatures was slow, especially for 2nd, 3rd and 4th experiment set up with powdered, shredded and solid tyres respectively. Although a minimum period of five days in between was allowed, the thermal inertia of the GLS in particular could have remained relatively warm; this could have offset the readsings, especially when compared to the HCB, the latter having a greater porosity and a lower thermal inertia.

Globigerina limestone, when quarried is typically wet with a relatively high moisture content. Standard building practicve in Malta dictates (rule of thumb) that new buildings should be allowed to dry up for at leat one year before such walls are plasterd or decorated. In this instance, however, due to time constraints and availability of the builder, only two weeks were allowed. Hence the possibly high moisture content could have contributed to a small degree fo error, even if marginally, especially when compared with hollow core blockwork. With hindsight, this could have been measured and assessed against similar values for HCB.

5.0 Conclusions

Given that recycled tyres can be transformed into these three forms of opened out, shredded and grain size, it can be concluded that powdered rubber provides the best thermal performance of the four types tested, including an air cavity.

However it is worth noting that since the alternative four (and any other) materials compared with are purposely manufactured as insulating materials, therefore solid, shredded or pulverised rubber tyres present an added value ("win-win" situation), since they curtail waste both in terms of volume and in terms of their hazardous material decomposition.

Therefore such recycled rubber, an offshoot of used vehicle tyres, lareg or small, is here potentially put to good use. This points to the case that a full rigorous LCA (Life Cycle Analysis) needs to be worked out in order to compare the overall energy saving of the different systems against the deployment of various types of newly manufactured insulation. At this stage such a study was beyond the scope of this research paper.

5.1 Scope for Further Research

There is much potential for further research. As outlined earlier, one can focus more specifically on the embodied energy of each material in order to assess, compare and contrast different composite wall systems for their overall energy balance, including the insulating material's potential for recycling or in itself being a derivative of another material, possibly outside the building industry (e.g. tyres). This will ensure exhaustion for its embodied energy for a full LCA, with a thorough "cradle to the grave" sustainable approach.

There are numerous software packages on the market, most of which come with their own library of individual materials embodied energy.[10] Another area of research could be to compare these for similar external wall systems.

Such an approach will certainly minimise the impact of these three scenarios: the building industry's demand for new resources, reducing waste and health hazards and ultimately a reduction in carbon emissions and a lower carbon footprint of the building in question.

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