FINAL REPORT

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Disclaimer

Summary

This document presents a description of the results achieved as a result of the project execution as well as summary of the overall technical work developed during the three years. The aim of this final report is to provide an overall description of the results and developments of Storepet Project. However, a deep analysis of scientific and technical results including further details can be found in the deliverables published during the execution of each Work Package. This final report also provides a summary about the project coordination and financial management tasks. Finally future exploitation routes are provided in the final chapter.

Apart from the RTD, all industrial partners (Industrial Associations and SMEs) in the Consortium have contributed with their effort to the successful achievement of the goals proposed in this period.

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1. INTRODUCTION

1.1. PROJECT SUMMARY

STOREPET is a project funded by the European Commission 7th Framework Program It started on 1st November, 2011 and it will last three years. The project is developed by a Consortium set up by partners from different European Countries. It is formed by four Industrial Associations, three SMEs and four research centres.

New building strategies addressing climate change effects and reduction of heating/cooling energy are two fundamental issues at EU level. Figures as the 35,000 excess deaths attributed to the last heat wave in the continent in 2003, or 10% of the world's energy being used just for heating of buildings support European citizen's concerns and new EU legislation. New national and communitarian stringent directives, together with the economic slump of the construction sector (showing two digit shrinkage rates) have set extremely high challenges to the already weakened companies in the construction sector, especially the SMEs. A market need and a new opportunity for them is researching competitive solutions for thermal and acoustic insulation of light-weighted constructions, a broadly recognized market driver for the next decade.

The project aims to bring a new product to the building market – StorePet – a new inexpensive thermally enhanced and "ready to use" fiber insulation phase change material (PCM) -based composite, that combines on a single product 3 major skills: thermal insulation abilities to block heat transfer into or out of the buildings, outstanding airborne sound control proficiency and now also thermal storage capacities. The versatility of the concept will make it adaptable for heating and cooling purposes, enabling this product to address different climate patterns and geographical markets just by tailoring its relative composition, dimensions and installation layout.

The participation of Construction Associations, having the ability to broadly disseminate the results throughout their members, will enable a large amount of SMEs to benefit both directly via manufacturing of knowledge-based materials and indirectly via a reactivated economy creating new business to installation and construction SMEs. It has been estimated that this will produce new streams of revenue worth € 170 million in the materials and installation sectors supporting more than 4000 employments, and energy savings worth above € 300 million.

1.2. PROJECT OBJECTIVES

To ensure the project's success a list of clear objectives were defined, covering base scientific and technological aspects, measurable and quantifiable technical product goals, up to economical and societal intents.

Scientific Objectives

✓ Achieve a clear and extensive understanding of the lightweight building systems currently available, their technical needs and most commonly thermal and noise insulation materials used, its relevant standards and building regulations dealing with the latest energy efficiency requirements;

- ✓ Clearly define the theoretical principles evolving thermal conductivity and heat storage and transfer behaviour of PCM fiber composite materials, as well as the fundamentals ruling its acoustic absorption and insulation;
- ✓ Noticeably identify the best technical fiber characteristics and which PCMs materials and are most likely to be used, based on their thermodynamic, chemical and physics properties, production costs and technological skills aiming the nonwoven PCM-fiber integration and its end using goals;

Technical Objectives

- ✓ Develop the product's design and the technology for its making by building a newly prototype line system for PCM-fiber integration and trial product manufacturing;
- ✓ Refine StorePET production technology, aiming to combine the best technical properties with the least embodied energy necessary for its production, using the most cost effective raw materials with the highest recycled content possible and least energy consuming production lines;
- ✓ Define the active ventilation systems that should accompany the installation of StorePET insulator, in areas of extreme absolute temperature but low fluctuation;
- ✓ Develop a software for thermal and acoustic properties evaluation aiming the design of the optimum StorePET product for a type of installation and a set of variables. It will bring an easy-to-use interface for professionals non highly qualified on the use of sophisticated simulation tools, but will relay on finite elements modelling, properties of raw materials, layer zone designs and climate patterns of the most plausible entrance markets.

Product Technical Objectives

- ✓ Achieve on a lab scale using a guarded hot box facility, reductions in heat flow of about 40% with the new PCM-fiber product, when compared on the equal conditions with the same fiber material produced without the PCM content;
- ✓ Achieve by field tests potential and significant cooling load reductions during a spring-summer season period. The fulfilment of this objective will be dependable on the location of these tests. For places with large daily temperature fluctuations during the hot season, peak-hour load reductions higher than 20% and cooling-dominated loads reductions up to 40%, shall be expected (representing real energy savings), when compared with regular fiber insulation materials (mineral wool, glass wool, etc.);
- ✓ Secure a thermal conductivity K (W/(mK)) not higher than 0,04 and preferably under this value;

- ✓ Accomplish a thermal resistance - RSI value (m^2K/W) not less than 2,5 for a nominal thickness of 100mm;
- ✓ Achieve a noise transmission insulation (Rw) not less than 55dB for StorePET, when placed between a wall partition made of a double drywall panel, with a 6cm cavity space;
- ✓ Guarantee all the other technical requirements to meet the national and communitarian building codes and regulations for each proposed entrance market. Special emphasis shall be given upon moisture and fire resistance, this last one with a European fire classification stated not less than Class Bs2d0.

Economic Objectives

- ✓ Accomplish significant energy savings concerning the reduction of air-conditioning needs related with the walls/roofs heat exchanges, and a controlled and balanced price for this new product, aiming a reasonable payback time for its end users considering the energy saving possibilities (within a maximum of 5 years).

Societal Objectives

- ✓ Increase the consumer (building constructors and home-owners) knowledge and acceptance of this new thermally enhanced insulation product;
- ✓ Demonstrate the market demand for a new building insulation material like StorePET;
- ✓ Protect/increase the employment in related companies, from raw materials and technical non-woven producers, to PCM suppliers, up to the overall building construction market chain;
- ✓ Increase citizen's level of indoor comfort and reducing health problems related with thermal and acoustic insulation issues;
- ✓ Contribute for the reduction of global CO_2 emissions by joining the effort to effectively decrease the building sector account for energy usage.

1.3. The Consortium

Coordinator

1. SGG / Slovenski gradbeni grozd, gospodarsko interesno združenje (Slovenia)

Industrial Associations

2. TECNIBERIA - Asociación Española de Empresas de Ingeniería, Consultoría y Servicios Tecnológicos (Spain)

3. TEXCLUBTEC (Italy)

4. DUNDJER / Gradjevinski Klaster Dundjer (Serbia)

SMEs Partners

5. Ecoterra Desarrollo Sostenible SL (Spain)

6. RAMA / Construcciones Garcia Rama SL (Spain)

7. Devan-Micropolis S.A. (Portugal)

Research and Development Partners

8. Tecnologías Avanzadas Inspiralia (ITAV)

9. IPN / Instituto Pedro Nunes - Associação para a Inovação e Desenvolvimento em Ciência e Tecnologia (Portugal)

10. CENTROCOT / Centro Tessile Cotoniero e Abbigliamento SPA (Italy)

11. ACCIONA Infraestructuras S.A. (Spain)

2. STOREPET PROJECT DEFINITION

2.1. BACKGROUND: SOCIAL AND ECONOMIC NEED

Currently buildings account for 40% of the world's energy and almost half of the today's Green House gas emissions. Most of buildings' energy consumption presently used for heating, cooling and ventilation is still needlessly wasted due to the lack or inefficient insulation measures. Under the recent climate change projections, it is estimated that this consumption will rise considerably on the next years to come. Under this scope, the last Intergovernmental Panel on Climate Change (IPCC) recommendations stated the need to drastically cut the energy use both in new and existing buildings, in order to reduce its energy-related carbon footprint by 77% (against the predicted 2050 baseline) and minimize and stabilize the corresponding CO2 levels. To reach this objective it's estimated that global building sector needs to cut energy consumption in buildings 60% by 2050, in order to meet the global climate change targets.

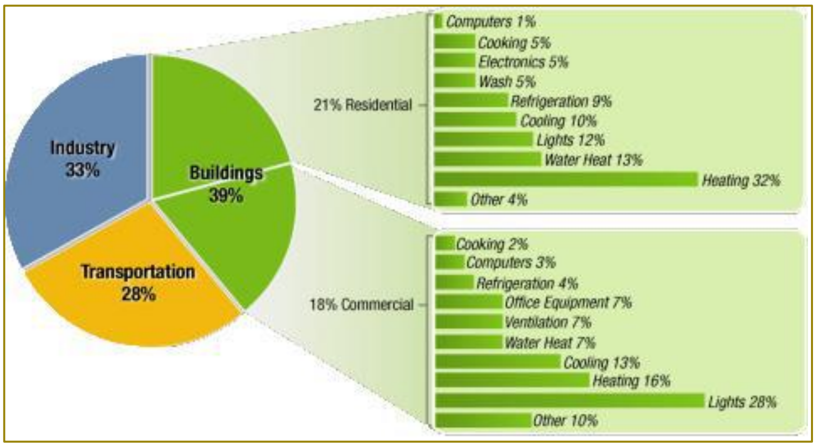


Figure 1: Energy consumption by industrial sector

On May of 2010, the new Energy Performance of Buildings (EPB) Directive was finally adopted as Directive 2010/31/EU. It calls for improved national regulations upon new and renovated houses energy efficiency, with very ambitious standards and mandatory goals. It also includes a framework for national requirements, related with heating/cooling and ventilation systems. In July 2012, the new directive has been implemented, though many elements including the regulation of building systems will only be fully enforced by July 2013. By the end of 2020, new buildings in the EU must consume 'nearly zero' energy. With a current stock of around 160 million buildings in the EU, the latest EPB Directive also tack the retrofit of existing buildings, including historic ones towards an effective action against climate change.

2.2. The Technical Problem

Lack of thermal mass in the lightweight constructions

The lightweight constructions represent an economical alternative to traditional buildings, one of their main drawbacks is their very high energy load needs to keep internal comfort conditions, as they are unable to curb rapid swings of temperature due to their lack of thermal mass. 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.

The effect of thermal mass is more pronounce in regions having seasons with large daily temperature fluctuations above and below the balance point temperature of the building (BPT), which represents the outdoor air temperature required for the indoor temperature to be comfortable without the use of any mechanical heating or cooling. This is the outdoor air temperature at which the heat gains due to electric lighting and equipment, body heat and solar radiation are in balance with the heat losses through the building envelope due to temperature differences. In cases of heavyweight constructions (e.g. masonry ones), a substantially part of energy is saved by avoiding a significant portion of heat flux being transferred through the envelop backward and forward. Often, the benefits are greatest during the seasons when fluctuations above and below the comfort temperature occur. In warmer climates, when outdoor temperatures are at their high peak, the inside of the building remains cool because the heat penetration through the mass is delayed. On the contrary, in cold climates requiring intensive heating, thermal mass is used to effectively collect and store solar gains and to store internal excess heat during the day, both something that lightweight envelope structures cannot do, even if highly insulated. Thermal mass stores and re-radiates heat, while insulation stops heat flowing into or out of the building. A high thermal mass material is not generally a good thermal insulator and the best insulation material has almost no thermal mass. Thus, for instance, in harsh hot climate conditions, the only way to maintain a comfortable temperature inside a lightweight building on a summer day without installing active air conditioning is to somehow increase its thermal mass. You can do it in traditionally manner with heavy building materials, or by introducing PCMs (Phase Change Materials) in its construction.

Phase Change Materials

PCMs are substances with high heat of fusion latent heat storage which, by melting and solidifying at a certain temperatures, are capable of storing and releasing large amounts of energy and thus somehow able to play effectively the energy storage role as thermal mass components in lightweight structures.

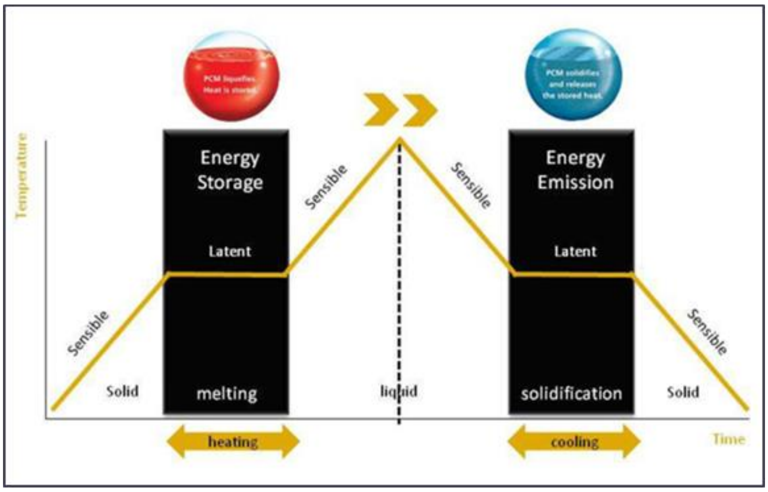


Figure 2: Phase Change Materials performance

PCMs take advantage of high latent heat that can be stored or released from a material over a narrow temperature range. These materials absorb energy during the heating process, as phase change takes place from solid to liquid, and releases back that energy to the environment during a reverse cooling phase change process.

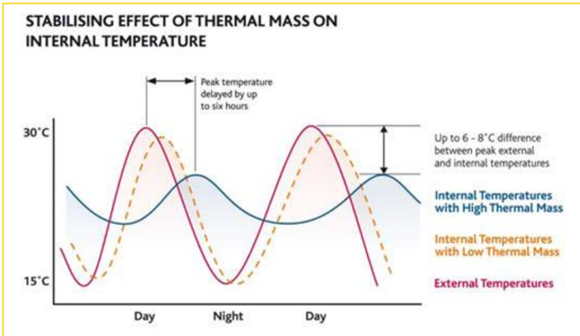


Figure 3 Effect of Thermal Mass in wall internal temperature

Desirable thermo physical and chemical properties for PCMs:

- Melting temperature in the desired operating temperature range and congruent melting of the phase change material
- High latent heat of fusion per unit volume
- High thermal conductivity of both solid and liquid phases
- Small volume changes on phase transformation and small vapour pressure at operating temperatures
- High nucleation rate to avoid super cooling of the liquid phase
- Chemical stability and no degradation after a large number of freeze / melt cycles
- Complete reversible freeze / melt cycles
- Non-corrosiveness to the construction materials
- Non-toxic, non-flammable and non-explosive materials
- Affordable

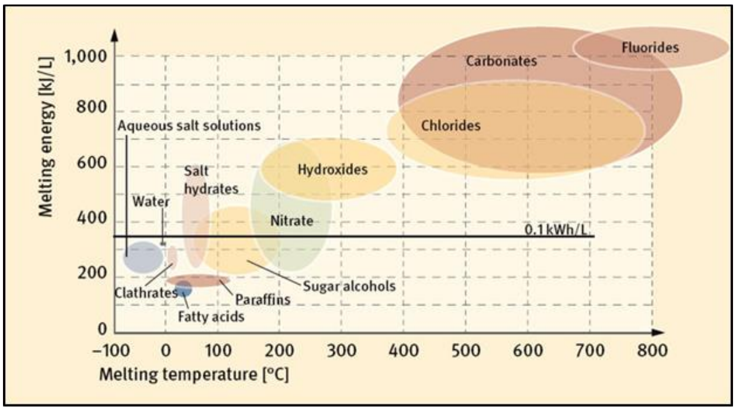


Figure 4: Classification of PCMs according to the melting energy and melting temperature

None of today's building materials incorporating PCMs in a stand-alone product are designed either to perform as heat flux blockers through the building envelope (external walls and roofs), or as a noise insulator. In fact, commercial PCM products available in the market, are commonly placed on the interior surfaces of walls, ceilings or floors (such as PCM integrated gypsum wallboards, concrete, plasters, etc) and generally used to reduce indoor day/night temperature swings, due only to diurnal solar gains through glazing, by storing autonomously the heat during the day and release it back during the night, providing an extra heat source to keep the inside comfort.

The StorePET project intends to overcome this market gap and act differently from any other PCM available product, using PCMs fiber incorporation technology to excel the extra advantage of the conventional fiber insulation work, regarding the large temperature fluctuations that take place in attics or at the exterior wall surfaces trough the envelope of lightweight building structures.

2.3. The Project Concept

The project concept is based upon the fact that outdoor/indoor heat exchanges (which plays 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-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. Although more suitable for warmer climates and expected to be more effective in places and seasons with large daily temperature fluctuations, while tailoring its composition with different phase change temperature materials and different installation layouts, StorePET will be able to respond to a broad range climate patterns.

This feature will give it a unique and unmatchable versatility amongst other building insulation products. Out of each design temperature season, the product will just act like a normal fiber insulation material, keeping all other thermal properties intact. 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. From the point of view of energy efficiency design, the added value of the PCMs is its extra ability (on top of the thermal resistance) to reduce energy consumption in the building.

