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RESEARCH & DEVELOPMENT OF NEW THERMALLY ENHANCED FIBER INSULATION BASED ON PHASE CHANGE MATERIALS1
ISTRAŽIVANJE IRAZVOJ NOVE TERMIČKIPOBOLJŠANE VLAKNASTE IZOLACIJE BAZIRANE NA MATERIJALU SA PROMENOM AGREGATNOG STANJA

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Abstract: 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 a 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.

Rezime: Gradjevinski klaster „DUNDJER", zajedno sa većim brojem evropskih organizacija, učestvuje na evropskom projektu FP7 pod nazivom „STOREPET" (FP7-SME-2011-2, Proposal 286730). STOREPET je projekat čiji je cilj da razvije jedan novi termički i akustički gradjevinski izolacioni materijal, baziran na materijalima koji pri korišćenju menjaju svoje agregatno stanje. StorePET će biti posebno projektovan materijal za lake konstrukcije sa omotačem koji ima malu termičku masu (termički kapacitet), kao i za bilo koju drugu stambenu/poslovnu/javnu novu ili rekonstruisanu zgradu sa posebnim izolacionim i toplotno-kapacitetnim potrebama. Sa budžetom projekta od 2.4 miliona € , procenjeno jeda će novi proizvod stvoriti novu vrednost u iznosu od 170 miliona € u uštedi u materijalu i 300 miliona € u energiji. Istraživanje je trenutno u toku. Jedan od završnih skupova, sa predstavljanjem rezultata istraživanja je održan u Nišu, u 2013. godini. Gradjevinski klaster„DUNDJER" će imati sva prava i licencu, uključujući proizvodnju i plasman u regionu.

Ključne reči: Gradjevinski materijali, termička izolacija, akustička izolacija, lake gradjevinske konstrukcije, energetska efikasnost, održiva gradnja.

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

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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.

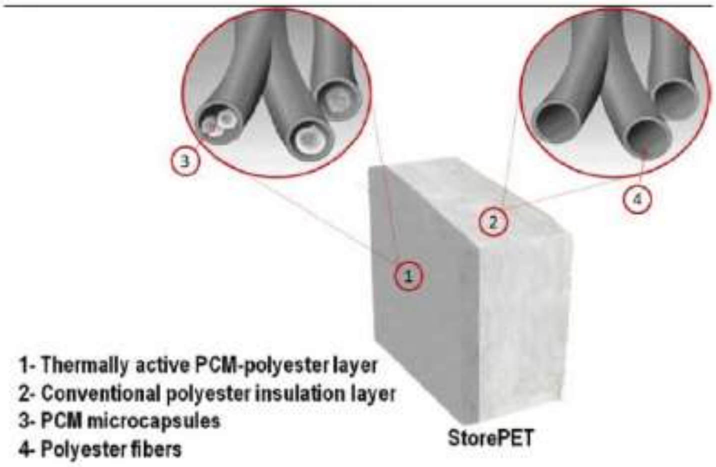

Figure 1. StorePET structure

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.

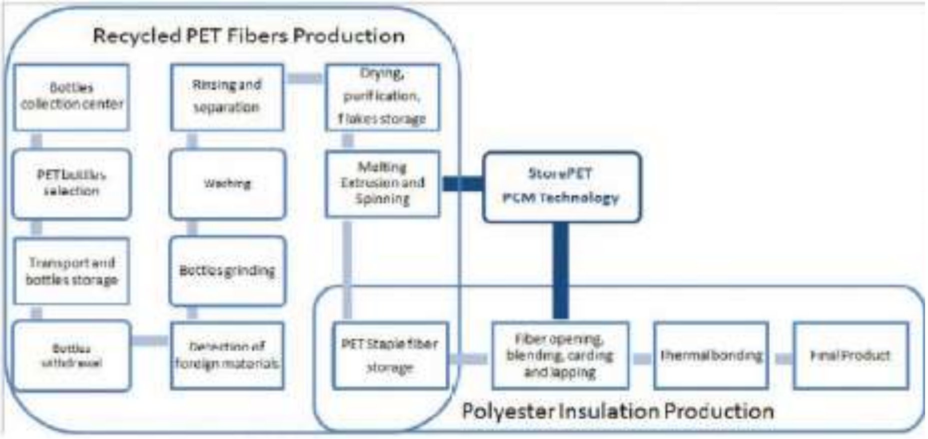

Figure 2. PET fibers and polyester insulation production

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 CO2 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.

