NEW THERMALLY ENHANCED FIBER INSULATION MATERIAL

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Summary: *Lightweight constructions represent an economical alternative to traditional buildings, one of whose main drawbacks is the very high energy load needed to keep internal comfort conditions, as they are unable to curb rapid swings of temperature. When compared to heavier weight materials buildings, it's estimated that to maintain a thermally comfortable temperature range of 18-24°C, low weight materials use between 2 and 3 times the heating and cooling energy needed by a heavy weight material construction. This paper deals with research which developes and new thermally enhanced active (PCM) fiber insulation material, named by research partners StorePET. Development of such insulation material is in final phase in frame of European FP7 project STOREPET (FP7-SME-2011-2, Proposal 286730) with researchers from Spain, Portugal, Italy, Slovenia, and Sebia. Project participant from SEE is Construction Cluster „Dundjer" from Niš.*

Keywords: *Building materials, thermal insulation, acoustic insulation, light building constructions, energy efficiency, sustainable building.*

1. INTRODUCTION

The research concept is based upon the fact that outdoor/indoor heat exchanges (which play a significant part of lightweight buildings cooling and heating loads) can be potentially controlled by a new fiber insulation that possesses a thermally active heat storage capacity. During the day, when temperature rises, the peak loads can be largely absorbed by a PCM (Phase Change Material) - enhanced fiber insulation layer, only to be slowly discharged back to the environment later (during the night time, when outside temperature drops), without affecting the interior building energy balance, as it is aided by the presence of an standard low heat transfer fiber insulation layer. This approach will provide a much slower response of the building envelope to daily temperature fluctuations, helping maintaining inside temperature in a comfortable range and thus avoiding the need for extra energy consumptions to accomplish it. Effective levels of indoor comfort will be also guaranteed by the well known fiber materials excellence,

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when it comes to reduce airborne noise transmission and its superior performance upon controlling the sound resonance in construction cavities.

2. TECHNOLOGICAL BACKGROUND OF STOREPET

The new thermally-enhanced fiber insulation proposed will be a technical nonwoven product, made mainly from polyester fibers resulting from the recycling of Polyethylene Terephthalate (PET) plastic bottles, where some of the fibers will be modified/impregnated with phase change materials (PCMs), on a single or multilayer bulk design, in the form of blankets, batts or rolls that shall be available ready to be installed.

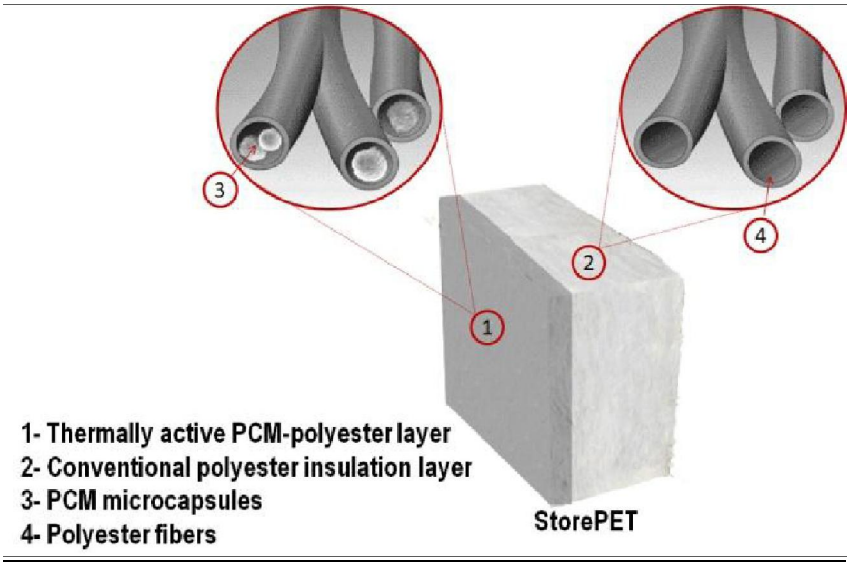

Figure 1. StorePET structure

Based upon the excellent thermal and noise insulation properties and market acceptance for commonly glass and mineral wool materials, it was reasonable to think upon using those types of fibers to integrate the StorePET approach, instead of the polyester. However, their manufacturing process, dealing with high temperatures and other technical issues, makes it almost impossible to incorporate the PCMs within its fiber structures. Other possible option was to choose cellulose fibers as the core material for this new product. The reason to withdraw this pathway was that cellulose insulation production is still too much based on low-tech machinery and methods, making it unfeasible to re-process the shredded recycled cellulose fibers for PCM incorporation sake, and still be competitive under the same basis. Thus, polyester fiber was chosen for this approach for being currently the most promising material to be able to incorporate this novel thermal enhancement.