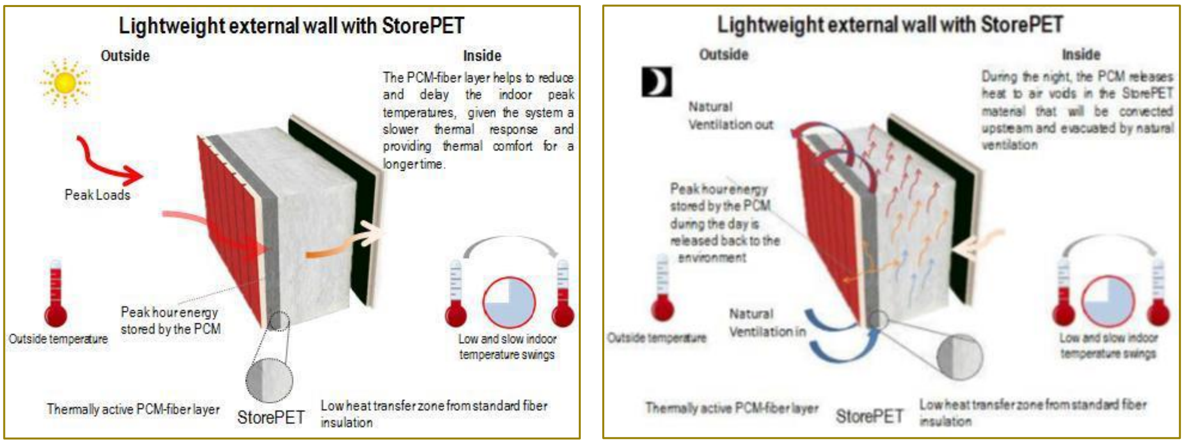


Figure 5: Storepet concept

The main goal of the STOREPET project is to develop a new nonwoven technical insulation product that integrates phase change materials for heat storage capacity skills.

Maintaining the superior levels of thermal and noise insulation commonly recognized for fiber materials, STOREPET will be especially design for lightweight and low thermal mass building envelope structures, as well as for any other residential/commercial/governmental new or refurbishing building projects, with extra insulation and heat storage capacities needs. Although expected to be more effective in places and seasons with large daily temperature fluctuacions, where it's possible to take full advantage of its performance abilities, this new product can also be used as standard insulation on any type of climates and a secure choice to counteract global warning rising temperatures.

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 the fibers will be modified/impregnated with organic 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.

It's foreseen that Storepet products will be able to secure a heat flow reduction in lab condition of about 40%, when compared with the same fiber material produced without the PCM content and guarantee similar reference values in terms of other thermal and acoustical properties and secure all the technical requirements to meet the national and communitarian building codes and regulations for each proposed entrance market. In terms of energy savings, it is expected to secure by field tests potential and significant cooling load reductions during a spring summer season periods representing real energy savings. Although very dependable on the climate location during the evaluation tests, reference peak-hour load reductions values higher than 20% are expected and cooling-dominated loads reductions up to 40%, when compared with the simultaneously usage of non-PCM activated fiber insulation materials (mineral wool, glass wool, etc.).

3. Project outcomes: the final product

The project outcomes are include the material insulation panel, its production technology and the simulation software which allows engineers and architect to choose the best PCM composition according to the geographical location of the lightweight building. The development of the product covers two steps:

- **STEP 1: Choose the adequate PCM for the type of application:** Firstly, the best PCMs materials for the application should chosen be used , based on the materials properties evaluation, like melting point, enthalpy value and sub-cooling, also with the aid of simulation software tools.
- **STEP 2: Choose the PCM integration technology:** A this step it is important to choose the product's design and the technology for the PCM-fiber integration and product manufacturing, to combine the best final technical properties with a feasible industrial up-scaling and the least embodied energy necessary for its production.

3.1. The Storepet insulation material

The final StorePET product referred in this report consisted on a flexible double panel -like PCM-fiber layer solution that was produced in an industrial environment. The STOREPET insulation material is a flexible insulation nonwoven panel made of:

- 100% recycled polyethylene terephthalate (PET) fibers;
- Thermo-regulating microencapsulated phase change materials (mPCMs) and flame retardant coatings.

Figure 6: Storepet panel

The main important factor in the development of Storepet is the choose of the most appropriate PCM for each location. Organic PCMs like paraffinic waxes and fatty acids both present phase changing temperatures around human comfortable range, making them suitable for building applications. Paraffins are the mostly used organic heat storage PCMs, but obtained from petroleum. Alternatively, fatty acids and their esters derived from common vegetable and animal oils can provide an assurance of continuous supply of PCMs, despite the shortage of fuel sources.

- Paraffins (18-38°C)
- Fatty acids esters (22-34°C)
- Eutectic mixtures

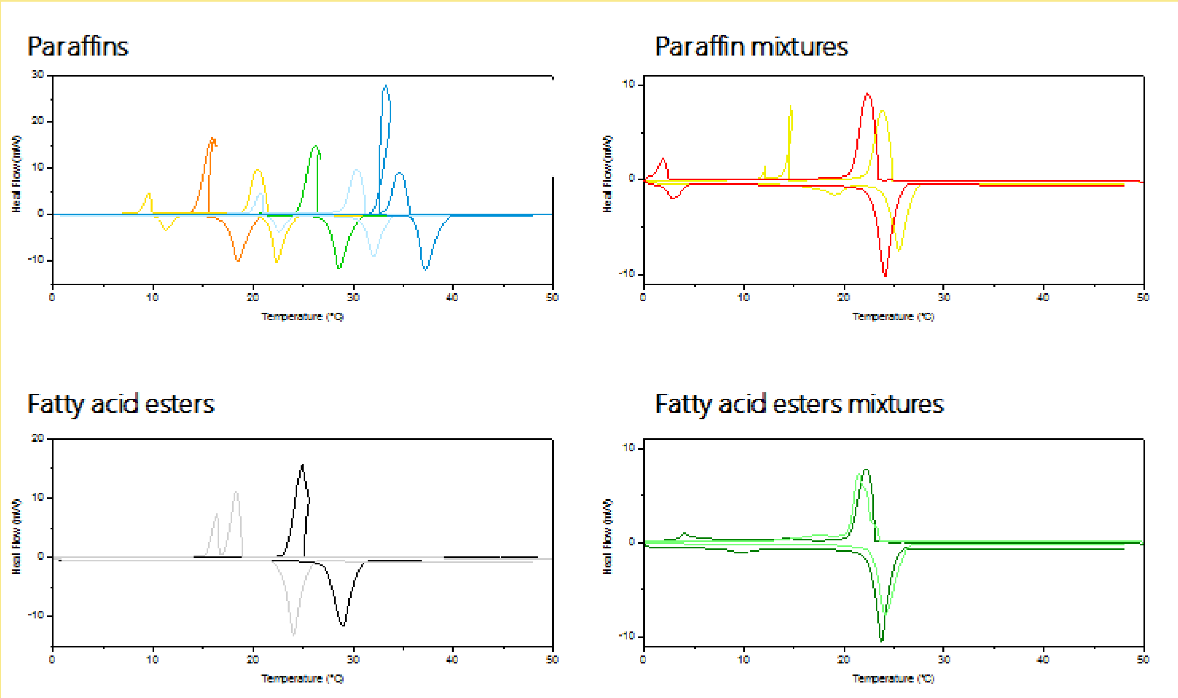


Figure 7: Behaviour of different PCMs

The product Ecozero® used as benchmark is a nonwoven thermal and acoustic insulation panel made of recycled polyester that has been used as raw component for the production of the StorePET composite panel. The following table shows the technical features of insulation product Storepet.

COMPOSITION	1 layer – Ecozero® (1450x600x40 mm) 1 layer – Ecozero® (1450x600x30 mm) Thermo-regulating microencapsulated PCM coating		
SIZE AND DENSITY	**Length and width**	1.45 X 0.60m	ASTM C 167 (other sizes and thicknesses possible)
	Thickness	84.1mm	
	Mass per unit area	4.529kg/m^2	EN 29073-1:1993
	Density	53.85kg/m^3	
THERMAL PROPERTIES	**Heat flow reduction (cooling demands)**	Up to 33% when compared with similar non-PCM additivated panels (hot-box test)	
	Thermal conductivity	0.04 W/mK	EN 12667:2001
	Thermal resistance (100mm)	2.5 m^{2}K/W	
OTHER PROPERTIES	**Noise insulation**	>57 dB*	EN 20140-3
	Fire classification	Class Bs1d0	EN 13501-1:2013

3.2. THE STOREPET PRODUCTION PROCESS

The production process required to manufacture Storepet panels will depend on the PCM integration technology. The PCM integration technology will be chosen depending if the PCM will be integrated inside the fibers and outside the fibers. The following drawing shows the production technology which could be used in each case:

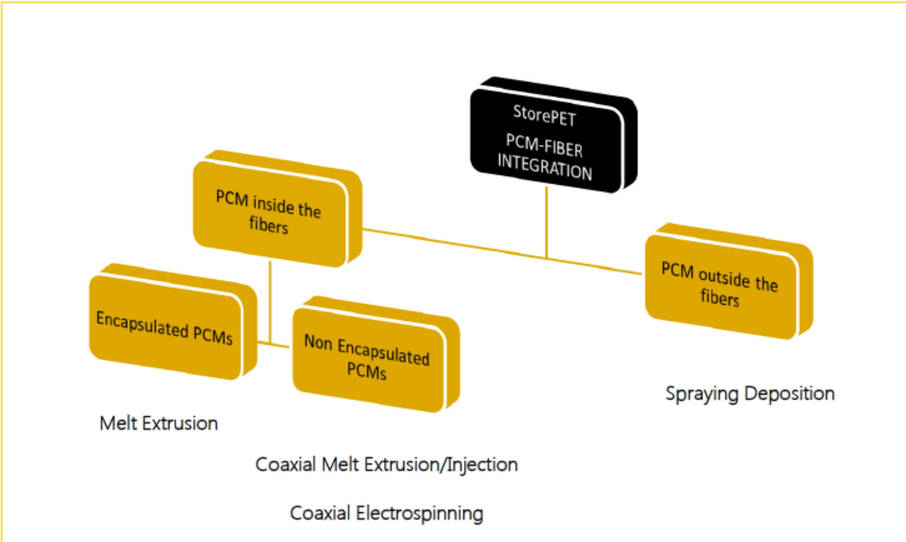


Figure 8: Classification of different kinds of production process for Storepet

1. **<u>Coaxial melt Extrusion/Injection:</u>** with a brand new fiber melt-spun design integrated with PCM injection system, it is possible to manufacture bi-component fibers having only a PCM material in its core. The PCM is staunched inside the core and PET is sheath part of the fibers. The drawback is the difficulty to scale-up for a mass production at this moment since the technology is still under development.

Figure 9: Coaxial Melt Extrusion for the production of Storepet

2. **Coaxial electrospinning:** The electrospinning process allows us to create continuos fibers with diameters in the nanometer to the sub micrometer range. However, currently can not be used for the mass production of Storepet due to its drawbacks: low production rate, not environmentally friendly (harmful polymer solvents) and difficult to up-scale.

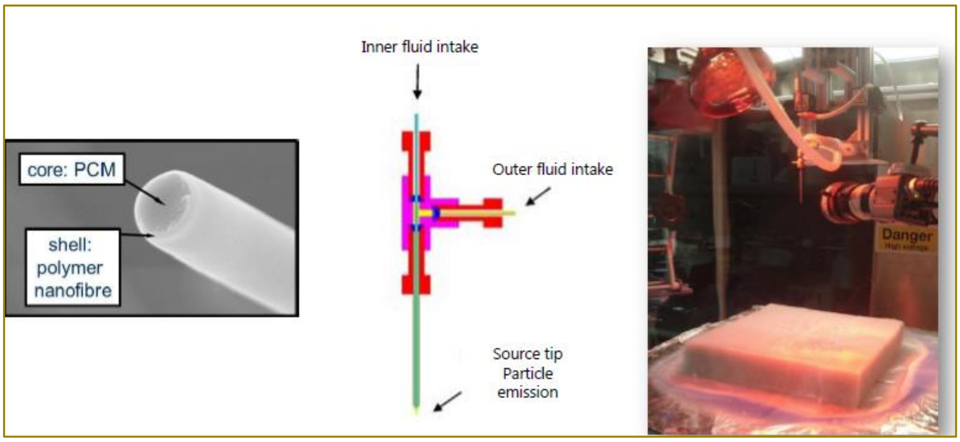


Figure 10: Coaxial Electrospinning for the production of Storepet

3. **Spraying deposition:** This technology allows us to integrate PCM outside the fibers. It consists on spraying of the PCM over the PET panels. Previously, it has been an optimization process of the distance between the nozzles and the panel and the panels themselves.

Figure 11: Spray deposition process for the prodcution of Storepet

3.3. THE STOREPET SIMULATION SOFTWARE

The Storepet final product includes a software tool which allows engineers to know the panel performance and profitability in each specific case depending on the PCM used. "Thermal Building" software was developed during the project for the computation of the thermal performance of cuboid buildings with multilayer walls containing insulating panels with layers of Phase Change Materials (PCM). The application can compute heat losses of a building (heating and cooling loads) and other parameters for user specified weather conditions. The software helps in making comparison of performance of the StorePET insulating panels with traditional insulating materials.

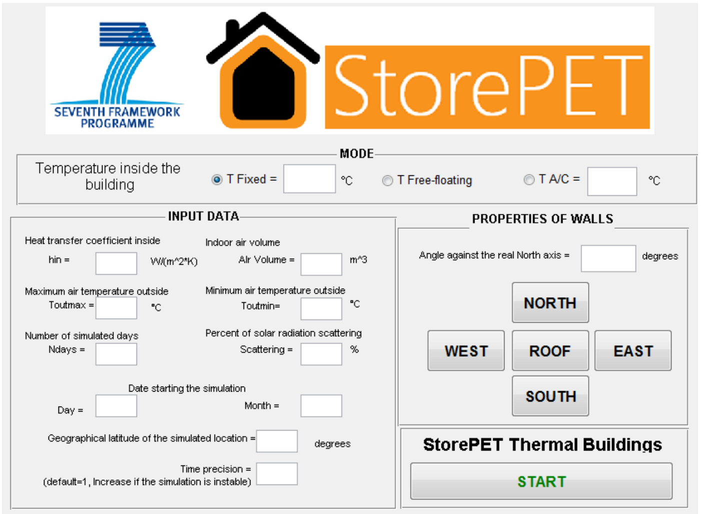


Figure 12: Front end of Storepet Software

The input required by software are the thermal building features such as the solar irradiation that the walls received and the indoor climate conditions (free-floating, A/C or fixed temperature). The software calculates the wall's external and internal temperatures as well as the cooling and heating loads. From that outcomes, the PCM layers simulations is launched. The difference between energy released and absorbed by the panel is the effect of PCM phase change, due to the heat is converted into latent enthalpy. In addition, the STOREPET software takes into account the effect of hysteresis and subcooling which is neglected by all programs available in the market.

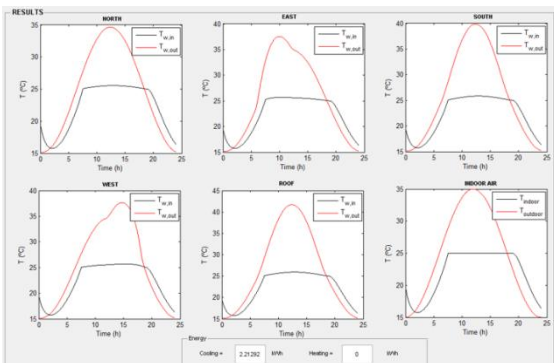


Figure 13: Outcomes of the simulation software

3.4. Validation of Storepet

Real scale mock ups were built in Madrid (Spain) to demonstrate phase change behaviour of StorePet material.