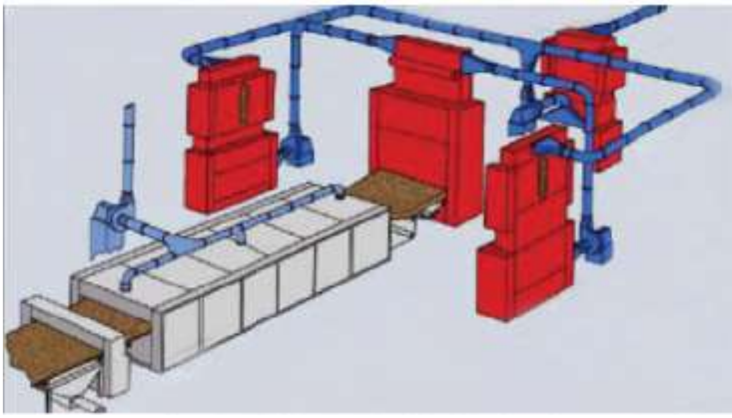

Figure 3. Dry-laid and thermobonding polyester nonwoven production line

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).

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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

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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 is 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 is 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), were 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 was not 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, were 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,

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towards a cost-effective solution with a good market acceptance and a minimum time energy saving payback for householders.

STATE OF THE ART

Nowadays builders and contractors can choose from a large variety of insulations that can vary in cost, performance, and ease of installation. Generally divided in two main categories – Bulk and Reflective, thermal insulation products are sometimes combined into one single product to be able to resist to radiant heat flow (Reflective part) and to block the transfer of conducted and convected heat (Bulk part), trusting on pockets of trapped air within its structure to the last job.

Figure 5. Lightweight timber construction;

Figure 6. LSF construction

Traditionally, lightweight building systems involving timber and steel framing elements have relied mostly on bulk fiber materials (fiberglass or mineral wool) for its heat insulation. Due to technical and time consuming on-site building limitations, these structures are been replaced by modern and less time consuming pre-fabricated plywood Structural Insulated Panels (SIPs), or pre-fabricated composite Light Steel Framing (LSF) systems, that combines faster buildings times, easiness of installation and resources economy, with good heat insulation and superior air-tightness.
Following the overall trend to use rigid foam insulation, the choice of insulation materials for modern off-site manufacturing approach is moving from the traditional fiber materials, and being replaced for thick insulation layers of polystyrene (PS) or polyurethane (PU) foams, sandwiched between oriented strand boards (OSB), or pre-finished skin products made of steel or light aluminium alloys, filled with polyisocyanurate (PI) or PU foams.
Although these materials generally provide better air-tightness and moisture control to the envelope structures, their heat insulation properties are not always superior and surely their abilities to reduce levels of airborne noise are considerably worse than the ones given by the majority of fiber solutions available. A balanced combination of thermal and noise insulation excellence is still only achievable by fiber materials.
A summarized list of the most common types of bulk insulation products is to be found in references and includes bulk rigid foams, fiber blankets bats and rolls and also spray-in-place insulation options, that can even be used together to yield higher R-values (Thermal Resistance, that indicates the material's resistance to heat flow. The higher the R-value, the greater the insulating effectiveness.
Rigid foam insulations are made from polymer materials – such as polystyrene, PU or PI, molded into rigid boards in a variety of sizes. Lightweight and easy to install, rigid foam provides higher insulating values (typical R-values range from R-4 to R-6 per inch of thickness), but generally offers much less guarantees as the fiber insulation materials, when it comes to fire resistance and to reduce noise transmission. The most common product made out of polystyrene is Styrofoam™ produced by DOW Chemicals. Ranging from R-3.20 to 4.00, depending on its density, Styrofoam values are generally adequate for most insulation needs. Closed-cell PI foam board products are being more welcomed (especially in the US), not only because of their thermal insulation abilities but mainly due to its superior reaction to fire.