Thanks to the peculiarities of the polyester fiber, this type of insulation differs from other similar products, for being breathable and because it's physical and chemical features remains unvaried over time, maintaining their excellent thermal and acoustic insulation and mechanical properties. Generally able to satisfy the different needs of application and/or of technical performances by meeting the standard regulations in terms of thermal and acoustical insulation, moisture resistance and reaction to fire. In addition, it contains no harmful substances for human beings, it is completely recyclable, and by being manufactured with materials obtained from post consumer PET bottles recycling, it also allows consequently savings of CO2 emissions.

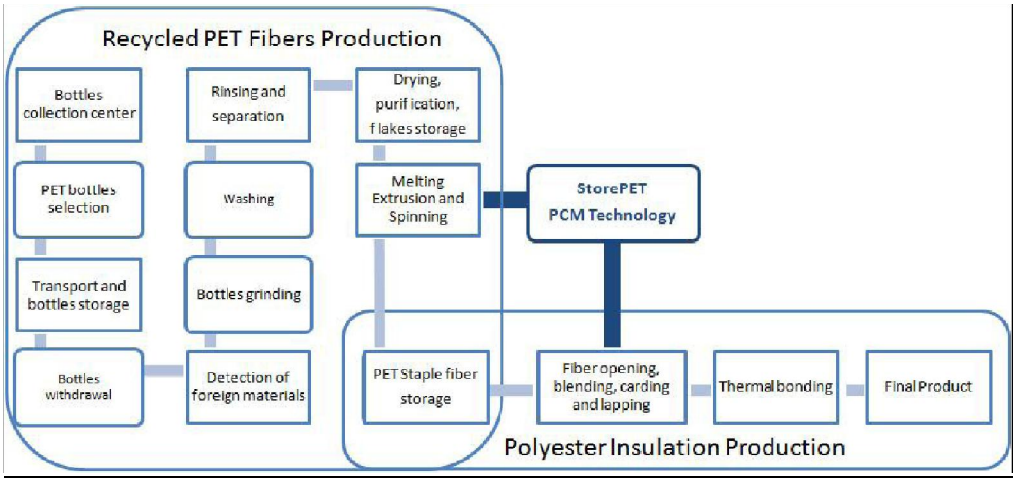

Figure 2. PET fibers and polyester insulation production

The best production process shall be carefully evaluated during the research part of the project, deciding which PCMs will be selected for the new concept and how they will integrate the nonwoven polymer fibers. The challenging proposal that shall be primarily developed is to incorporate micro size encapsulated PCMs inside the hollow or no-hollow recycled staple polyester fibers, during its early production stage. This is probably the most challenging and revolutionary attempt made over the last decades on the fiber insulation sector and should be regarded as a huge breakthrough that will vastly contribute for its market competitiveness.

Up until now this PCM fiber integration has only be successfully made in the textile industry by a limited number of companies, mostly using wet spun acrylic viscose techniques and modified cellulose fibers using Lyocell technology. Complementary, recent research has proved that it is possible to impregnate non encapsulated PCMs (i.e. Ecosine) into polyester fibers, with the aid of supercritical CO_2 fluid suspensions. Although this can be much more expensive solution, leading to the need of extra industrial-size pressure chambers to perform the impregnation, supercritical carbon dioxide is seen as an alternative promising technique.

If proved technical possible and commercially feasible, for instance by advanced manufacturing with fiber electrospinning techniques, the PCM-fiber incorporation will

have major advantages over other technological integration solutions, mainly because the PCMs content will be protected by a dual wall - the first being the wall of the PCM microcapsule and the second being the surrounding fiber itself. This way, the PCM is less likely to leak from the fiber during its liquid phase and it will not settle or be lost from the fiber matrix during handling, storing, application and end-using of the product, enhancing its own life and the repeatability of its thermal response.