Figure 14: Mock up built to test Storepet panels behaviour

Averaged peak to peak analysis revealed internal temperature differences of around 1ºC during the day and 1.5ºC during the night, between the STOREPET and the Standard test-cells for a typical summer period. Parallel energy consumption tests over cooling systems showed a reduction in the electrical demand of around 40% for the STOREPET demo building comparing to standard one having no PCMs. The following graph shows the peak to peak temperature:

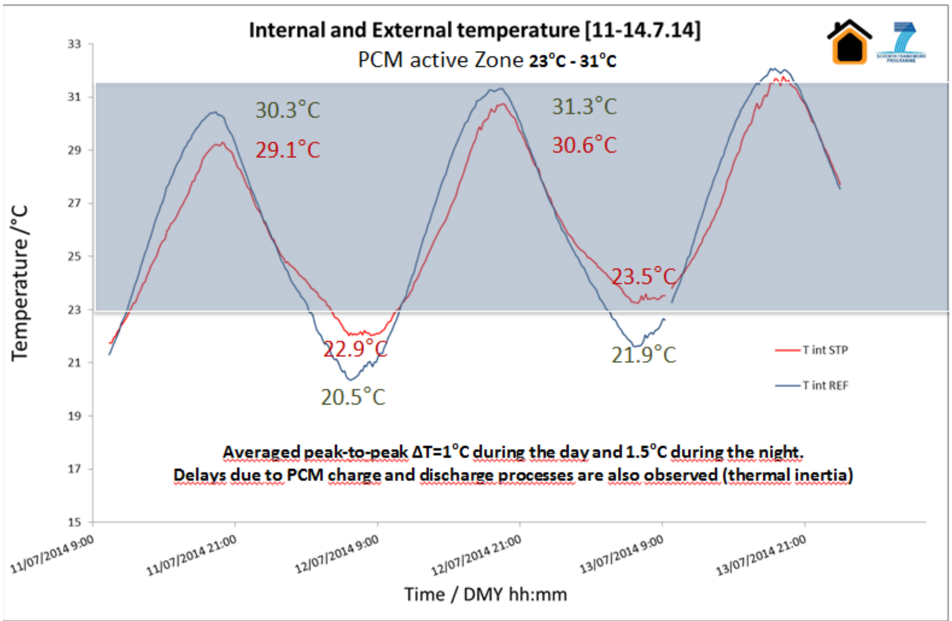


Figure 15: Analysis of Storepet performance in real conditions

4. Project Development and Achievements

4.1. Main Achievements

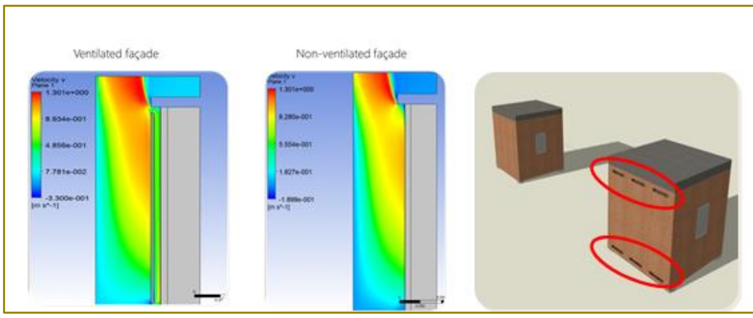
The Consortium has overcome the project objectives which have been described in section 1.2. of the present document. We list below the main achievements related to the project results

1. **Result 1: Fiber manufacturing process and fiber products:** We have achieved the development of fibers modified/impregnated with raw/encapsulated PCMs on a single/multilayer bulk design through three production processes: Coaxial Melt Extrusion/Injection (bi-component PCM/polymer fibers); Coaxial Electrospinning (micro/nano bi-component PCM/polymers fibers) and Spraying deposition (micro-encapsulated PCM) (See section 3.2. of the present document for further description and pictures).

2. **Result 2: Design of functionally textured non-woven acoustic and thermal panel - StorePET:** We have developed a Novel PCM enhanced fiber insulation with heat storage capacities. The following picture shows the features achieved:

Figure 16: Technical features of Storepet panel

3. **Result 3: Design of natural ventilation systems integrated with StorePET:** We have studied the StorePET integration in ventilated façades by simulation tool with these two main conclusions: both ventilated façade and PCM have significant effect on energy consumption and using PCM and ventilated façade reduces cooling need nearly to zero (assuming 26°C indoor)



PCM	Ventilated façade	Cooling MJ/m²	kWh/m²	kWh	saving
NO	NO	14.9	4.1	34.8	base
ALL	NO	8.9	2.5	20.8	40.1%
ALL	West	7	1.9	15.6	55.2%
NO	West	11.8	3.3	27.7	20.4%
NO	ALL	6.5	1.8	15.2	56.3%
ALL	ALL	0.4	0.1	0.8	97.6%

Figure 17: Simulation of natural ventilation facade

4. **Result 4: Product Performance Assessment Software Tool:** We have developed a Software to assist production (product specification definition) and foreseen product performance according different constructive solutions and climates (See section 3.3. for further details and pictures).

Apart from the achievements related to the project results defined in DOW, we have carried out complementary tasks which have allowed us to reach the following outcomes:

- Defined possible climate patterns (market oriented) and suitable PCMs for the e ach location
- Produced diverse binary mixtures of organic PCMs
- Developed/assessed fire retardants for different PCM Storepet applications
- Defined a suitable set of tests for technical evaluation (heat flux tests) and assessed Storepet product on-site in demo houses
- Developed dedicated simulation tools including subcooling effects for the PCM action
- Initiated the pre-market procedures : MSDS sheets; life Cycle Assessment; CE marking and Green building certification
- Envisaged multiple industrial scale up settings
- Established industrial production collaborations for future exploitation
- Promoted cluster integration since Storepet has become a member of the EU Advanced Material and Nanotechnology Cluster (AMANAC) - Nanoinsulation & HVAC working group
- Produced training material for future knowledge
- Promoted Storepet on multiple platforms (congresses, fairs, magazines, flyers, posters, internet, e-seminars, etc.)

4.2. TECHNICAL COMPLIANCE OF THE FINAL PRODUCT

The main achievement is the production of a Storepet panel able to reduce the cooling electric demand by 33% compared with other similar products. In addition three different production processes has been analyzed with the development of new coaxial melt spinning technology. Apart from the Storepet Panel, the Consortium has developed the tailored software "Thermal Building" which provides the thermal performance of the building according to the insulation material, i.e. the kind and quantity of PCM used.

The following table shows the features of STOREPET faced with project goals.

Product Technical Objectives	Goal	Achieved	Remarks
Heat Flow reduction	~40%	33%	Very close to accomplish the objective
Noise transmission insulation	≥ 55 dB	57 dB 61 dB	Objective exceeded
Thermal conductivity	≤ 0.04 W/(mK)	0.04 W/(mK)	Objective accomplished
Thermal resistance for a nominal thickness of 100mm	≥ 2.5 m^2K/W	2.5 m^2K/W	Objective accomplished
European fire classification	Class Bs2d0 (at least)	Class Bs1d0	Objective accomplished

As conclusion all the critical objectives of project linked with the technical compliance of the new developed StorePET product were either accomplished or very close to it, clearly attesting the potential of the novel PCM based insulating solution created for the lightweight building sector. Furthermore, additional product characterization was accomplished (dimension, mass per unit of area, density, mechanical strength, water adsorption, moisture absorption, mildew and hot resistance and corrosiveness).

4.3. MILESTONES ACHIEVED

The above technical objectives have been accomplished by means of an excellent technological development carried out by RTDs in the Consortium with the support of the rest of industrial partners. In order to ensure a successful project development, a list of 5 milestones were defined in the Workplan which measure if an important technical event in the project had been achieved. The following table shows the milestones and the means they have been verified during the project development.

MILESTONE NUMBER	MILESTONE NAME	WORK PACKAGE	MEANS OF VERIFICATION
MS1	StorePET composition, design and technology for its making	WP1, WP2	Samples of PET with PCM were produced and tested in the laboratory providing full reports about the features. Three production technologies were tested: electrospinning, coaxial melt spinning and spray.
MS2	Development of thermal and acoustic software tools aim to aid in the material and production	WP3	A software tool based on mathematical models has been developed which is able to determine the best PCM and its concentration for a required thermal storage in a temperature range.

MS3	Industrial PCM-fiber technology integration and creation of a new and technically validated production		Although three integration technologies were tested, just spray deposition could be used for a mass production in the time period of the project. By means spray deposition, a large amount of panels were produced to build the two mock ups to validate the technology. Additional panels were produced for final tests and certifications.
MS4	Software application for end-users to evaluate energy savings when using StorePET in a building	WP6	"Thermal building" software was developed. This software allows engineers to know the energy savings for different PCM and for each building.
MS5	StorePET field performance validation and marking certification	WP7	The required standard test have been performed (fire, mechanical, ...etc) showing that the product can be certified as insulation material for building construction

4.4. DEVELOPMENT OF WORKPACKAGE 1

The goal of WP1 named “Preliminary research. Application of relevant scientific concepts to the product context” is to establish a scientific research framework in order to analyze the different parameters which are involved in the development of Storepet products. The work developed in WP1 has been carried out by means of 5 tasks, each one has produced its own deliverables (D 5.1, D 5.2, D5.3, D5.4 and D5.5) as it is described in this section.

Task 1.1. Recognize and characterize the most recent lightweight building advanced systems, in terms of different envelop facades, inner walls and roofs dwellings.

During the task 1.1., a full study about the parameters involved in the construction of lightweight building and retrofitting dwellings have been carried out. Given that the development of ventilation systems is a result of STOREPET project, the constructive technique of ventilation facades has been studied. An important issue for the development of new construction products such as STOREPET is to know which European directives regulations and standards must accomplish. For that reason, the European buildings and codes have been analysed. The first regulation that STOREPET has to fulfil is the Construction Products Regulation (305/2011/EU – CPR) adopted on 9 March 2011 but it will enter into force from 1st July 2013. Taking into account that STOREPET products availability is 2014, the new developed materials will apply to get Declarations of performance and all other technical compliances according to CPR.

The CE marking process has been described since the Consortium intends to apply for it. Apart from CPR directive, the energetic efficiency regulations requirement has been showed. The main policy driver affecting the energy use in building at European levels was the 2002/91/C Energy Performance of Building Directive. This directive was recast in 2010 (2010/31/EU) in order to promote the uptake of very low and nearly zero energy buildings. Due to national legislation are more strict than

European, the requirements for new buildings have been studied in in different countries. Finally the thermal insulation products standards have been analized: performance requirements, dimensional and mechanical standards, acoustic and fire retardant standards.

Task 1.2.: State the current non-woven polyester insulation production technology and technical skills available for PCM materials integration.

The task 1.2. is focus on the description of the state of the art of nonwovens which are the base material for STOREPET production. An extensive research about nonwoven and its properties have been carried out during the development of task 1.2.. Raw materials have been analysed showing the tree more promising for STOREPET technology: PLA; Fiber fireproof recycled from PET and sheep wool. The manufacture process of nonwoven materials has been described, showing the three steps of the production cycle: web formation, bonding and post-treatments to improve the product. The last technological developments in nonwoven production is the introduction of microencapsulate ingredients such as phase change materials, which is the objective of Storepet project. A detailed description of measurements parameters has been included in the state of the art, describing the measurement methodology for each parameter and the corresponding norms. Finally, the market of consumption of nonwoven materials for the building sector has been exposed. Further information can be found in deliverable D.1.2.

Task 1.3. Typify the different PCM materials available on the market, their application on building insulation systems and on fiber textile products.

The work developed in task 1.3. is focus on an extensive scientific, technical and commercial literature review related with different types of PCMs available on the market. Literature review has proved that PCMs can be used successfully as thermo-regulating materials, both for building and textile applications.

The aim of this preliminary work was to identify the most suitable PCMs types to be used in STOREPET development. Based on established indoor thermal comfort ranges and following the assumption that SOTREPET will perform better under cooling load dominate climates with hot summer seasons, its was defined tow ranges of “summer/winter” temperatures, where PCMs should have their melting/freezings phase transitions (between 18-22ºC and 23-36ºC, respectively). It was also recommended that the research team should primarily focus upon the summer related ones. Under this context, climate information data from different European locations have been collected, particularly from the possible sites where STOREPET field tests can be done in future WP7.

Given the above properties, inorganic salt hydrates were found the obvious choice to take. However, salt hydrates materials are not considered to be a proper candidate for the specific STOREPET “building-textile” application for several reasons, mostly due to their incongruent phase change and supercooling drawbacks, that would be difficult to overcome. Alternatively, the scientific and commercial literature review as proved that both organic paraffinic and no paraffin PCMs incorporation within fibers already have been preliminary tested with good results and that they can be used for STOREPET development, with many plausible candidates suitable to undertake the task at appropriate transition temperatures, both in raw form or microencapsulated. Also the flammability characteristics are vital when it comes to select the appropriate PCM materials for STOREPET, since the final product will benefit if the PCM will be the least flammable possible. Paraffins are well known for not passing this goal, so for them to be used some sort of flame retardant must be employed. Under this scope, project partner DEVAN will be in charge of supplying a non-halogen fire retardnay material to overcome this disadvantage. The ability to chosen PCMs to be microencapsulated is another requisite that ust comply, especially for attaining the STOREPET solution of mixing the PCM content within the PET fiber matrix. In principle almost every single commercial PCM is capable of being microencapsulated, although its price will increase considerable. Again the use of a flame retardant shell could bring other technical improvements other than increasing the conductive surface area and liquid phase leakage containment.

PCMs				
	Melting Temperature	*Latent Heat of Fusion*	*Raw form / microencapsulated*	*Possible PCMs types*
Organic PCMs	Group A (16-22°C)	>180 kJ/g (preferably higher than 200 kJ/g)	Both	Paraffins: Hexadecane and Heptadecane (supplied by DEVAN); Non-paraffins: Fat and oil based PCMs (supplied by DEVAN or other company)**
	Group B (23-36°C)*			Paraffins: Octadecane, Nonadecane, Eicosane (supplied by DEVAN); Non-paraffins: Fat and oil based PCMs (supplied by DEVAN or other company)**
Additives				
Thermal conductivity enhancers	Expanded graphite micro or nanosized powders (if needed).			
Fire Retardants	Non halogenated ones (provided by DEVAN, both for fiber incorporation and coating)			

* Preferential group for initial research stage;

** Select at least two (and no more than five) inside the working temperature ranges with the highest latent heat fusion possible and that can also attain the following properties: fiber integration potential, reduced supercooling, fire resistance capabilities and chemical and thermal stability under many phase change cycles.

Based on that criteria, it was settled that both solid-liquid organic paraffinic and no paraffin PCMs based on renewable socurces (fatty acids from fats and oils) are the best candidates to use in STOREPET development for fulfilling of most part of the requisites needed. Regarding their major weaknesses, related with their low heat conduction and flammability associated problems, the research team has identified some additives that can be sued to overcome these drawbacks (like expandable graphite particles and non-halogen fire retardant materials). The following table summarizes the PCMs and relative additives that have been primarily used for the A brief discussion of possible PCM-fiber integration technologies available was also discussed, covering both conventional and novel melt spinning and electrospinning techniques, as well as coating and lamination process. Finally, the extensive literature survey done helped the subsequent research tasks as an initial scientific and commercial PCM related baseline database.

Task 1.4. To state the mathematical equations (model) and the corresponding physical parameters required to analyse the heat transfer and storage and the sound transmission and absorption of fiber materials with and without PCMs.

The aim of task 1.4. is to establish the mathematical equations to model the heat transfer and propagation of acoustic waves in different building materials and in particular in nonwoven fibrous materials and Phase Change Materials (PCMs). The equations derived are the basis for developing and implementing, respectively the thermal and acoustic software modules in WP3.

On one hand, the first part of this task was to present the mathematical equations that model heat transfer in building materials (solid, porous and PCMs). Formulas and numerical methods are derived for solving these equations in different situations. In order to establish the mathematical equations of the thermal performance of building elements, the fundamentals of thermal insulation were presented describing the heat transfer equations for porous materials and for walls. The parameters used for the evaluation and comparison of thermal performance of building elements were: heat transfer coefficient, decrement factor and time lag. Using these parameters, it has been analysed two cases: homogenous wall with constant thermal inertia and multilayer walls with constant thermal properties.

On the other hand, the Sound Reduction Index (SRI) was considered for the evaluation of the acoustic performance of a building element. The Sound Reduction Index is the parameter employed to characterise the airbone sound insulating properties of building elements (walls, floors, facades, door, windows, etc) in stated frequency band. The experimental method to measure this parameter is specified in the standard EN ISO 140-3:1995.

The different equations that model the acoustic propagation in different types of media were stated: air (acoustic fluid in general), porous (rigid skeleton), porous (flexible skeleton) and viscoelastic solid. These equations have to be solved for computing the SRI in the frequency range 100 -400 Hz for different configurations and materials.

Task 1.5.: Preliminary investigate the materials life cycle assessment (recycle content, carbon foot print and embodied energy involved) upon the production of polyester fibers and the PCMs most likely to be used.

The goal of task 1.5. is to collect different scenarios in STOREPET production in order to find the best one from an environmental point of view since STOREPET has two main purposes: decrease the required energy in constructions by the use of novel materials and, simultaneously, use the best solution to minimize dioxide carbon emissions. The work developed in task 1.5. is a preliminary study in terms of environmental impact. It can be used as basis to find the optimum model for construction which will be studied in WP7.

For that reason, a preliminary study in terms of Life Cycle Assesment (LCA) has been carried out in order to see the possible impact of materials. The methodology adopted in the LCA followed the guidelines and procedures defined in the ISO.