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Figure 7. Spray-in-place cellulose

Polyisocyanurate insulation is a closed-cell rigid foam board manufactured with isocyanate and polyether mixed together in the presence of a catalyst that allows the molecules to rearrange, forming closed cells. Typical R values of PIR insulation range from R-5.6 to R-8. Finally, there are a large number of commercially available products made of PU foams systems, in the form of large lightweight boards capable of achieving extremely high insulation values, or more commonly a two component, spray-applied on site polyurethane foam that creates a seamless, monolithic barrier for protection against water vapor, heat and air in the interior of steel stud walls. Although generally regarded as good thermal insulators, these product are incapable of levelling with fiber materials (like the StorePET) when it comes to acoustic insulation, which represents their major drawback.


Figure 8. Fiberglass installation

“Spray-in-place” has become one of the most popular types of insulations products, especially due to the increasing number of retrofit actions. Spray-in-place cellulose, fiberglass and mineral wool are cavity insulations that are mechanically blown into the wall. R-values vary depending on installation but generally range from R-3 to R-4 per inch of thickness. This insulation technique usually costs more than blanket insulations, but is well suited to use around obstructions and irregularly shaped areas. However, it usually takes too long to be completely installed, as it must dry completely before being covered by a drywall panel and reach maximum performance. Another potential drawback to loose-fill spray-in-place insulations is that, over time, the R-values can decrease because of particle settling. Spray plastic foam usually overcomes this problem while it‘s usually made of polyurethane or other polymers that have no settling problems. However, special equipment is still required to meter, mix, and spray the foam into place. After application, spray foam expands and conforms to the shape of the wall cavities, helping to minimize air infiltration. The ability to conform to space makes spray foam ideal for insulating around obstructions and other hard-to-reach areas. Spray foam materials and installation usually also cost more than blanket insulation, but its effectiveness for air-tightness is sometimes its major advantage.