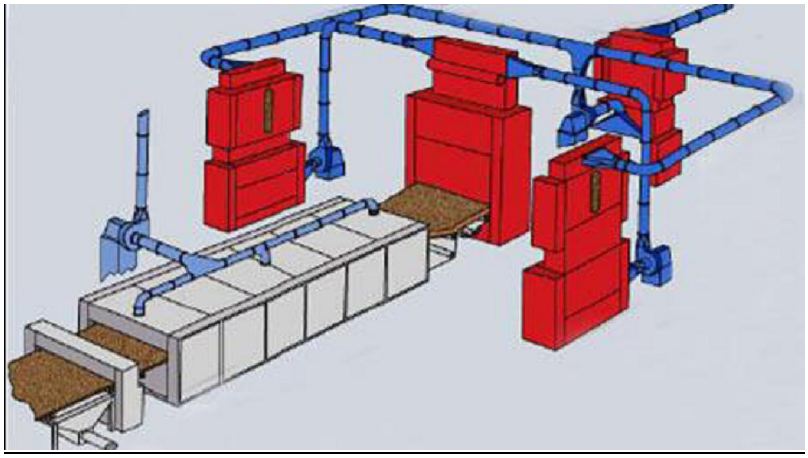

Figure 3. Dry-laid and thermobonding polyester nonwoven production line

StorePET product shall be engineered according to the specific end-use goals and the best nonwoven technology available for its production. The PCM type that will be chosen will take in consideration aspects like its nature and cost, physical and chemical properties, considering the application market climates, its ease of being supplied and its technological ability for being integrated with the polyester fibers at an industrial level, with minimum economical and environmental costs associated.

One of the most important issues to accomplish will be the need to achieve the new heat storage ability for the StorePET product, without compromise and preferably enhance, all other thermal, acoustic, mechanical and fire resistance properties of the standard polyester insulation. This means that it is important to maintain, at least, the same standard polyester fiber properties, like its density, size, thermal conductivity, etc.

The PCM inclusion shall be preferably made during the extrusion or the melt spinning process stage of the recycled polymer PET chips, when pluralities of individual synthetic fibers are formed to be collected into a strand or made into a cut staple type. Afterwards, the standard Dry-Laid process normally used to produce polyester insulation batts and boards seems to be the best option to choose, as it is the easiest to perform the fibres opening mixing and carding. The carding step will provide the thin web layers, which will be subsequently conveyed to a crosslapper unit to produce a multilayered overlapping product on a synchronized process before the final thermobonding process.

If the regular carding Dry-Laid process should find unfeasible to reach the PCM incorporation goal, other techniques should be evaluated like Spun-Laid, Spun-Bond, Melt-Blown or even Wet-Laid processes to perform the job. On the other hand, if the

thermobonding process should proved derlictic for the PCM content, other fiber bonding ways should be searched, minding not to compromise the final properties aimed for the product. Old and environmental unfriendly bonding techniques like the latex ones should be avoided and, alternatively, consider other techniques like the mechanical bonding ones (needle punching, stitchbonding or spunlacing –hydroentangling).

3. NEW PRODUCT BASIC CHARACTERISTICS AND APPLICATIONS

Designed for thermal and acoustic insulation of new residential/commercial lightweight building structures or for overall retrofit operations, StorePET is specially planned to be used on external walls cavities and roof spaces, but also able to be installed under floor, between floors or inside internal walls.
On its double/multilayer design option, it is proposed to be produced in the form of batts, blankets or rolls, with commercial standard sizes and thickness, like, for example: 50, 60, 80, 100, and 120, up to 150 mm. The PCM integrated fibers should have a parallel production line, alongside with the non modified polyester ones until the overlapping stage of the nonwoven manufacturing process. The product will be made of, at least, two different zones - one inner (bottom) side zone made of a thick stack of several layers of regular polyester fibers (low heat transfer zone of the bulk insulation) and a outer (top) zone made of thinner pile of PCM-polyester fiber sheets (the heat storage part of the bulk insulation).
One of the most challenging and positive advantages of StorePET solution will be the capability to be produced and sold a thinner version of the product, made of a single PCM-polyester integration bulk layer (from 10 to 50mm). This slim version will provide the constructors and homeowners a novel and thermally active insulation material, easily combined on site with any other type of standard insulation materials available (mineral and fiber wool, cellulose fibers, foam boards, etc.). Whenever extra thermal mass is needed, thermal storage skills and superior thermal and noise performance provided by the slim StorePET version can be unmatchable for renovation actions, where the lack of available space for insulation is usually small.