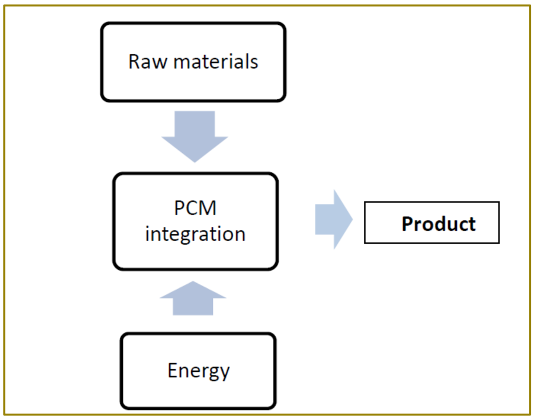


Figure 18: Life Cycle Assesment Diagram

Within the societal objectives, it is established that STOREPET will contribute to the reduction of global carbon dioxide emissions, what can be measured by the next items: produced CO2 emissions in the production and manufacturing of new products, recycling and energy required to get the final product from raw materials. These concepts have been measured respectively with carbon foot print, recycle content and embodied energy.

4.5. DEVELOPMENT OF WORKPACKAGE 2

Comprised in its full extension inside the first period, WP2 named "Raw materials, product technology and design definition" based its activity on laboratory research and testing and had 3 main objectives including the definition of the best fiber material and the most suitable PCMs to be used upon product development, the definition of STOREPET design and the technology for its making, the later including all the mitigation and risk assessment measures to accomplish the PCM-fiber integration goal. All the objectives were achieved by means of the development of the 3 tasks proposed in the DOW (T2.1, T2.2 and T2.3).

Task 2.1.: To investigate the best fiber raw materials to be used on the product development.

The goal of T2.1 was to choose the fibers that would best comply with the technical properties needed for trial production and for the overall project targets. The selection of the materials was based on the information stated on the deliverable D1.2 of WP1.

Under this context, both natural and synthetic materials were taken into consideration, from mineral and glass wool fibers, up to expanded polystyrene and polyurethane polymers along with the initially proposed polyester fiber ones, for their well-known thermal and acoustic insulation ranks and their common usability in the construction field. Among the different materials possibilities to create the STOREPET thermal and acoustic insulation, polyethylene terephthalate (PET) fiber was chosen.

Although there are many reasons for this choice (including price, availability, recyclability content, etc.), the main ones were not only that PET is already established the in the industrial nonwoven insulation market (making it easier the technology transfer), but mainly for the superior ability of this material to undertake all the PCM-fiber integration processes foreseen for the project, specially the ones involving the making of a PCM-Fiber integration using unshielded PCMs in a sheath-core bi-component fiber system by melt-spinning or electrospinning techniques, for having much lower processing temperatures than, for instance, mineral and glass wool materials.

The laboratory characterization and testing of the polyester PET fibers was made upon commercial available ones, supplied by the Italian subsidiary of Freudenberg Politex, from their non- hollow Ecozero® label fibers, with denier and dimensions manufactured special for thermal insulating and sound absorbing construction products, entirely using 100% recycled polyester staples from post-consume PET bottles wastes. In close partnership with the over mentioned company, it was possible to underline the materials supply network and process control parameters needs for the subsequent up-scaling tasks of STOREPET product development. Following what was proposed in the DOW's task description, the extensive laboratory characterization of these fibers and of their related insulation panels has involved the determination of mass per unit area (UNI EN 29073-1:1993), Measurements and weight (MIP 019:2008 Rev.1), identification of fibers in textiles, the assessment of antibacterial activity and antimycotic effect (UNI EN ISO 20645:2005 and SN 195921:1994), the determination of air permeability of fabrics (UNI EN ISO 9237:1997), the thermal properties of the fibers like thermal resistance, the determination of enthalpy and temperature of melting by DSC and mass variation and temperature of decomposition by TGA (UNI EN 31092:1996 Par. 7.3, ISO 11357-3:2011 and UNI EN ISO 11358:1999), the water-vapour resistance (UNI EN 31092:1996 Par.7.4), the reaction to fire (UNI 8457:2010) and the evaluation of sound insulation (EN ISO 10534-2:2001). All results are detailed expressed in Deliverable D2.1 and in the following table.

TESTS	RESULTS	
Mass per unit area	656 g/m^2	
Thickness	50,0 mm	
Identification of fibers in textiles	100% polyester	
Antibacterial activity (agar diffusion plate test)	with Staphylococcus aureus and Klebsiella pneumoniae: no growth, good effect	
Antimycotic activity (agar diffusion plate test)	with *Candida albicans* no growth, good effect	
Air permeability (applied depression 200 Pa)	1278 mm/s 153 l/min	
Thermal resistance	0,488 m^2K/W	
Water-vapour resistance	31,2 m^2Pa/W	
Melting temperature (N_2 atmosphere)	246,7 °C	
Crystallization temperature (N_2 atmosphere)	194,6 °C	
Mass variation and temperature of decomposition (N_2 atmosphere)	onset decomposition temperature: 409,7 °C offset decomposition temperature: 449,5 °C maximum decomposition temperature: 432,9 °C loss of mass: 86,9 % residue: 12,3 %	
Reaction to fire (mean values)	afterflame time : 0 s afterglow time : 0 s cotton yarn breaking: not present damaged area - height : 90,4 mm damaged area - width : 21,4 mm molten debris : none product category I	
Determination of sound absorption coefficient	Frequency (Hz)	Absorption coefficient
	500	0,22
	630	0,25
	800	0,33
	1000	0,40
	1250	0,49
	1600	0,61
	2000	0,71
	2500	0,81
	3150	0,87
	4000	0,88
	5000	0,85
	6300	0,85

Task 2.2.: To investigate the best PCMs materials to be used on product development.

Task T2.2 comprised the investigation of the different PCMs materials possibilities to be used on product development with the ultimate goal of choosing the best ones to comply with all the technical properties needed for trial production (WP4) and for the overall project targets.

The initial selection of materials was based on the information stated on Deliverable D1.3 of W1, which have previously defined organic based PCMs like paraffins waxes and special tailored fat and vegetable oil based PCMs are the ones that could best meet the project goals, with proven results either inside the core of bi-component systems or mixed along the fiber matrixes. The extensive laboratory thermal characterization preformed involved 5 different types of paraffinic PCMs, pure and technical grade ones, the last ones provided by the PCM manufacture partner that integrates the STOREPET consortium, who also supplied microencapsulated ones and was responsible for the paraffinic PCM raw material supply for the subsequent project working progress.

Figure 19: PCM samples

Thermal tests performed by conventional dynamic and isothermal step method DSC analysis have demonstrated that saturated hydrocarbons (paraffins) of type C_nH_{2n+2}, from n-hexadecane to n-eicosane, clearly have melting/crystallization transitions temperatures inside the range previously considered optimum for product application (16-36°C) and superior latent heat storage values above 200J/g, with congruent melting and minor subcooling effects during the crystallization stage. Also inside the goal conditions are the two technical grade octadecanes (in a raw form) supplied by DEVAN (Devan A and Devan B) and also their microencapsulated reference (Mikrathermic D28 – Devan mA), the last one with enthalpy values around 180J/g, meaning that there are all valid solutions for using in STOREPET. A comprehensive report of this study can be found in Deliverable D2.2.

Supported by the simulation tools developed in WP3 and in accordance with the provisional locations foreseen to be used to evaluate and demonstrate STOREPET energy savings potentials by field tests (WP7), it was decided that it should be primarily used n-octadecane (onset - - 243J/g) and n-heptadecane (onset - - 222J/g) for STOREPET production, with the possibility to use also n-nonadecane. The possibility to produce paraffinic binary mixtures was also considered and tested, with some promising combinations, specially the 10:90 wt.% ones of n-hexadecane or n-heptadecane and n-octadecane ones, showing the best performances with enthalpies of fusion around 214J/g and 246J/g, respectively and substantially lowering the fusion onset temperature of octadecane and reducing its melting temperature around 2°C.

As expected from their flash point temperatures, all non-encapsulated paraffins tested have showed to be thermally degraded at relatively lower temperatures (around 100-120 °C), which came to prove the tremendously challenging task of processing it for fiber integration by standard and traditional fiber meltspinning methods. Complementary, the flame resistance enhancement of these materials was also tested using paraffin mixtures with a shape stabilizing fiber polymer (HDPE) and intumescent flame retardants, such as ammonium polyphosphates, pentaerythritol and expanded graphite. Preliminary results have shown that with these additives (specially expanded graphite) it‘s possible to get more thermally stable mixtures, for being able to generate char residues at elevated temperatures. On the contrary and as expected, the encapsulated sample (Devan mA) showed a much better thermal stability behavior, by being able to resist until 360° C with only 12% of weight loss due to the protection of its melamine shell. Still, it was emphasized that the use of microencapsulated materials by spraying deposition techniques for STOREPET production should employ nonwoven’s halogen free flame retardant additives already developed to increase the final flame resistance of the generated prod ucts, thus avoiding the need of extra and time consuming developments of novel flame resistant microencapsulation formulas. The selection of additives was discussed with DEVAN and it was decided to used their “Eco-flam” brand formulation for the purpose. Although the laboratory research was mainly focused upon an extensive thermal analysis evaluation (phase change and operational (thermal stability) temperatures, latent heats of fusion and crystallization and heat capacity determination), other properties were evaluated under this task, like the variation of the PCMs density with temperature, the microencapsulation sizes and the rheological properties of the unshielded paraffins, not only to provide data inputs for the thermal and acoustical simulation tools being developed (WP3), but also to assists the PCM-fiber integration works in progress by different technological approaches.

In conclusion, the work proposed in the DOW for this task was fully approached, with all results generated reported in detail in Deliverable D2.2. The main goal of this task was also attained by electing the PCMs to be used for trial production in the subsequent WP4 tasks.

Task 2.3.: Product design and initial risk assessment

One of the most important assignments of Task 2.3 was to define all the industrial technological needs for STOREPET production and, particularly, evaluate which technological approach should be envisaged during WP4 (up scaling production) for the PCM-fiber integration. Under this context, 2 major technological process approaches (routes) to obtain the STOREPET products were evaluated: PCM-Fiber incorporation by melt spinning and electrospinning techniques, involving both raw and encapsulated PCMs and a 2nd route, involving, not the integration of the PCMs inside the polymer fibers in core-shell structures, but an alternative microencapsulated PCM-Fiber mixture by spraying deposition.

- Route A: PCM-Fiber incorporation by melt spinning techniques-

For this approach it was initial tested the possibility to use microencapsulated PCMs by uniaxial melt-spinning, with Devan's Mikrathermic D28 characterized in Deliverable D2.2 and a commercial PET using ratios of incorporation from 5 to 10% of the thermally active material. This process will always set serious restrictions to the maximum levels of mPCMs capable of being used and, ultimately, high thermal storage efficiencies like the ones needed for building applications should not be expected. To think upon developing, if feasible, a new type of capsules that could comply with all the mPCM-Fiber integration melt-spinning needs (as suggested on the DOW's risk assessment), would have involve a high risk of failure and would be too much time consuming for the time frame of the project. This way, the project research team decided that this option should be withdraw as an option for STOREPET manufacturing and that, alternatively, other approaches involving melt-spinning should be investigated, like the possibility to use unshielded PCMs by coaxial melt-spinning process and produce core/shell PCM-fibers.

While the viscosity differences between the paraffin materials (PCMs) and the fiber polymers at the processing temperature of the later ones put serious difficulties to melt spun fibers by conventional coaxial processes, initially it was investigated the possibility to overcome this obstacle by previously mixing and alloying the raw PCMs (octadecane grade by Devan) with a suitable and compatible polymeric thickener (HDPE), thus capable of closing the gap between the viscosity differences during the coaxial melt spinning process. Tests were performed in laboratory and different ratios of PCM/HDPE alloys were produced using a laboratory polymer extruder with 60%, 70% and 80% of paraffin content. Thermal analysis results have revealed much better results than the ones from the previous mPCM/PET tests, reaching latent heat of fusions as high as 136J/g to the 60-40% PCM-HDPE composition up to 174J/g for 80-20% PCM-HDPE ones.

Figure 20: Production of Storepet for melt spinning process

This way this approach was regarded as a possible and feasible route for STOREPET's Fiber Manufacturing Process and Fiber Products (Project Result 1) and the accomplishing of Milestone 1 - STOREPET composition, design and technology for its making. Since it's very difficult to find a company that deals with the whole production process, the consortium will need to find another company who can provide the crimping and the cutting of the yarns to produce the final bi-component staple fibers. Moreover and afterwards, another company must be sought for making the final STOREPET insulation products (possibly Freudenberg Politex, Italy, with whom the consortium is already collaborating). Trying to maximize the overall PCM content inside the polyester fibers, the research team tried to develop a brand new fiber melt-spun system design, specifically for the STOREPET project. This novel and unique design combines both extrusion and injection systems to create bi-component fibers, having only a PCM material in its core. A full and deep explanation of the new extrusion tool developed can be found on Deliverable D2.3.

Figure 21: The innovative coaxial melt spinning process designed for Storepet production

Both PCM-HDPE and PCM-PET bi-component fibers were produced in laboratory with the new double chamber extrusion/injection melt-spun prototype and using octadecane grade PCM from Devan and while the PCM-HDPE composition reached an average latent heat of fusion of roughly 22J/g, a remarkably enthalpy of 78J/g was registered for the PCM-PET ones.

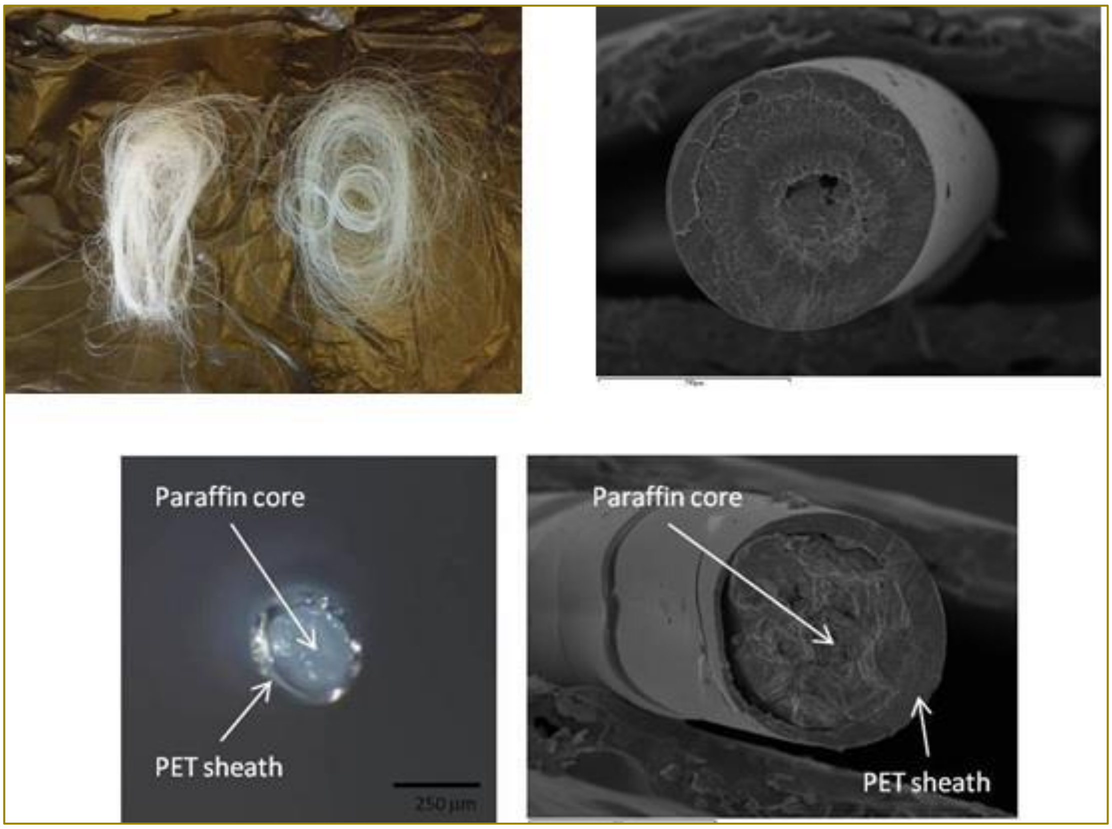


Figure 22: Chacterization of fibers made by coaxial melt spinning process

Being results for full core-shell fibers, these lasts ones were clearly much more satisfying than any of the other melt-spinning solutions tested before, simply because this new technique allows much higher concentrations of phase change materials inside the fiber, without huge detrimental restrictions during the extrusion process. Preliminary tests showed that this brand new technique opens a new window of possibilities to have PCM enhanced fibers with much higher phase change enthalpies than today's state-of-the-art market products (having latent heats only up to 10-15 J/g). However and for the project subsequent tasks this new technique is still in an embryonic stage of development and, although a lot of effort have been done to develop it, it will be extremely difficult to completely up-scale it in time for full final product production in WP4. Complementary, the research team also tried to obtain the raw PCM-Fiber incorporation by coaxial-melt electrospinning techniques using octadecane along with multiple polymers like PET, PS, PVP and PCL.