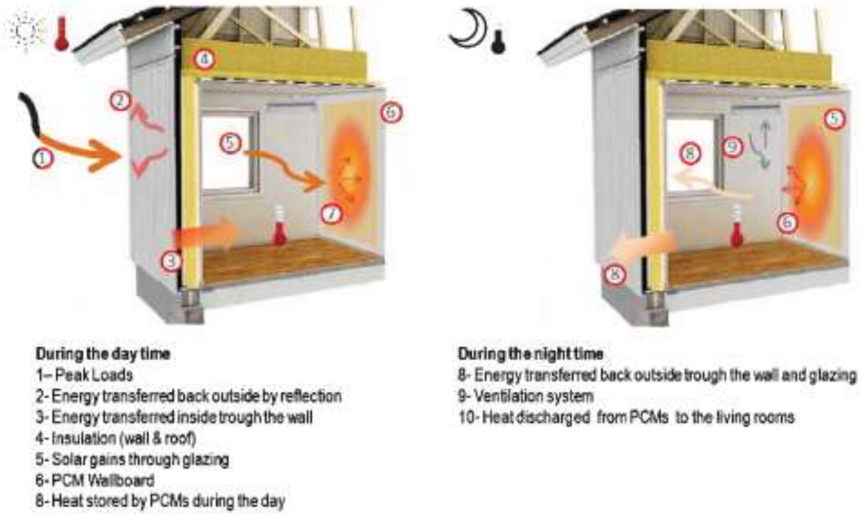

Figure 9. Standard PCM building application

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By the other hand, fiber blankets, batts and rolls, available in different widths and thickness, are the most cost-effective and widely available types of insulation. They are usually made from glass and mineral wool, but also from recycled polymers (polyester insulation) and a long list of natural materials like cotton fibers, sheep wool fibers and even recycled denim jeans, with R-values ranging between R-1 and R-5 per inch of thickness. Rolls come in long lengths that can be cut to required dimensions and batts come in pre-cut standard lengths. Blanket insulation is inexpensive, but the pieces must be hand-cut to fit snugly around obstructions, such as window frames, wires and pipes. Small aps between batts or small non covered areas of the wall are generally the most important factors that lead to a loss of efficiency of these products. Although capable of combining thermal and acoustic insulation skills, there‘s still no fiber product available on the market at a broadly affordable price that is sold as a standalone product and includes thermal storage abilities, thus being able to provide extra energy savings on both cooling and heating dominant loads, like the StorePET.
Worldwide there are several manufactures and supplier of different polyester insulation products that compete with other common fiber materials in the form of soft or semi-rigid boards, batts and rolls, or even on in-situ blow applications. Primarily made out recycled plastic (PET) bottles, this technical nonwoven insulation involves the melting of the polymer materials, to then be spunned to form fibres that are bound together and cut into different shapes and thickness. It‘s an excellent insulation product that does not release fiber dust or irritate the skin as other insulation products can (i.e. fiberglass and mineral wool), thus very easy to handle without the need of personal health safety equipment.
With R-values varying from 1 – 5.0 depending on its thickness, polyester insulation is essentially the same material used in many pillows and often manufactured by the same companies. Polyester allies its excellence heat insulation properties to its no-toxicity and outstanding acoustic blocking properties, as also high resilience and outstanding compressional resistance. Polyester is fire resistant material as it requires quite high temperature to burn. However, poor polyester installation procedures, particularly on roofs and ceilings, can be troubled if batts are not well protected or let to cover down lights & ceiling fans with overheat potential. While being easy to install, resistant to fungis and insects, unaffectable by moisture, produced without formaldehyde, borates or other chemicals and none allergic or irritant, the main environmental benefit of polyester insulation is that it is manufactured out of up to 70% recycled plastic bottles, reducing landfill and contribute for carbon emission cutbacks.