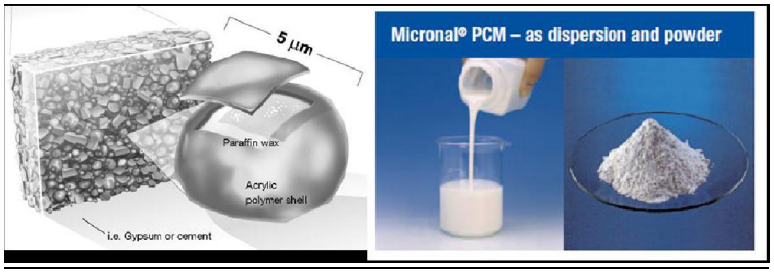

Figure 4. PCM microcapsules

The guaranty of indoor warmth in winter and coolness in summer offered by StorePET insulation products will be conjugated with a superior performance upon on reducing airborne noise transmission by controlling resonating noise inside construction cavities. The excellent acoustical insulation and absorption properties of polyester nonwoven fabrics mainly depend on fiber geometry and fiber arrangement within the fabric structure. Usually, vertically lapped fabrics are ideal materials for use as acoustical insulation products, because they have high total surface area. This surface area is directly related to the denier and cross-sectional shape of the fibers, where smaller deniers yields more fibers per unit weight of the material, thus greater possibilities for a sound wave to interact with the fibers in the fabric structure. The PCMs incorporation technique will try to provide that the sound wave interaction with the insulation matrix remains unaffected.

Regarding the PCMs to be used upon StorePET, nowadays the chemical industry has a large set of different PCM types to offer to all different sorts of markets, based on their phase change process (solid-liquid, liquid-gas and solid-solid) and on their composition (organic, inorganic, or eutectic).

While the list of technical features is long, for building application proposes, one can point out the following as the most important ones: proper phase changes at daily regular climate temperature fluctuations with high latent heat storage capacity and small volume change during their phase shifts, desirable heat transfer characteristics (e.g. good thermal conductivity), low vapour pressure, no or limited supercooling, sufficient crystallization rate, long term chemical stability, compatible with different container materials, no toxicity and no or acceptable fire risk. Other crucial issues are the economics requisites for PCM usage: plenty of resources, available for application and, most important, to be cost effective for large production.

While metallic inorganic PCMs generally show high latent heat of fusion but are seldom used due to their scarce availability and high cost, the hydrated salts of the same group (considered as alloys of inorganic salt and water), lay their merits on a large amount of cost effectiveness candidates at proper temperatures, and on their high latent heat of fusion and thermal conductivities during their phase shift process. However, their biggest disadvantage is related to their incongruent melting during phase change processes, which leads to the separation of the hydrated salt from water, preventing their smooth recombination during the re-hydration phase (freezing process).

Organic PCM and especially the paraffin subgroup („waxes" like alkane hydrocarbons) have been the most used for building purposes, due to: large availability for a wide range of temperatures, chemical stability at multiple change cycles, no phase segregation, sufficient crystallization rate and very limited supercooling, as well as they are not normally corrosive.

Over the last years, technical grade paraffins with some impurities levels are being available at very reasonable prices, showing high levels of reliability concerning their thermo physical properties. Their major drawbacks are normally the low thermal conductivity (solve when possible by their coating with metallic fins or heat exchangers) and their moderate flammability, possible to overcome by incorporating flame retardants. On the other hand, the large variety and versatile grades of non-paraffin PCMs (made from fatty acids or esters and glycols), although with very promising technical properties, are still very expensive and thus not very cost effective for usage.