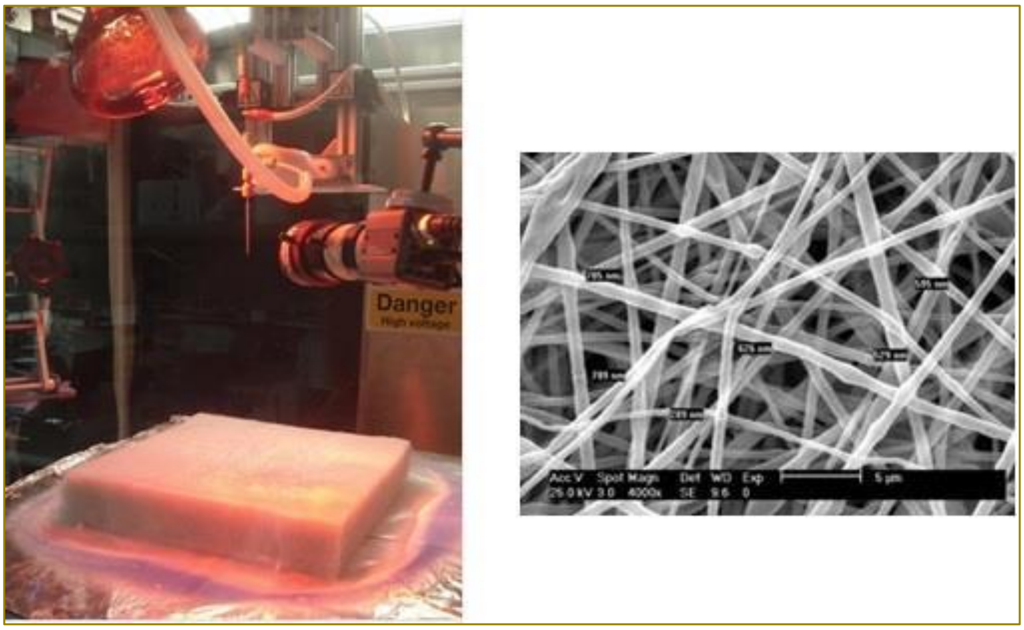


Figure 23: Electrospinning process used in Storepet production

A full description of the tests performed can be consulted in Deliverable D2.3. Although high levels of PCM incorporation were possible to attain by coaxial electrospinning in a laboratory environment, the fiber production rate provided by this technique is extremely low and the industrial up-scaling of this approach would involve the access to hi-tech industrial electrospinning, that to our knowledge, are still inexistent today in the market.

- Route B: mPCM-Fiber bulk mixture-

In order to avoid huge incurred delays and the high risk prospect of not accomplishing a full industrial upscale from the previous techniques within the timeframe of the project, the project research team called to practice the implementation of the project contingency plan, i.e. creating the STOREPET products by spraying techniques that would allow the impregnation of PET fiber blankets with a microencapsulated PCM slurry emulsion. To perform the PCMs deposition on the PET blankets, a spray deposition equipment was specially developed for the project and designed in order to be used also for WP4 tasks.

Initial trials were made using Politex's Ecozero PET blankets having thickness of 50 mm and a densities of 12 and 30kg/m3, which were sprayed and thermo-fixated by two ways (surface spraying only and multiple layer impregnation) and with different amounts (from 3% to 40% in weight) of octadecane microencapsulated PCMs emulsion provided by DEVAN with an average particle size of 18 µm. The initial laboratory characterization program underline to evaluate the properties of these new products is fully documented in Deliverable D2.3. Preliminary thermal efficiency tests made with a guarded hot plate apparatus, revealed that the best results so far were accomplished by impregnation levels around 30-40%, which were able to secure differences between the hot and the cold plate of more than 2°C after 30min, when compared with similar non treated panels, and more than 4°C after one 1hour. Route B will then comprise a safer production path, involving a much easier up-scaling, for which the consortium already have one possible company interested in up scaling it in a near future - Freudenberg Politex.

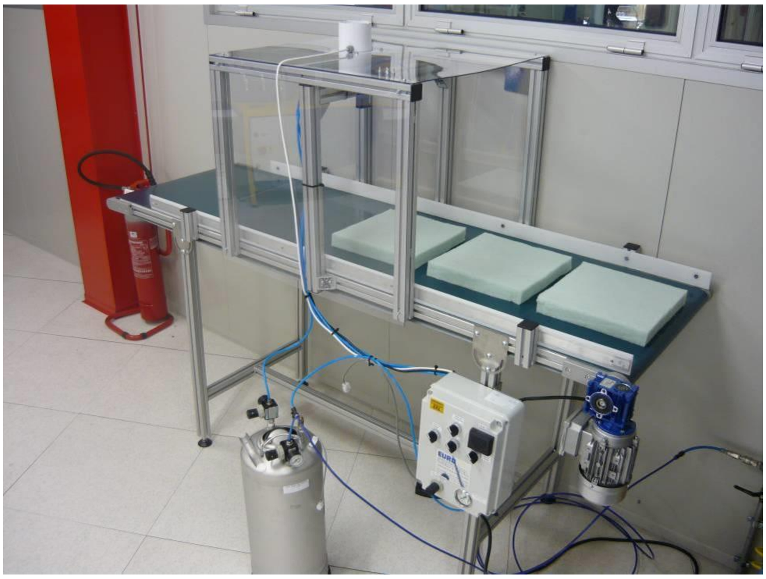


Figure 24: Production of Storpet by Spray Deposition

4.6. Development of WorkPackage 3

The objectives of the WP3, named "Study of the thermal and acoustic behaviour of the system by numerical simulation", for the first period are: to develop and implement software module for computing the thermal performance of outer and inner walls containing fiber PCMS layers and to extend current acoustic software modules to cover the new develop fiber materials containing PCMs. These objectives have been achieved by means of the development of task 3.1 and task 3.2.

Task 3.1.: To model the heat transfer/storage in PCMs based materials.

The goal of task 3.1. is to develop and implement a software tool based on mathematical models stated in WP1 to compute the thermal performance. This thermal simulation tool will have two functions: it will help to understand and build a deeper knowledge on how the PCMs affect the thermal behaviour and on the other hand, it will be used to evaluate the thermal performance (energy savings) for potential STOREPET product configurations with different types of PCMs, mass content of PCM and position. It can be also used to evaluate the effect of different indoor and outdoor conditions. Moreover, it is foreseen its integration in a more general software which is intended to be a tool for designing more energy-efficient buildings.

The Heat Transfer problem when PCMs are present the solution can be computed only with numerical methods because of the high variability of the heat capacity c_p (T) during the phase change (non-linear problem). The mathematical equations and the parameters (U-value, decrement factor and time lag) that model the heat transfer in multilayer walls was derived and presented in WP1.

As part of Task 3.1 of the STOREPET project, three numerical schemes have been implemented in the programming language MATLAB,: Finite Element Method (FEM), Finite Volume (FV) and a FEM based on an Enthalpy Formulation (EF), to compare their performance, accuracy and computational time. FV is the method with the best computational performance and thus, the one finally selected, among the three, for the definite implementation of the STOREPET Thermal Software module. The developed software module has been successfully validated in two representative cases: Monolithic walls with constant properties (EN ISO 13786: 2007 and formulas derived in Deliverable 1.4) and Multilayer walls containing PCMs (comparison with simulations from a commercial CFD software (ANSYS CFX).

Once validated, the software module was employed to analyse the effect of different parameters: type, amount and location of the PCM as well as indoors conditions in order to tailor the STOREPET products for specific applications and climate requirements. . The different configurations are shown in the figure below. A full description of this work is expressed in Deliverables 2.3, D3.1 and D3.2.

The simulation results showed that the phase transition temperature range of the PCM, its latent heat and mass content (per square meter of wall) is crucial for taking advantage of the use of this kind of materials. In this regard, it has been observed that the temperature variations the PCM undergoes and its relation with its phase transition temperature range (how much the former overlaps the latter) are determinant to enhance the thermal performance. The simulations showed also that outdoor maximum and minimum temperatures values as well as indoor temperature are important parameters for selecting the most suitable PCM for a given application. The position and dimensions of the PCM-fiber composite as well as the thermal resistances of the layers surrounding it will have also an influence on the thermal performance of the overall multilayer system.

Task 3.2.: Based on the model derived for the acoustic/transmission and absorption in fiber PCMs materials, and numerical method for solving the corresponding equations will be formulated.

Similarly to the task 3.1. the goal of task 3.2. is to implement a software tool to evaluate the acoustic performance of walls with layers of fiber PCMs. For that reason, an acoustic software module has been implemented, in the MATLAB programming language, for the computation of the Sound Reduction Index of multi-layered walls including layers of sound absorbing materials based on fibre materials which might contain PCMs. The physical parameters required as input data for the module were also stated. These physical (input) parameters depend on the 'acoustic nature' of the material: acoustic fluid (air), porous material (fibres, fibres + PCM) and viscoelastic solid (wood, clay, concrete, etc).

The Acoustic Software is based on two methods for the computation of the SRI of multi-layered walls: the Equivalent Networks method and the Transfer Matrix method (TMM). The former is simple and faster, in terms of computation time, but more limited since it is only applicable when the sound absorbing layer (fibre porous material) can be accurately represented with the so-called rigid frame model (also known as equivalent fluid). Also, it covers only double leaf walls with an inner cavity partially or totally filled with a porous layer. In contrast, the TMM allows for poroelastic characterisation (Biot model) of the porous layers which is more accurate for lightweight multi-layered walls. Moreover, in the TMM the number of layers is not limited. In a first step, the Equivalent Networks method was implemented for the computation of the SRI. In this method the porous material was modelled as a rigid frame (equivalent fluid) and only applied for configurations consisting of double leaf walls with an inner cavity partially or totally filled with an porous material. Although this method can be extended to n-layers and poroelastic materials, this enhacement is complex and involved. To overcome the limitations of the Equivalent Networks method, an alternative and more general scheme, the Transfer Matrix Method was also implemented in the software module.

Task 3.3: Using a set of case studies and the experimental/field data measured in WP4, the software modules will be validated to assess their level of accuracy and computing performance.

The main goal of the task T3.3 was validation and determination of the accuracy level of the software modules developed in the previous tasks: thermal (T3.1) and acoustic (T3.2).

In case of the Thermal Module partial validation has already been done in the T3.1 against the commercial CFD software ANSYS CFX. In the simulated examples the validation was successful and indicated that the implementation for solving the mathematical model is correct. However in order to complement this validation it was crucial to verify the mathematical model itself because it is based on simplifications and assumptions. That is, to assess the reliability of the heat transfer equations, on which the simulation module is based, to represent the real physical phenomena, especially the heat transfer, melting and solidification process of the Phase Change Materials (PCMs). For the verification of the thermal model, experiments performed by IPN, with a Guarded Hot Plate apparatus, were considered. The experimental setup is shown in Figure

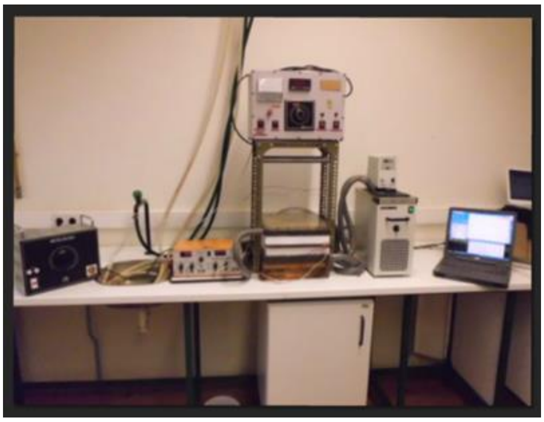


Figure 25: Hot plate apparatus

The hot plate apparatus was used to measure heat conduction through a PET blanket with and without PCM then the results were compared with results from the software Figure 2. The comparison between simulations and measurements showed a very good agreement for the temperature on the hot face of the blanket. However, in both cases, the temperatures on the cold face differ and further measurements and checks will be carried out to find the reason for that.

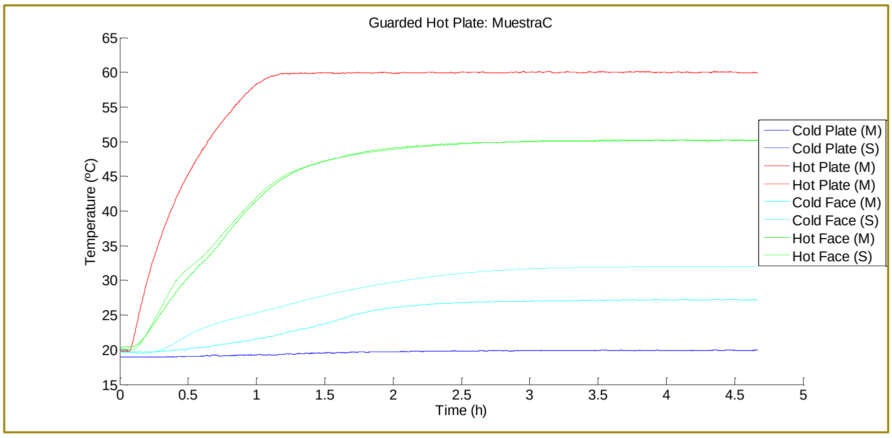


Figure 26: Guarded Hot Plate. PET blanket with sprayed mPCM Mikrathermik G (40% w/w): measurements (solid lines) versus simulations (dashed lines).

The validation of the Acoustic Module has been performed against measurements that had been done in the previous tasks in the following test cases:

1) Double glazing (Literature results used as reference)
2) Multilayer including an inner layer of a porous material (Literature results used as reference)
3) Sound Absorption tests on PET blankets with and without PCMs (Tests done by CENTROCOT as part of Task 3.2)
4) Sound Transmission tests on PET blankets with and without PCMs (Tests done by CENTROCOT and IPN as part of Task 2.3)

The results show that the predictions with the Acoustic Module are accurate in sound absorption and transmission tests, for standard fibre porous materials and also when they include PCMs. The prediction when very thin air layers are present (double glazing test) is not very accurate and the dissipation effects between the air and surfaces must be taken into account to improve the accuracy of the model. From the point of view of the acoustic simulations, it is a crucial fact that the so-called 'rigid frame' method (equivalent fluid), for modelling the sound transmission in fibre porous materials (with and without PCMs), is reliable. This simplifies greatly the material characterisation since only the flow resistance of the fibre material is required as input for the acoustic simulations. In contrast, the poroelastic model, although more precise, would require up to nine parameters as input, most of which are difficult to measure.

T3.4: The thermal and acoustic simulations tools developed and validated in the previous tasks will be used to find optimal designs and fiber PCMs products to comply with the project goal performances for a range of applications: inner and outer walls, outdoor temperature variation (different climates zones), summer, winter and other variables to be identified in WP1.

The objective of the T3.4 was definition and design of the suitable PCM products and wall solutions for a wide range of applications. It was done applying the thermal and acoustic StorePET software modules developed in previous tasks of the WP3 as well as in Energy Plus, which is a free building simulations software developed by Department of Energy of the United States of America.

Thermal simulations were performed for three locations representing various climatic conditions: Madrid (Spain), Warsaw (Poland) and Niš (Serbia) and two types of PCMs: with a peak melting point at Tpeak=26.9°C and second with Tpeak=22.9°C. Thanks to the use of Energy Plus it was possible to prepare a model of the entire demo-house (tested in reality in WP7)(Figure 3) and simulate its thermal behavior for weather and solar irradiation data of the three possible test sites. The simulations were performed to aid in the choice of configuration for each climatic zone, that is, what kind of PCM should be used, the amount of PCM required, where it should be placed and what are the best A/C and heating temperature settings. Four main sets of thermal simulations were considered:

- PCM amount optimization
- cooling test
- heating test
- free-floating test (no HVAC system in the building)

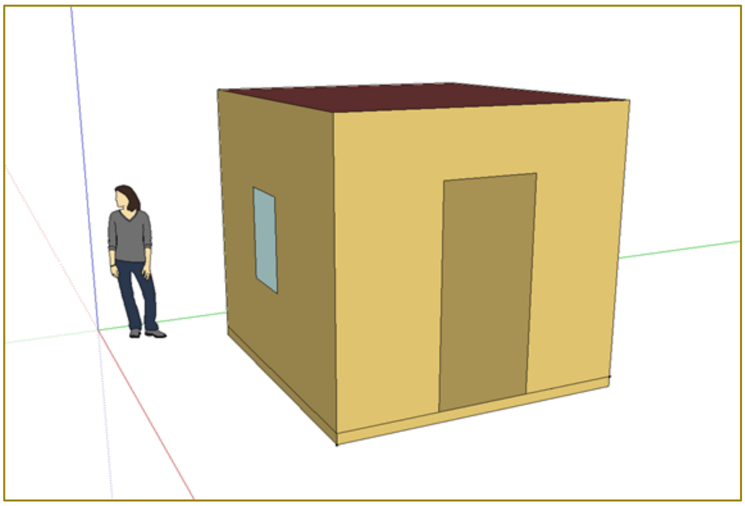


Figure 27: demo-house model used for thermal simulations, drawn in Google SketchUp.