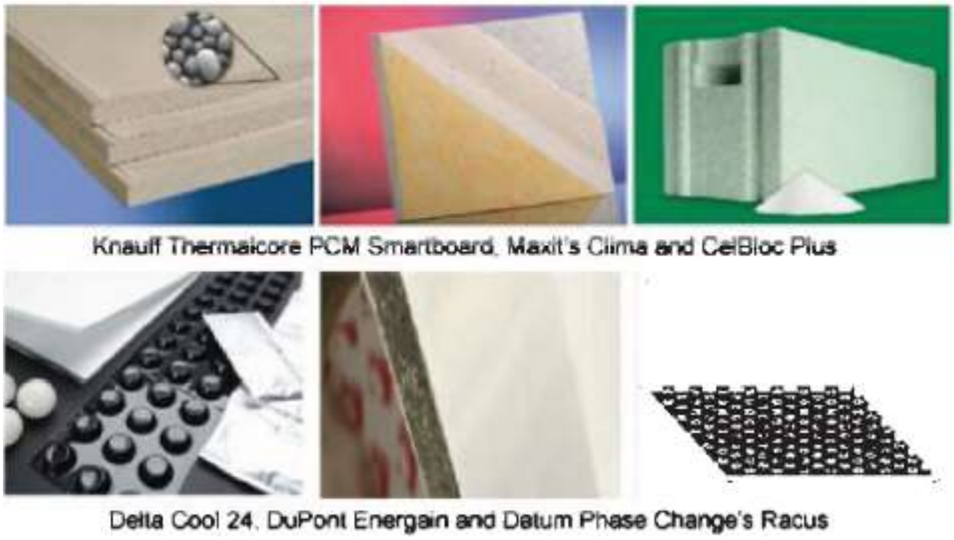

Figure 10. Different PCM applications

Apart from the most common insulation products, recently the market has been receiving some new materials and composites with very good performances and high R-value rates. 99% air-made material, Aerogel is probably the most notable one, as it can reach R-values of about R-10 per inch and is capable of insulate up to 37 times more than fiberglass (the lowest thermal conductivity yet available - 13 mW/mK, while mineral wool is 30-45 mW/mK). Its major drawback is still its mechanical fragileness and huge price. For example, fiber aerogel containing blankets with nominal conductivities of 14 mW/mK, like the Aspen‘s Spaceloft23 ones (capable of reaching a 10.3 R-Value/Inch), are not expected to cost less than $65 US dollars for each m2, for a 5mm thick

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batt24. Aerogel price has been limiting its use in regular residential constructions, although other alternatives are arising like their use inside R-30 and R-50 per inch vacuum insulation panels (VIPs)25, or instead in cheaper but still efficient solutions, like the Thermablock26 aerogel thin tape that helps eliminate thermal bridges on stud wall constructions that can be sold for about \$21/m2.However none of these aerogel solutions act like phase change materials, thus incapable to overcome thermal mass issues and their price is not yet competitive for a broad adoption.

APPLICATION OF PHASE CHANGE MATERIAL (PCM)

Regarding the utilization of PCMs on the building sector, most studies have demonstrated that the application of thermal mass in well-insulated structures could generate heating and cooling energy savings of up to 25% in residential buildings. Considering that new PCM-enhanced building envelope components could be installed in about 10% of both new and existing U.S. homes, the potential for energy savings would be between 0.2 and 0.5 quad/year.

All the extensive scientific research work that has been made over the last 40 years in this area have allowed PCMs to hit the market by being incorporated into products such as: plasterboards or drywall systems (Knauff Thermalcore PCM Smartboard28), interior plasters with a temperature regulating effect (Maxit clima®29) or aerated concrete blocks (H+H Deutschland GmbH‘s CelBloc Plus®30), all of them based on microencapsulated paraffin waxes form BASF. BASF‘s Micronal® 23 is also the component that Datum Phase Change incorporates into a magnesium oxide-based matrix to create the Racus®31 PCM ceiling tile system. DuPont‘s Energain®32 is another PCM related product that is used in construction. It consists of paraffin-based gel core held between two sheets of conductive aluminium, designed to be sealed behind plasterboard walls or above ceiling panels, so they can act as a fire-retardant barrier to the material. The PCM is formulated to absorb heat above 22°C, storing it until the temperature drops below 18°C, when it releases it back to the room. DuPont claims that it can help reduce heat consumption by 15% and air conditioning costs by 35%. Finally, Delta-Cool 24 by Dörken33 is a packaged PCM suited to retrofit situations, that can be easily placed on top of suspended ceilings or under floors, ensuring comfortable room temperatures around 25 °C. Nevertheless, contrary to the StorePET proposal, all the current building market solutions dealing with PCMs do not have any acoustical insulation skills or the same thermal properties like the ones expected from StorePET, which combines thermal storage and thermal insulation in one single product. On traditional applications, PCMs uses the day solar gains through glazing to be able to store the heat without affecting the indoor comfort temperature, and then slowly release it, during the night and with the aid of ventilation, avoiding the need for extra artificial heating during this period. They do not block or buffer the heat exchange between the outside and inside like the StorePET solution proposes.

Up until now, PCMs association with fiber insulation materials has only been tested on in-situ blowing test applications, at construction sites built for academic and industrial-driven research purposes. Some US studies have proved that using loose-fill cellulose and fiberglass insulations mixed with microencapsulated paraffinic organic PCMs can be effective technique to reduce wall generated peak-hour cooling loads on roofs and wall cavities. It was found that it was possible to reach considerable heat flow reductions values (up to 40%) and peak-hour load reductions of 30% during the summer months, depending on the construction site climate conditions.