Extensive research developments on PCM science, led to the possibility of nutshell the thermal material inside thin polymer capsules, preventing it from leak during its phase change and providing higher flame resistance. These progresses gave birth to a new thrust on PCM production for building materials. For example, chemical giant BASF currently uses a paraffin-based PCM in its Micronal® system, which completes a phase change from solid to liquid within the indoor temperature and human comfort range (i.e. at 21°C, 23°C or 26°C) and by doing so it can store a large quantity of heat (heat storage capacities from 51 to 145 KJ/kg). With microcapsules as small as 5μm and supplied different forms (dry powder or liquid powder blends), this microencapsulation technique is consider today the best way to incorporate PCM technology into all sort of building materials, thus also to expected to be within non-woven technical products like the proposed StorePET one.

The PCM type to be used on the project will be carefully chosen, not only for its technical capabilities, price, and manufacturability as impregnated or co-extruded with the fiber, but also for its merits when it comes to provide an indoor comfortable and healthy temperature zone, which is between 21°C and 26°C.

Without discarding other climates, StorePET research program shall be largely focused upon hot summer weather climate conditions. Thus it should spotlight primarily on high melting point and high overall storage and latent heat capacity materials to absorb the excess of heat, preventing the surroundings from heating up any further. Values around 26°C, 145kJ/kg and 110kJ/kg respectively, like the microencapsulated paraffinic ones provided by BASF Micronal DS 5001 (with 5 to 20 μm), should be a good work starting point, as it provides also a huge number of possible and complete phase change cycles (averages of 300 phase changes per year, 10,000 cycles correspond to a minimum life expectancy of more than 30 years).

Although the research program should not be tight only on organic paraffin waxes (other PCMs must be considered), it should be present that the PCMs ability to store heat over a period of several hot summer days will depend always on the amount present. When storage capacity reaches saturation no more heat can be absolved and its performance is diminished. Thus, the overall PCM content to be included on StorePET must be carefully identified towards maximum performance, aiming at least 20% wt content as a start working value.

The selection of PCM type and its overall content, the fibers characteristics and the best and most suitable technology process to accomplish their combination, will be subject of an extensive materials research, backed up by thermal and acoustic modelling and analytical simulation, towards the making of a prototype product that will be largely tested. The thickness of the PCM integration zone-layer shall be evaluated on the same bases, in order to achieve all the anticipated technical properties, and the fulfilment of the mandatory building codes, before it can be delivered to the market. Other important characteristics like moisture and particularly the fire resistance will also play an important role of the project towards the compliance of the specific market regulations, especially considering the PCM content. Nevertheless, when installed, StorePET will be contained within the cavity sheathing and internal lining board until these layers are destroyed. Therefore, it will not contribute to the development stages of a fire or present a smoke or toxic hazard until the lining is compromised.

The research program will also be committed to the need to combine, the least embodied energy and energy footprint possible for StorePET production, with the lowest manufacture expenses, towards a cost-effective solution with a good market acceptance and a minimum time energy-saving payback for householders.

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НОВИ ТЕРМИЧКИ ПОБОЉШАНИ ВЛАКНАСТИ ИЗОЛАЦИОНИ МАТЕРИЈАЛ

Резиме: *Грађевински кластер „DUNDJER“, заједно са већим бројем европских организација, учествује на европском пројекту FP7 под називом „STOREPET“ (FP7-SME-2011-2, Proposal 286730). STOREPET је пројекат чији је циљ да развије један нови термички и акустички грађевински изолациони материјал, базиран на материјалима који при коришћењу мењају своје агрегатно стање.StorePET ће бити посебно пројектован материјал за лаке конструкције са омотачем који има малу термичку масу (термички капацитет), као и за било коју другу стамбену/пословну/јавну нову или реконструисану зграду са посебним*

изолационим и топлотно-капацитетним потребама. Са буџетом пројекта од 2.4 милиона € , процењено је да ће нови производ створити нову вредност у износу од 170 милиона € у уштеди у материјалу и 300 милиона € у енергији. Истраживање је тренутно у току. Један од завршних скупова, са представљањем резултата истраживања је бити одржан у Нишу, у 2013. години. Грађевински кластер „DUNDJER“ ће имати сва права и лиценцу, укључујући производњу и пласман у региону.

Кључне речи: *Грађевински материјали, термичка изолација, акустичка изолација, лаке грађевинске конструкције, енергетска ефикасност, одржива градња.*