Optimization of the PCM amount was done by comparing the potential energy savings on A/C for amounts of PCM between 0-2.4kg/m2. After analysis of the first simulations results, taking into account the elevated costs of the PCM and that the mass of panels should not exceed certain value it was decided that 40% of heat load reduction would be a good compromise between costs and benefits, therefore the chosen amount of PCM is 1.2 kg/m2.

For all the simulated locations only minor heating savings were observed. The cooling test simulations showed that the optimum configuration of a wall with StorePET panels is when the PCM layer is facing the indoor. In case of Madrid PCM with Tpeak=26.9°C was chosen, it showed potential for over 40% cooling heat load reduction. In case of Warsaw the PCM with lower peak temperature would perform much better showing also potential savings of over 40%. Building simulated in Niš climatic conditions would require intermediate PCM between the tested ones, for A/C set to 24°C for both PCM26.9 and PCM 22.3°C savings of roughly 24% were observed.

Table 1 The demo-house in Madrid, A/C 26°C, PCM Tpeak=26.9°C and 1.2 kg/m2, with air gap, period: 15 Jul – 15 Aug.

Configuration	Cooling, MJ/m^2	Cooling, kWh	Saving, kWh	Saving,%
NO PCM, air gap outside	15.68	36.7	base	base
PCM outside	12.28	28.8	8.0	21.7%
NO PCM, air gap inside	13.50	31.6	base	base
PCM inside	8.03	18.8	12.8	40.5%

In the acoustic module of the StorePET software SRI (Sound Reduction Index) RA and RW were computed for a wall of the demo-house with Ecozero (reference) and StorePET panel at various configurations. The results showed that the presence of PCMs on neither external nor internal surface of PET insulating panels changes their acoustic properties in any practical way.

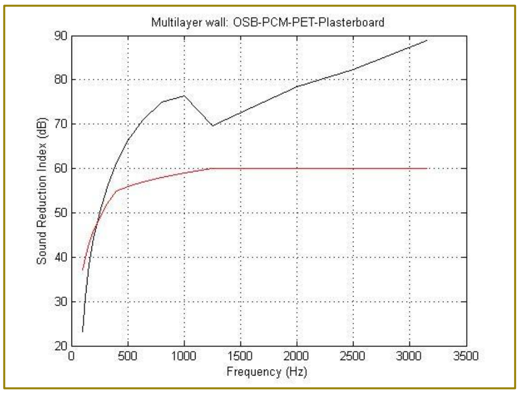


Figure 28: Graph of Sound Reduction Index (without the adaptation terms) against frequency of sound for the simulated wall (the black line)

4.7. Development of WorkPackage 4

Work Package 4 (WP4) of the StorePET Project was focused on the product design research and specifications for industrial manufacturability. In particular, WP4 was structured in 3 different Tasks:

StorePET prototype line production (Task T4.1), Preliminary laboratory tests on trials samples (Task T4.2) and Risk assessment (Task T4.3).

T4.1: To project and build a new prototype system or develop a production line adaptation for StorePET making, based on the data reported on D2.3.

During the activities of Task T4.1, the contingency plan (already studied and tested during WP2), was developed and up-scaled with the aim to produce the StorePET prototype with the performance and amount needed for the subsequent demonstration activities. PET nonwoven panels used as base material for the StorePET production were from Freudenberg Politex Srl (Italy) and their industrial manufacture was described in the Deliverable D4.1. The second manufacturing stage needed for the StorePET production was the superficial application of micro-encapsulated phase change materials (mPCMs) on the PET nonwoven panels by spray deposition. PCM formulation was optimized by the partner ¬Devan-Micropolis S.A. (Portugal) in order to reach the optimal chemical and physical properties needed for the deposition by spray technique. Water-based mPCM formulation was deposed by using an industrial low pressure multi-nozzle spray machinery, after a specific adjusting of the spraying heads configurations to optimize the spray distribution along the length of the samples. Water excess was removed by drying in a single-pass conveyor dryer, also used for the curing. It was observed that the drying process (120°C for 4 h), was not able to completely dry the panels, so the panels were further maintained in the dryer. This evidence can be explained considering that the dryer was not designed to dry nonwoven panels with a significant thickness (40 mm). In spite of this, the results of Task T4.1 indicated the feasibility of StorePET prototype manufacture at industrial scale.

Figure 30: Spray deposition.

Figure 29: Treated panels in the dryer for drying and curing.

T4.2: Run preliminary laboratory tests on trial samples produced on T3.1, in order to characterize and evaluate the StorePET product (This task shall be made at the same time as the previous one).

The goal of Task T4.2 was to perform preliminary laboratory tests on trial samples in order to characterize and evaluate StorePET products made at an industrial scale. In particular, thermal analysis tests were performed for better refining of the products, and the influence of PCM addition to the fiber was investigated by heat flux analysis and steady-state thermal conductivity. Results of thermal performance and heat storage capacity have indicated the ocatadecane-based PCM28 as the best PCM option to be used for in field tests (considering the location climate conditions and a comfort indoor temperature of 26°C). Moreover, results have indicated that the best layer configuration is a single PCM coating, which should be faced towards the inside in the wall system. In fact, if faced towards the outside, the PCM content will be too much exposed to higher temperatures causing a faster melting and reducing its effect suppressing the indoor temperature fluctuation. Furthermore, the effect of PCM addition was also evaluated for other properties, namely acoustic insulation, fire resistance, moisture resistance and air and vapour permeability. The results of these tests indicated that the flammability issues reported on Deliverable D2.3 were apparently suppressed by coating the panel with Devan's proprietary flame retardant coating Eco-Flam C271. Moreover, PCM deposition increased the sound absorption and the resistance to the water-vapour transmission, whilst the air permeability was strongly decreased.

T4.3: A risk assessment task will be open during this WP, in order to fully describe and quantify any drawback that can possible arise from the making of the new product and propose and implement a mitigation plan during this WP, if some of the technical properties aimed for the project should proved difficult to be accomplished (redefinition of the production technology follow up to this stage, introduction of new materials, StorePET combination with other materials or products, etc.).

During the Task T4.3, an analysis of the risk associated with the StorePET production was performed and a contingency plan was illustrated. Moreover, the possible problems that may arise using this contingency plan were outlined. Considering the spray deposition as StorePET production method, no special risks are associated with the PET nonwoven panel used as substrate, since the plastic industry is one of the fastest growing sector in the world. PCMs used for panels treatment are already known and recorded, and there are no problems with REACh regulation and no risk to safety and environment, so also for PCMs no special risks are found. Regarding the industrialization of the process developed in pilot-scale during Task T4.1, possible problems can be related to the cost of machineries and the space taken by them. About the commercialization of the final product and the CE marking, the only note to focus concerns the fire resistance that is affected by the paraffinic nature of the used PCMs, determining the need of a flame retardant treatment. Finally, if the heat storage capacity of the final product will not be enough according to the project requirements, the best option is to develop a new PCM formulation with greater capacity to store heat for a given mass.

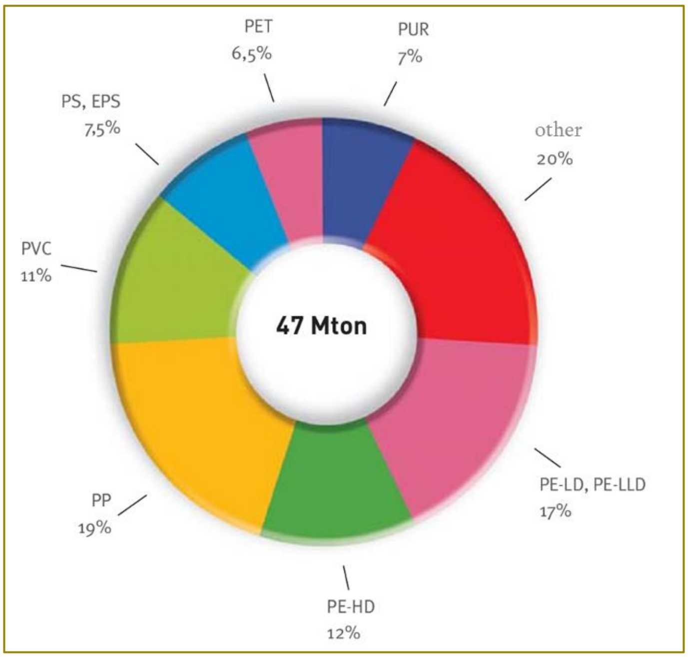


Figure 31: Demand for plastics in Europe* for resin type in 2011; Source: PlasticsEurope Market Research Group (PEMRG)

4.8. Development of WorkPackage 5

In WP5 a comprehensive list of performance laboratory tests were executed for StorePET's final product to evaluate the technical compliance of the product and to assess if the technical objectives of the project were met according to its DOW. The evaluation of the accomplishment of these goals is the means of verification of Milestone 3 compliance (Industrial PCM-fiber technology integration and creation of a new and technically validated product). The development of a StorePET industrial level product subject to this test performance assessment was carried out under the conditions defined in Work Package 4, following the microencapsulated PCM-Fiber mixture by spraying deposition technique envisaged in the work program as one of the possible routes to obtain the StorePET fiber thermal insulation.

The final StorePET product subjected to technical compliance and referred in this report consisted on the same flexible double panel-like PCM-fiber layer solution having 1.45 meters length by 0.6 meters width and a total thickness averaging between 0.07 and 0.08 meters that was produced in an industrial environment (WP4) and used for on-site verification on WP7.

T5.1: Perform a complete list of performance tests, on national or international reference laboratories.

The determinant technical objectives of the project where investigated task 5.1. The requirements were:

- Achieve on a lab scale using a guarded hot box facility, reductions in heat flow of about 40%, when compared on the equal conditions with the same fiber material produced without the PCM content;
- Secure a thermal conductivity not higher than 0.04 w/mK (preferably under this value) and a thermal resistance not less than 2.5 m²K/W for a nominal thickness of 100mm;
- Accomplish superior noise insulation properties capable, for instance, to achieve a Rw higher than 55dB for a 6cm thick product when placed between a wall partition made of a double drywall panels;
- Guarantee technical requirements needs to meet the European national and communitarian building codes and regulations, especially the ones regarding having a sufficient fire European fire classification rank which should not be less than Class Bs2d0.

All the tests were carried out resorting to European standards, specifically EN ISO. The tests and standards employed where:

Thermal properties (thermal conductivity and thermal resistance):	
Hot Box apparatus (no existing standard for the test that was preformed)	
EN 12667:2001	Thermal performance of building materials and products. Determination of thermal resistance by means of guarded hot plate and heat flow meter methods. Products of high and medium thermal resistance.
Noise insulation and sound absorption (noise reduction and sound insulation):	
EN ISO 10534-2:2001	Acoustics. Determination of sound absorption coefficient and impedance in impedance tubes. Part 2: Transfer-function method.
Fire resistance:	
EN 13501-1:2013	Fire classification of construction products and building elements.
EN ISO 11925-2:2010	Ignitability of building products subjected to direct impingement of flame - Part 2: Single-flame source test.
EN 13823:2010	Reaction to fire tests for building products - Building products excluding floorings exposed to the thermal attack by a single burning item.

Under the work performed under task T5.1 concerning the StorePET's technical compliance, the following conclusions can be addressed:

- Hot-box test data confirmed laboratory and simulation results on the cooling load reduction potential of StorePET technology and approach. Although the heat flow reductions given by the trial products were slightly below the 40% suggested as a project technical goal, the value obtained (33%) was nevertheless very close to it, meaning that a small refinement of the PCM amount needed or a stricter control of the homogeneity of the panel's industrial PCM spraying would have allowed to perfectly match the targeting value. Still, a new thermally enhanced fiber insulation product solution capable of storing and releasing large amounts of energy was fully and successfully created;

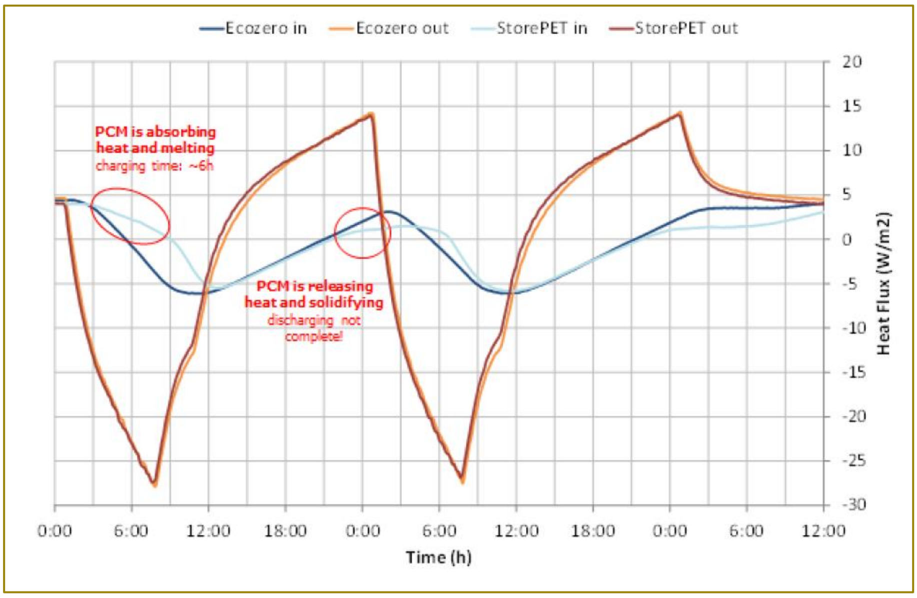


Figure 32: Hot box test – Heat flux

- Thermal conductivity of the final StorePET product was not significantly increased by the addition of PCM content, still securing a thermal conductivity within the 0.04 W/mK mark and a thermal resistance (R-value) inside the project technical goal of 2.5 m^2K/W for a possible nominal product thickness of 100mm. The possibility of a large scale industrial production of a PCM integrated inside the PET fibers, also investigated in this project, may as well result in a product with improved thermal resistance;

- Noise insulation ranks are improved with StorePET products, when compared with similar PET fiber insulation solutions without PCM additivation. Simulation showed that one can expect to have an Rw of 61dB for a double drywall system with a 6cm thick StorePET blanket, not only outstanding by 1dB the value given by a similar and comparable approach made without the PCM add-on and by 6dB the project goal. Moreover, according with the simulation preformed, the project's 55dB threshold is also expected to be accomplished for the end-use application currently being tested on the demo-site park.

- The constructive solution envisaged for StorePET product supersedes the fire resistance objective stated for the project by securing a Class Bs1d0 classification. Although having a similar classification as standard commercial polyester insulation products (even a slightly better one), still it represents a marginal rank, meaning that storePET fire resistance should be improved in order to gather a better market entrance/acceptance with future research advised under this scope.

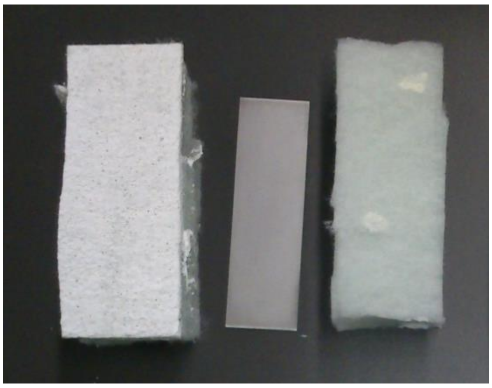
Figure 33: Fire resistance test

T5.2: Complementary characterization tests should be preformed following fiber insulation or nonwoven standards. Properties like Bulk Thickness, Dimensions; Mass per unit of area, Density, Water and Moisture Absorption, Vapour Adsorption, Mechanical Properties, Air Permeability and Airflow Resistance, Corrosiveness and Fungi Resistance are among the ones that can be considered on this task.

In task 5.2, complementary characterization tests were performed following the work program stated in WP5. Such tests should provide the technical information necessary for legislation compliance. For evaluation purposes StorePET product was compared with an equivalent commercial PET fiber insulation without the PCM and thermal storage capacity (Ecozero® from Freudenberg Politex, Italy) and the following standards have been used for the description of the StorePET product:

ASTM C 167	**Standard Test Method for Thickness and Density of Blanket or Batt Thermal Insulations**
UNI EN 29073-1:1993	Textiles – Test methods for nonwovens – Determination of mass per unit area
UNI EN ISO 9073-6:2004	Textiles – Test Method for nonwovens – Part 6: Absorption
UNI EN ISO 12571:2013	Hygrothermal performance of building materials and products – Determination of hygroscopic sorption properties
AATCC Test Method 30-2013	Antifungal activity. Assessment on textile materials: mildew and rot resistance of textile materials
ASTM D5035-11	Standard test method for breaking force and elongation of textile fabrics – Strip method”
UNI EN ISO 9237:1997	Textiles - Determination Of Permeability Of Fabrics To Air Describes a method for measuring the permeability of fabrics to air
UNI EN 31092:2012	Textiles -- Physiological effects -- Measurement of thermal and water-vapour resistance under steady-state conditions (sweating guarded-hotplate test)
ASTM C665-01	Standard Specification for Mineral-Fiber Blanket Thermal Insulation for Light Frame Construction and Manufactured Housing

Tests performed have better enlighten the StorePET products properties, its main advantages and aspects that still need future refinement. The corrosion tests have indicate that further testing should be done regarding a the usage of a less corrosive flame retardant material to be applied on the panels, as the fire retardant selected for trial production have revealed to be a corrosion agent for steel.