Although indoor temperature control and energy saving abilities were confirmed by those research reports, none of the trial products tested have yet hit the market. Apart from time consuming procedures, skillful application and specific machinery needs to perform its installation, there are two major drawbacks of this on-site technique that the StorePET product and technology production will aim to overcome – The difficult and inefficient PCM-fiber mixing using a insulation blower and the tendency for the PCM content to become loose and settle on the bottom of the insulation cavity during its life-time, thus reducing its efficiency.

Alternatively, the project proposal was to produce a technical nonwoven insulation on a bulk form (blanket, batt or roll), easily to be installed on the construction site like similar standard mineral or glass wool products. Moreover, the precise layer concept and the ability to get the most out of the PCM content by insert it inside the fibers, seems to be another advantage that surely suppress what‘s being tested on the other side of the Atlantic. Thus its innovation beyond the state of the art is clear. Not only it will outstand the fiber insulation products presently available for having the PCM-fiber technology integration, its stockage, transport, installation and usage will not limitate its time-life performance.

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A patent search on fiber insulation products incorporating PCM materials was also undertaken. A number of patents relating PCM integration with textile fibers were found, like the WO 0224830 (A2) regarding the using of stable PCMs in temperature regulating synthetic fibers, fabrics and textiles and the WO 9812366 (A1), concerning the PCM incorporation throughout the structure of polymer fibers, as a loose fill insulating materials for clothes or bedding articles. Directly linked with thermal control of nonwoven materials, 2003‘s patent Nº 20030551 (A), stated by Frisby Technologies Inc. [US] as applicant, have secured a method to produce fibers, where thermal control material dispersed within a binder could be blown onto a preformed fiber web, to form a bi layered product with one layer having thermal control properties, and another one without such properties. US 2010/0264353 A1 patent assigned by Outlast Technologies INC, describes thermal regulation building materials and other constructions components containing polymeric phase change materials, which shall be taken in consideration not to collide with the StorePET manufacturing production system.

StorePET aims to offer a new solution to a large SME community by adapting already existent technologies used by the textile industry. The latest achievements dealing with the PCMs on this sector have been enormous, mainly dealing with the production of thermo-regulated fabrics (TRF). Several manufacture processes, such as impregnating hollow or non-hollow fibers with a PCM solution, wet-spinning, melt-spinning and electro-spinning are used to fabricate TRFs. Whilst the concept of using PCMs is clearly a very attractive one, there are still a number of limitations. Up to now, only a very small group of fibers are compatible with PCMs, and there is an upper limit to the amount of PCM that can be incorporated into them, before tensile properties are appreciably reduced.

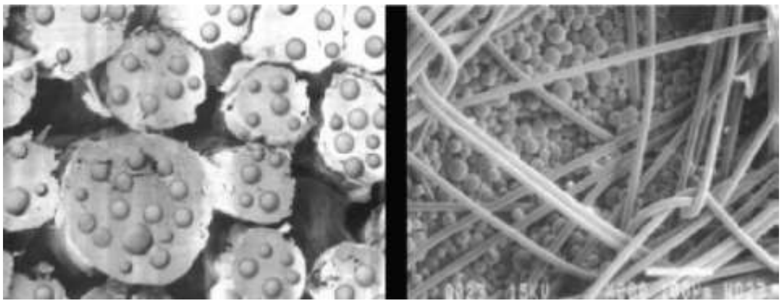
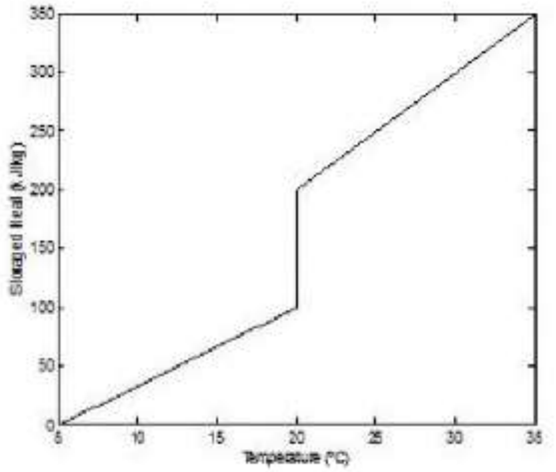