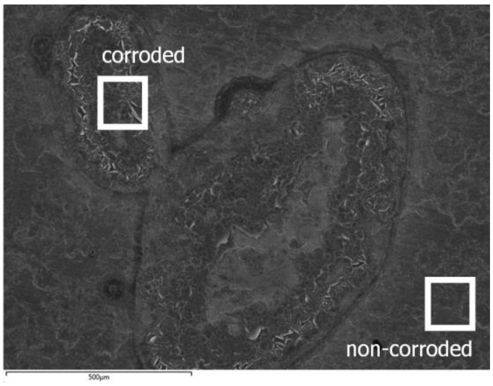


Figure 34: Corrosion tests

On the other hand, StorePET panels performance at break and overall mechanical performance did not differ greatly from similar non PCM additivated products, even after the burial of the samples, attesting also its resistance to mildew and rot.

Figure 35: Mechanical Performance Tests

Considering the StorePET material behaviour in respect to water/moisture/vapour, results have shown that, when compared with a similar but non additivated fiber product, the PCM content of the Storepet fiber insulation tends to increase the resistance to water-vapour transmission and to block the vapour passage through the material, as well as to increase of the moisture sorption and to decrease of the water sorption. It is possible to conclude that the PCM formulation layer acts as a "cap", blocking the passage of the water vapour/moisture, while at the same time the PCM layer does not absorb water as pointed out by the water absorption results. As observed for the comparing non additivated material, normally the PET fibers blanket can act like easy vehicle for water vapour/moisture transport through the material, while when the PCM layer is added to the material, the passage of vapour/moisture is reduced, explaining the parabolic profile of the moisture sorption curve of StorePET panel. This can eventually lead to an accumulation of moisture inside the finer insulation material. Moreover this could signify that the PCM layer will be working similarly to a "vapour barrier". Moisture vapour will move from a region of high vapour concentration to an area of lower concentration, until they reach equilibrium, when the temperature difference between indoors and outdoors is great the vapour drive can be quite strong. Moisture vapour will also naturally move from the warm side of the wall to the cooler side, so in a summer scenario, when the temperature gradients are greater, the fact that the PCM layer is facing the inside of the wall inhibits the condensation on the insulations as it doesn't allow for abundant vapour penetration.

4.9. Development of WorkPackage 6

The main objective of the WP6 is to develop a software tool to assess the energy saving of buildings which incorporate Storepet Product. This software tool will aid building designers and constructors to choose the best STOREPET product configuration (in terms of PCM composition and mass) in order to know the energy savings when combined with other energy saving systems and taking into account the geographical and climate conditions for each particular construction.

T6.1: The effect, in the overall energy efficiency, of ventilated façades incorporation PCMs will be studied with Computational Fluid Dynamics (CFD) software.

The objective of this task was an assessment of the feasibility of use of ventilated façades to improve the energy performance of PCM panels. Simulations of lightweight and heavyweight walls with and with and without ventilated façades were performed in ANSYS CFX (CFD software) as well as in Energy Plus (building simulations software).

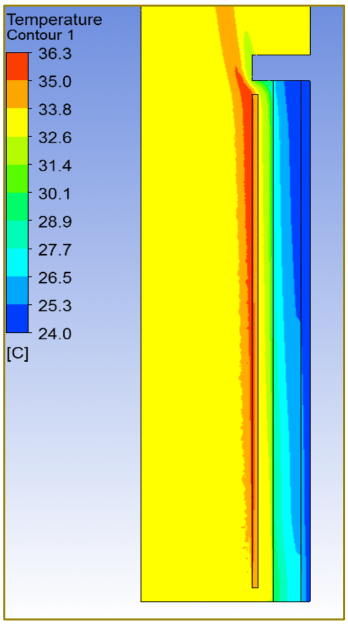


Figure 36: Ventilated façade CFD simulation (cross-section) – temperature distribution

Solar radiation has a very big influence on the temperature of walls, it increases heat flux transmitted to the indoor of a building and quickens the melting process of the PCMs. The simulations showed that the most important effect coming from ventilated façade use is the elimination of solar radiation influence and better night cooling of the façade. In this way a ventilated façade could prolong the time of melting of PCMs and decrease the time required to solidify them again during the night, so in total would improve the performance of the StorePET panels in lightweight buildings. The results showing the performance of various combinations of walls with PCMs and ventilated façade are presented in the Table 1.

PCM	Ventilated façade	Cooling, MJ/m2	kWh/m^2	kWh	saving
NO	NO	14.9	4.1	34.8	base
ALL	NO	8.9	2.5	20.8	40.1%
ALL	West	7	1.9	15.6	55.2%
NO	West	11.8	3.3	27.7	20.4%
NO	ALL	6.5	1.8	15.2	56.3%
ALL	ALL	0.4	0.1	0.8	97.6%

Simulations of a heavyweight masonry façade showed that its thermal performance could be increased by application of a ventilated façade. However use of panels with PCMs would not give any additional energy benefits because masonry wall by itself has a big thermal inertia and therefore use of panels with PCMs in this type of walls does not give any notable improvement for the user

T6.2: The software tools developed in WP3 are aimed at product design for different applications and its field of application is focused on R&D activities. The purpose of this task is to develop a software tool aimed at end users (architects, building designers and constructors) for assessing the energy savings when incorporating StorePET products.

The main goal of this task was development of software that would simulate whole buildings with StorePET panels. The target groups of the of software would be potential clients interested in buying StorePET panels, civil engineers or architects, using the software they should be able to estimate to precisely estimate potential energy savings and indoor thermal comfort increase coming from StorePET in their specific case.

To meet the goals of the Task 6.2 ´Thermal Buildings´ application was developed in the Matlab programming language. The application can compute heat losses of a cuboid building (heating and cooling loads) and other additional parameters for different weather conditions. It takes into account not only outdoor temperature but also heat flux coming from solar irradiation at each wall. The software helps in making comparisons of StorePET insulating panels with traditional insulating materials like mineral wool, such comparisons should facilitate decision of an end user whether it is profitable to apply StorePET products in their specific case. It works in three principal concerning indoor temperature:

- fixed temperature (the temperature is maintained as constant),
- free-floating (the temperature is free to change)
- A/C (temperature cannot exceed the air-conditioning onset point however it is free to drop below it)

The fixed temperature and A/C modes can be used to estimate potential energy savings coming from use of StorePET panels. The free-floating mode was done with intention of facilitating the estimation of thermal comfort difference.

What is very important unlike any other simulation software package currently available on the market, StorePET software 'Thermal Buildings' simulates not only simple melting-freezing cycle of a PCM, but takes also into account an effect called subcooling and the hysteresis of melting-freezing cycle. In reality the freezing of PCMs starts in a lower temperature than ends the melting process and this difference is known as the subcooling. As a result the melting-freezing cycle of PCMs is a cycle with a hysteresis loop (see the Figure 37) which means that the function takes different path depending on the temperature change direction (ascending/heating or descending/cooling).

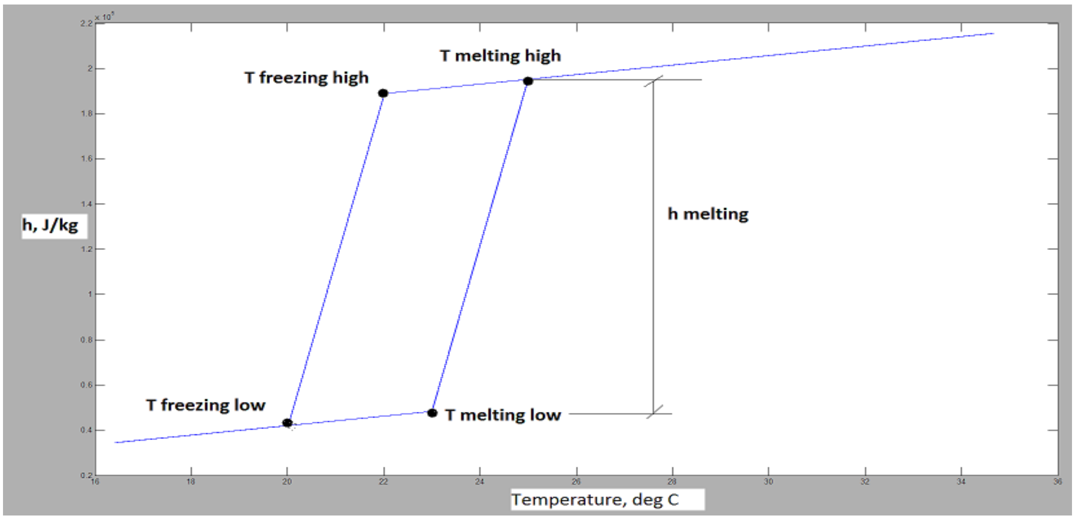


Figure 37: Hysteresis of melting-freezing cycle of a PCM

Graphical User Interface (GUI) has been developed to facilitate the use of ´Thermal Buildings´, see Figure 38). The software is provided together with a manual describing all its features and necessary input parameters as well as examples of calculations. Thanks to the simple GUI and the manual ´Thermal Buildings´ does not require any expert knowledge to be able to use it properly.

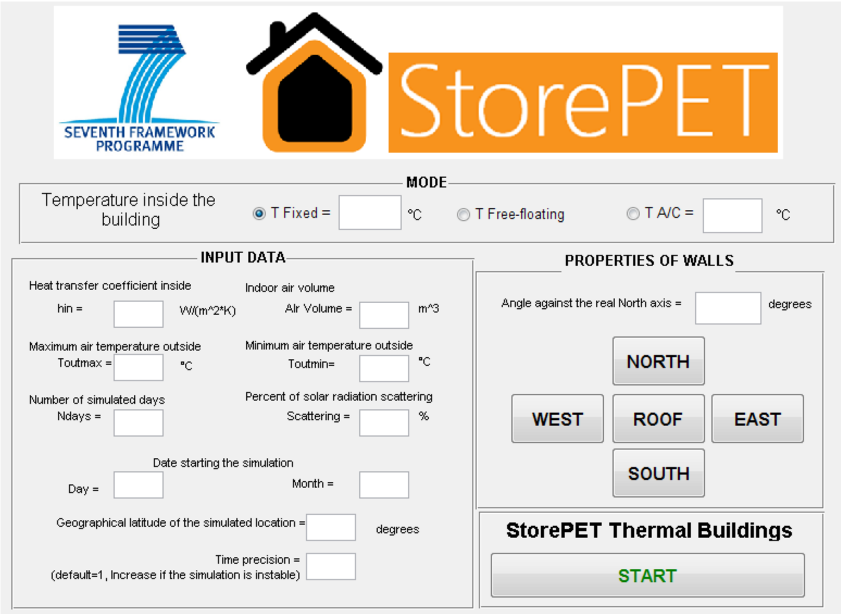


Figure 38: "Thermal Buildings" software main menu

The user specifies how is constructed each wall of the simulated building, they can choose between materials already provided with the program or add its own. The user can also decide about the type and amount (in kg/m2) of PCM used in each wall. It is also possible to decide that the selected wall is equipped with a ventilated façade what diminishes the influence of the solar radiation on that wall.

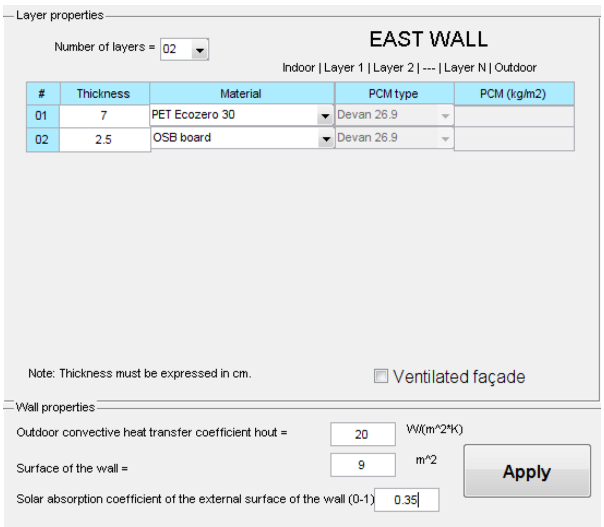


Figure 39: The eastern wall properties (identical for all other walls)

As results the software gives cooling and heating need of the simulated building, external and internal temperature of each wall and indoor air temperature. The results are not only displayed in the GUI they are also saved as .xls spreadsheet, so they can be accessed later and post-processed.

4.10. Development of WorkPackage 7

Work Package 7 (WP7) of the StorePET project aimed to validate at real scale the results of thermal and acoustic performance of StorePET panel obtained at laboratory scales (WP5) in previous stages of the project, which indicated that the StorePET panel showed enhanced thermal performance thanks to its thermally active heat storage capacity provided by the incorporation of PCMs technology. In addition, after having ensured the compliance of StorePET product with EN fiber insulation standards and building codes in previous stages of the project, WP7 focused on determining the environmental performance of StorePET by means of Life Cycle Assessment (LCA), as well as its economic feasibility by determining the overall cost of the product and the expected user's payback time as final step to obtain a "ready to place on the market" product.

T7.1: Built up at least one set (preferably two) of two small-scale field wood or steel frame small and identical houses, in order to evaluate the performance of the its walls insulated with and without StorePET (compare it with equivalent standard fiber insulation).

In task 7.1 StorePET energy savings potential was evaluated in a real scale demonstration. For this purpose, two twin lightweight test-cells equipped with varied thermal and acoustic sensors to monitor thermal and acoustic performance were built in E2B Cluster Demo Park Madrid. First test-cell counts on a building envelope in which the developed StorePET panel was used as insulation layer. In the second one, a commercial nonwoven PET board without PCMs was used as reference insulation system to establish comparison. Since the PCM used for the StorePET boards had been design for hot weather, the real-scale evaluation was carried out in Madrid during the spring and the summer Seasons (from February to October 2014).

Figure 40: Twin mock-ups built for real-scale demonstration in Madrid (Spain)

Results of field tests performed during the demonstration period showed StorePET similar acoustic properties when compared with the reference material.

Furthermore, thermal and dynamic monitoring for the two twin mock-ups proved that differences in PET composition have a direct effect on internal temperature (room temperature) in favour of StorePET mock-up, which enhanced building envelope thermal inertia decreasing temperature maximum and minimums 1ºC in average during the testing period.

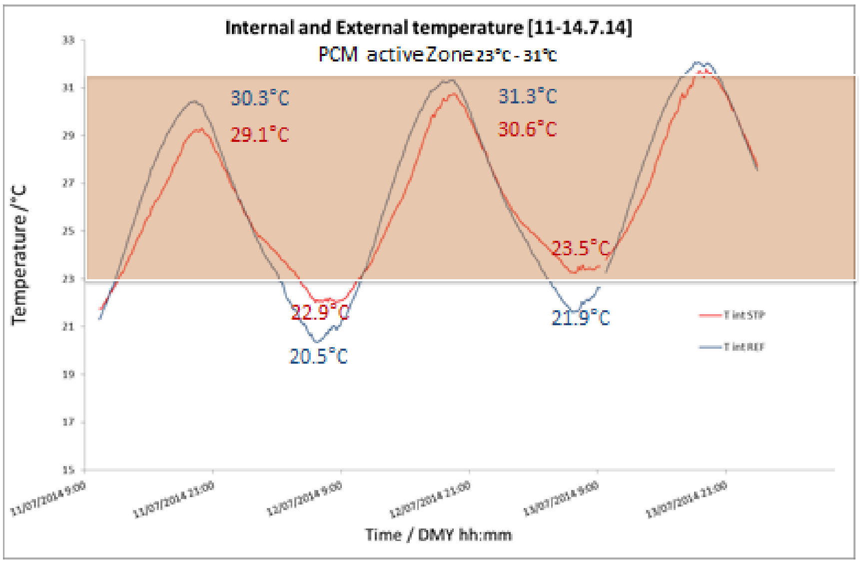


Figure 41: Internal and external temperature during three full thermal cycles from July 11th to July 14th

This improvement in thermal inertia led to reduction in the electrical demand of around 40% for the STOREPET demo building comparing to STANDARD one having no PCMs.