Figure 11. PCM integration with fibers

Currently, the textile market has to offer some commercial TRF products, like the viscose fibers containing MicroPCMs manufactured by Kelheim Fibres (Germany), which provides all of the benefits of regular viscose with temperature-buffering capabilities for extreme comfort. Also, a new environmental friendly technology developed for cellulose shaping was recently accomplished by Thuringian Institute of Textile and Plastics Research (TITK). TITK introduced the Smartcell™ clima fibre - an alloy of cellulose and a phase change material made by using lyocell technology. Unlike the related viscose-based product produced by Kelheim Fibres using the Outlast™ encapsulated phase change material, the TITK process uses the PCM directly and disperses it in the dope with the aid of inorganic nanoparticles. Outlast Technologies microencapsulated PCMs (mPCMs) called “Thermocules” can then be applied as a finishing on fabrics, or infused into fibers during the manufacturing process. Presently it´s undisputable that TRF can response to ambient temperature and maintain the microclimate equilibrium and that is why worldwide researches are currently trying to explore it.

From the knowledge acquired regarding the incorporation of PCMs into fibers, it‘s clear that to produce the novel StorePET product there will be several implicit technological innovations to be undertaken and that optimization process will be needed to provide frameworks for decision making. Thus, risk assessments mitigation procedures and contingency plans must be described by the consortium (type of PCMs and fiber integration technology amongst the most important ones).

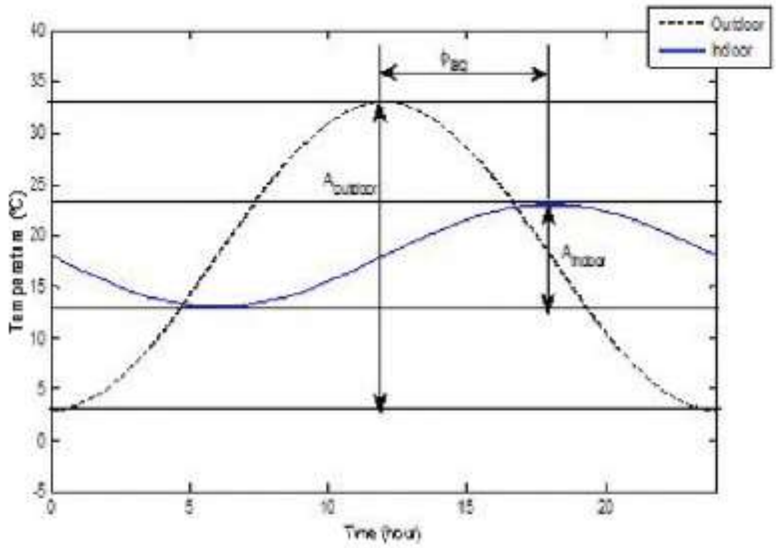


Heat storaged by a PCM with latent heat of 100 kJ/kg
and transition temperature of 20 °C

Figure 12. PCM heat storage

SIMULATION OF PCMAND ACCOMPANIED SOFTWARE

In parallel to the development of the new PCMs products and technology it is fundamental to develop suitable thermal and acoustic simulation tools to aid in the definition of a range of fiber PCM products and system solutions to fulfil the requirements for different applications. In order to implement these tools we had first to establish the mathematical models and physical parameters that drive the heat transfer/storage and sound transmission/absorption in these materials.
With regard to the mathematical model for the analysis of the heat transfer in layers containing PCM materials, the standard methods/algorithms for current materials/applications are based on the equivalent electric circuit with the following analogies:
Temperature – electric potential, thermal resistance – electric resistance, heat capacity – capacitance, heat flow - current. In this circumstances the thermal behaviour of a wall consisting of homogeneous layers can be characterized by the period of the outdoor thermal wave (time between temperature peaks), the thermal resistance and heat capacity of each layer.



Parameters used to characterise the effect of the thermal storage of a wall

Figure 13. Parameters for thermal storage characterisation

However, the equivalent electric circuit method is not applicable to materials with PCMs because this analogy is valid only for materials with constant heat capacity (thermal mass) and thus, the effect of the fusion latent heat exchanged during the phase change cannot be taken into account by these models. Moreover, due to the non-linear behaviour of the PCMs, the standard parameters used to measure the thermal performance of the thermal mass,
that is the time lag φlag (time delay between the peak temperatures in the outdoor and indoor peak temperatures) and decremental factor f=Aindoor/Aoutdoor which measures the ratio between

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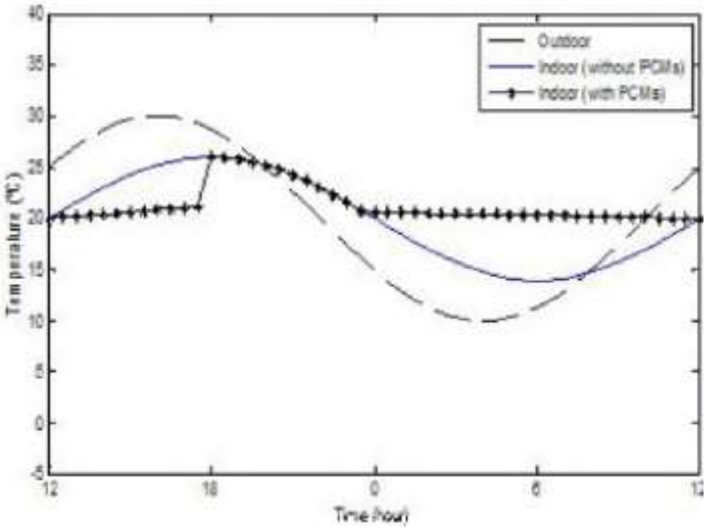
outdoor and indoor temperature wave amplitudes (see figure above), are no longer suitable and new parameters have to be defined to evaluate the enhance in the energy saving introduced by the PCMs.



Indoor temperature profile with and without PCMs

Figure 14. Effect of PCM on indoor temperature

The simulation tool will allow then to calculate the energy saving of a certain wall configuration, containing layers of the developed fiber PCMs materials, for different weather conditions represented by the corresponding outdoor thermal wave. The simulation tool should also cover situations in which the thermal mass of the PCMs is complemented with other indoor temperature control techniques such as night ventilation and/ or solar thermal storage systems. The simulation tool will allow for an optimization of the PCM layers and wall system for a wide range of applications.

On the other hand, in order to implement an acoustic tool it is necessary to fully understand first the effect on the sound transmission and absorption of the embedded PCMs in fiber materials. The mathematical equations and the physical parameters that characterize their acoustic behavior are stated and included in software module that will be employed to compute the sound reduction index of multilayer walls including PCMs. Since the sound absorption and transmission through porous materials is mainly driven by its flow resistance and matrix stiffness, it was investigated whether the PCMs change substantially these properties of the fiber matrix. The acoustic simulation tool has the following input data: number of layers, thickness of each layer, acoustic properties of each layer and computes the sound reduction of the wall.

CONCLUSION

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

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 been 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 remain 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, furthermore not containing harmful substances for human beings, being completely recyclable, and by being manufactured with materials obtained from post consumer PET bottles recycling, it also allows consequently savings of CO2 emissions.

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