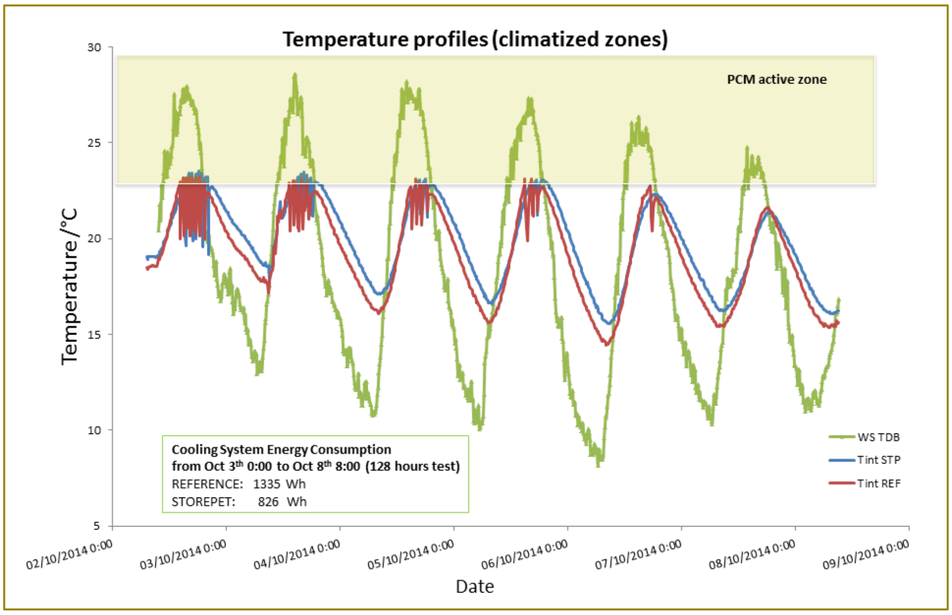


Figure 42: A 128h-test found energy consumption differences of around 40% in the electric demand in favor of StorePET systems

All the detailed information regarding the field tests performed to evaluate the thermal and acoustical performance of StorePET panels, containing PCM, with reference to nonwoven PET panels, without PCMs, is provided by Deliverable 7.1 "*StorePET thermal performance evaluation by field-scale tests*".

T7.2: Generate StorePET Material and Safety Data Sheet (MSDS). MSDS will be prepared in compliance with Controlled Product Regulations, international and local for each country where the developed product will be launched.

Task 7.2 delivered the Material and Safety Data Sheet (MSDS) of StorePET board compiling the results of the previous characterization works performed by the Consortium of the project. In addition, this task defined the suitable technical and safety procedures to fulfill for the installation of StorePET panels, based on the experience on building the mocks-ups for demonstration activities of Task 7.1. As conclusion, it can be said that there are not additional procedures and costs associated for the installation of StorePET panels. The information regarding task 7.2 is contained in Deliverable 7.2 "*StorePET Material and Safety Sheet (MSDS) and Technical and Safety Installation procedures*".

T7.3: Evaluate StorePET life cycle assessment, embodied energy involved and other environmental indexes like Global Warming Potential (GWP) Index and the Ozone Depletion Potential (ODP) one.

Task 7.3 assesses the environmental impact associated to all the stages of the life cycle (production, construction, in-use and end of life) of StorePET insulation panel, using as benchmark the equivalent non-PCM enhanced fiber insulation. With this aim, the LCA of the two insulation systems, StorePET and reference, was performed using Gabi v6 software. The functional unit for this analysis was "1 m^2 of insulation panel over 40 years".

Deliverable 7.3 "*Report on StorePET life cycle assessment, production cost and expected users payback time*" calculates some environmental indexes such as Global Warming Potential (GWP) (also known as carbon footprint), Ozone Depletion Potential (ODP), Acidification Potential (AP), Photochemical Ozone Creation Potential (POCP) and Eutrophication Potential (EP), Embodied Energy (EE) for each stage of the lifecycle of StorePET and reference panels. Furthermore, the recycled content of StorePET panels was defined as 75%. The following table shows LCIA results for lifecycle of 1 sqm of reference PET board without PCMs. LCIA results breakdown per lifecycle stage.

Environmental Indicators	PRODUCT phase	CONSTRUCTION phase	USE phase	END OF LIFE phase	TOTAL
ADP elements [kg Sb-Equiv.]	1.70E-06	8.50E-08	1.89E-05	7.50E-09	2.07E-05
ADP fossil [MJ]	338.5484	7.9180	818.3929	0.5415	1165.4007
AP [kg SO2-Equiv.]	0.0831	0.0007	0.2516	0.0001	3.36E-01
EP [kg Phosphate-Equiv.]	0.0053	0.0001	0.0159	0.0001	2.14E-02
GWP 100 years [kg CO2-Equiv.]	21.8569	-0,3759	61.4279	0.0376	83.3224
ODP [kg R11-Equiv.]	2.03E-09	1.32E-11	2.75E-08	1.46E-12	2.95E-08

POCP [kg Ethene-Equiv.]	0.0089	0.0001	0.0207	0.0000	0.0297
Resource use	**PRODUCT phase**	**CONSTRUCTION phase**	**USE phase**	**END OF LIFE phase**	**TOTAL**
Embodied Energy (Primary energy demand from ren. and non ren. Resources) [MJ]	419.6929	16.7897	1740.9381	0.5953	2178.0160
Primary energy from **non-renewable resources** [MJ]	375.5651	8.6276	1213.0643	0.5669	1597.8239
Primary energy from **renewable resources** [MJ]	44.1278	8.1621	527.8738	0.0284	580.1921

The second table in this task shows LCIA results for lifecycle of 1 StorePET board with PCMs and LCIA results breakdown per lifecycle stage.

Environmental Indicators	PRODUCTION phase	CONSTRUCTION phase	USE phase	END OF LIFE phase	TOTAL
ADP elements [kg Sb-Equiv.]	6.64E-06	8.50E-08	1.17E-05	1.62E-08	1.84E-05
ADP fossil [MJ]	662.2782	7.9180	506.3557	1.1677	1177.7195
AP [kg SO2-Equiv.]	0.1737	0.0007	0.1557	0.0003	0.3303
EP [kg Phosphate-Equiv.]	0.0123	0.0001	0.0098	0.0003	0.0226
GWP 100 years [kg CO2-Equiv.]	43.2970	-0.3759	38.0066	0.0810	81.0087
ODP [kg R11-Equiv.]	6.99E-08	1.32E-11	1.70E-08	3.15E-12	8.69E-08
POCP [kg Ethene-Equiv.]	0.0169	0.0001	0.0128	3.13E-05	0.0299
Resource use	**PRODUCT phase**	**CONSTRUCTION phase**	**USE phase**	**END OF LIFE phase**	**TOTAL**
Primary energy demand from ren. and non ren. resources [MJ]	1054.0106	16.7897	1077.1525	1.2836	2149.2365
Primary energy from **non renewable** resources [MJ]	865.7166	8.6276	750.5466	1.2224	1626.1132
Primary energy from **renewable resources** [MJ]	188.2940	8.1621	326.6059	0.0612	523.1232

Analysis of the results concludes that the addition of PCM to provide thermal storage capacity to the standard nonwoven PET board does not contribute to increase the overall environmental impact of the product. The reason is that PCM-containing StorePET insulation board avoids the emission of huge amounts of CO_2 during its 40 years of operation thanks to its enhanced thermal performance which leads to energy savings of around 40% for acclimatization of the indoor space in lightweight building.

In addition, also the StorePET overall cost was determined in Task 7.3 using actual costs incurred by the StorePET consortium for prototypes manufacturing within the project. The overall cost of StorePET product was set in 108.61 EUR/panel, driving to an expected user's payback time of 48 years. Given that the costs are highly dependant on the quantity of PCM added to the raw PET panel, efforts for the reduction of the production costs should entail the minimization of PCM content. Nonetheless, it is important to keep in mind that all the calculations were done under the scope of the project, and therefore in order to determine a reliable final price for the product, a scaling factor should be applied.

T7.4: Apply for European CE marking and green building certifications like the international EPD® environmental product declaration system, the Leadership in Energy and Environmental Design (LEED) one or the Eurofins Product Testing - IAC Indoor Air Comfort. Other Eco and Quality labels available should be applied for each country where the developed product will be launched.

The activities developed in the framework of Task 7.4 are described in Deliverable D7.4 "European CE marking and green building certifications appliance". These activities had the purpose of investigate and evaluate the possibility for the StorePET product to obtain a future CE mark, in order to guarantee its market entranceinternational. Moreover, the application for EPD® environmental product declaration system was studied as well.

Concerning CE marking, due to the innovative nature of the StorePET product, a Product Standard is not available. For this reason the European Technical Approval (ETA) for Ecozero® (ETA 10/0075, Freudenberg Politex Srl, Italy) was used as reference document, also considering that Ecozero® (non-woven panel for thermal and acoustic insulation for building) is the base material used for the StorePET product development.

In regard to EPD®, EPD of panel Ecozero® and LCA results of task 7.3 considering PCM technology environmental impacts, were taken as reference for the potential application.

5. EXPLOITATION AND DISSEMINATION ACTIVITIES

The Consortium has carried out several activities led to the exploitation and dissemination of the project outcomes. The related activities are included in the WP8, and they have been well described in deliverables D 8.2 for the first period and D8.7 for the overall project titled *"Final plan for the use and dissemination of the knowledge".* Nevertheless, we provide here a brief summary of the most important activities performed within this issue.

5.1. EXPLOITATION AND IPR PROTECTION PLAN

The three main results from Storepet Project has been described in section 3 of the present document (please see page 16 -21). Briefly these results are:

1. Storepet insulation panel composed by PET and PCM able to reduce the heat flow up to 33% when compared with the same material without PCM.
2. Manufacturing process tailored for the mass production of Storepet product
3. "Thermal Building" software to support engineers to find out the energy savings while using Storepet.

Taking into account the above results, the Consortium has designed a plan for the protection of IPR. This plan will start with a patentability study which will show us the most convenient protection for each result regarding the highest benefit for industrial partners within the Consortium. However, we have agreed a first strategy based on the following issues:

- **Protection of coaxial melt spinning production process:** We believe that this process has the novelty level required to grant a patent. In case that patent is not recommended in the patentability study, it will be protected by Utility Model. After protecting this result, the IAGs and DEVAN will search insulation materials manufacturers will to acquire the license for a mass production of Storepet.
- **Storepet final thermal insulation panel:** We believe that this product cannot be protected under patent since the final panel is an integration of different materials: PET; PCM and fire retardant coating. For that reason, other modalities of protection will be analyzed such as utility model (protection for 10 years) or trade secret. The patentability study will provide the information required to make the best decision for its future commercialization.
- **Storepet simulation software *"Thermal Building":*** We have checked that nowadays there aren't any commercialized or lab stage software able to allow engineers to choose the best PCM composition for each location and building features. For that reason, the Consortium agreed on protecting this software under copyright for the exploitation in European market.

5.2. DISSEMINATION ACTIVITIES

As we have already clarified, a detailed description of all dissemination activities has been provided in D8.7. These activities cover:

- Start up and op-dating of the web page of the project: http://www.storepet-fp7.eu/
- Preparation of diverse brochures and flyers presented in trade fairs, exhibitions and conferences related to building , advanced materials or textile industrial sectors.
- Preparation of posters and communications in Conferences and Workshops.
- Preparation of scientific papers, articles in specialized magazines and press releases.
- Development and updating of a Wikipedia article: http://en.wikipedia.org/wiki/The_Store-Pet_Project
- Organization and impart different workshops and training sectors for SMEs of the building sector as well as students of Industrial Engineering.
- Participation in the following events:

No	Partner responsible or involved	Name	Date	Country	Website
1	TexClubTec	Techtextil	11-13th January 2013	Frankfurt /D	the most important fair dedicated to technical textiles
2	SGG	Sejem Dom	March 2013	Ljubljana, Slovenia	Largest selection of products and services from the field of building construction. http://www.home-fair.si/for-visitors/home/
3	IPN, DEVAN & ITAV	Materiais 2013, Conference Materials Science and Engineering whatever the application	25th -27th March 2013	Coimbra, Portugal	http://www.spmateriais.pt/materiais2013/
4	TEXCLUBTEC & CENTROCOT	AICTC Conference	31 th May 2013	Dalmine, Italy	http://www.aictc.org/Home
5	TexClubTec	Proposte	6th-8th may 2013	Como, Italy	fair dedicated to textile for furnishing & Design & Architecture

6	**TEXCLUBTEC & CENTROCOT**	Techtextil, International Trade Fair for Technical Textiles and Nonwovens	11 th -13 th June 2013	Fankfurt, Germany	http://techtextil.messefrankfurt.com
7	**TEXCLUBTEC & CENTROCOT**	Conference Nanoitaltex 2013	18 th October 2013	Italy	http://www.eventseye.com/fairs/f-nanoitaltex-17315-1.html
8	**TEXCLUBTEC**	A+A 2013, International trade fair for safety and health at work	5 th - 8 November 2013	Dusseldorf, Germany	http://www.messe-duesseldorf.com/tradefair/company/news-archive/aa-1240-5504.php
9	**DUNDJER**	Conference Sustainable building SB 2013 Graz	25th – 28th September 2013	Graz, Austria	http://www.sb13.org/index.php/en/
10	**GARCIA RAMA**	Presentation of the project to Construction Cluster of Asturias	6th November 2013	Asturias, Spain	http://www.clusterica.com/
11	**GARCIA RAMA**	Meetings with the householders to whom it is explained directly the services provided and also the R&D projects in which the company is participant.	2013 - 2014	Asturias, Spain	702 attendees
12	**TexClubTec**	Ispo 2014	26th -29th January 2014	Munich (D)	the most important fair for materials / equipment used in the winter sport sector and extreme cold. Exhibiting in the hall dedicated to textile materials.
13	**TexClubTec**	Jec Composites	12 – 14 March 2014	Pais (F)	
14	**SGG**	Sejem Dom	11 – 16 March 2014	Ljubljana, Slovenia	http://www.home-fair.si/news/#id_39
15	**ACCIONA**	Industrial Technologies 2014	9th - 11th April 2014	Athens, Greece	http://www.industrialtechnologies2014.eu/

16	**GARCIA RAMA**	Conference about the "Financial support of the CDTI for the development of R&D activities in the construction sector and its auxiliary industry" Example of European projects: STOREPET.	7th May 2014	Asturias, Spain	45 attendees
17	**TexClubTec**	Techtextil North America	13-15th May 2014	Atlanta, USA	fair dedicated to technical textiles
18	**TexClubTec**	Milano Unica	9-11th September 2014	Milano, Italy	the most important textile fair in Italy (fabrics)
19	**TexClubTec**	AITTCT conference	24-26th September 2014	Shagnhai, China	fair dedicated to technical textiles
20	**TexClubTec**	NanoItaltex 2014	12th November 2014	Biella, Italy	
21	**IPN**	CINCOS	14 – 15th November 2014	Porto, Portugal	http://cincos.pt/language/pt/
22	**CENTROCOT**	ITMA 2015 Exhibition	12th - 19th Novembre 2015	Milano, Italy	http://www.itma.com/

5.3. The Future of StorePET

Regarding the promising results of the project for future commercialization, the Consortium discussed the future steps which should be performed to a definitive launch to the market. First of all, the StorePET concept should be more publicised and promoted to create a market need and attract stakeholders, investors and companies interest.

In fact, StorePET as a building product using microencapsulated PCMs fiber mixture by spray deposition or alternative process can be easily scaled up with the right equipment and hence, get StorePET into the Market. Regarding the manufacturing process, two directions should be addressed:

- Electrospinning as an alternative technology for PCM-Fiber integration will be harder to bring to industry.
- There's a big potential upon using non-encapsulated PCM inside the fibers by extrusion/injection, towards the reduction of production costs.

On the other hand, we must highlight that there's still margin to improve with a StorePET follow up, especially regarding: Production technology; use of alternative (green) PCMs; fire resistance and production costs.

6. CONCLUSIONS

The project Storepet has been developed between November 2011 to October 2014 with the goal of developing a new insulation material which allow building's owners to save energy related to heating and cooling process. Thanks to the fruitful collaboration of 4 SME-AGs, 3 SMEs and 4 RTD institutions, the project goals have been achieved by means of the technical development based on:

- Testing and evaluation of more than 30 different types of PCMs and 6 polymer compositions, in order to choose the best composition for Storepet materials based upon many different factors including, indoor thermal comfort condition ranges, typical market location seasonal climates, melting/freezing phase transitions temperatures, latent heat ranks, supercooling, stability under multiple cycles trends, etc..
- Several manufacturing routes were assessed, either involving the development of bi-component fibres systems with PCM cores using electrospinning and unique coaxial melt-spinning extrusion/injection techniques, or by means of spray deposition of microencapsulated PCMs (mPCMs) .
- Development of modelling simulation tools to assist the right selection of the type and amount of PCM to reach the required thermal properties for different climate patterns.

The StorePET final product consisted on a layered 4.53Kg/m2 and 85mm thick mPCM-fiber blanket solution. Regarding the benefit effect of the heat storage capacity of the PCM content, hot-box tests proved to be possible for StorePET to attain up to a 33% reduction in cooling demands, when compared with similar non-additivated panels. Energy consumption evaluations have shown possible to reach reductions in the electric demand of around 40% for the StorePET demo building. . Following the successful of the StorePET project, the consortium is currently considering the right partnerships for the commercialization of this novel fiber insulation and make its market entrance in specific markets in a near future.

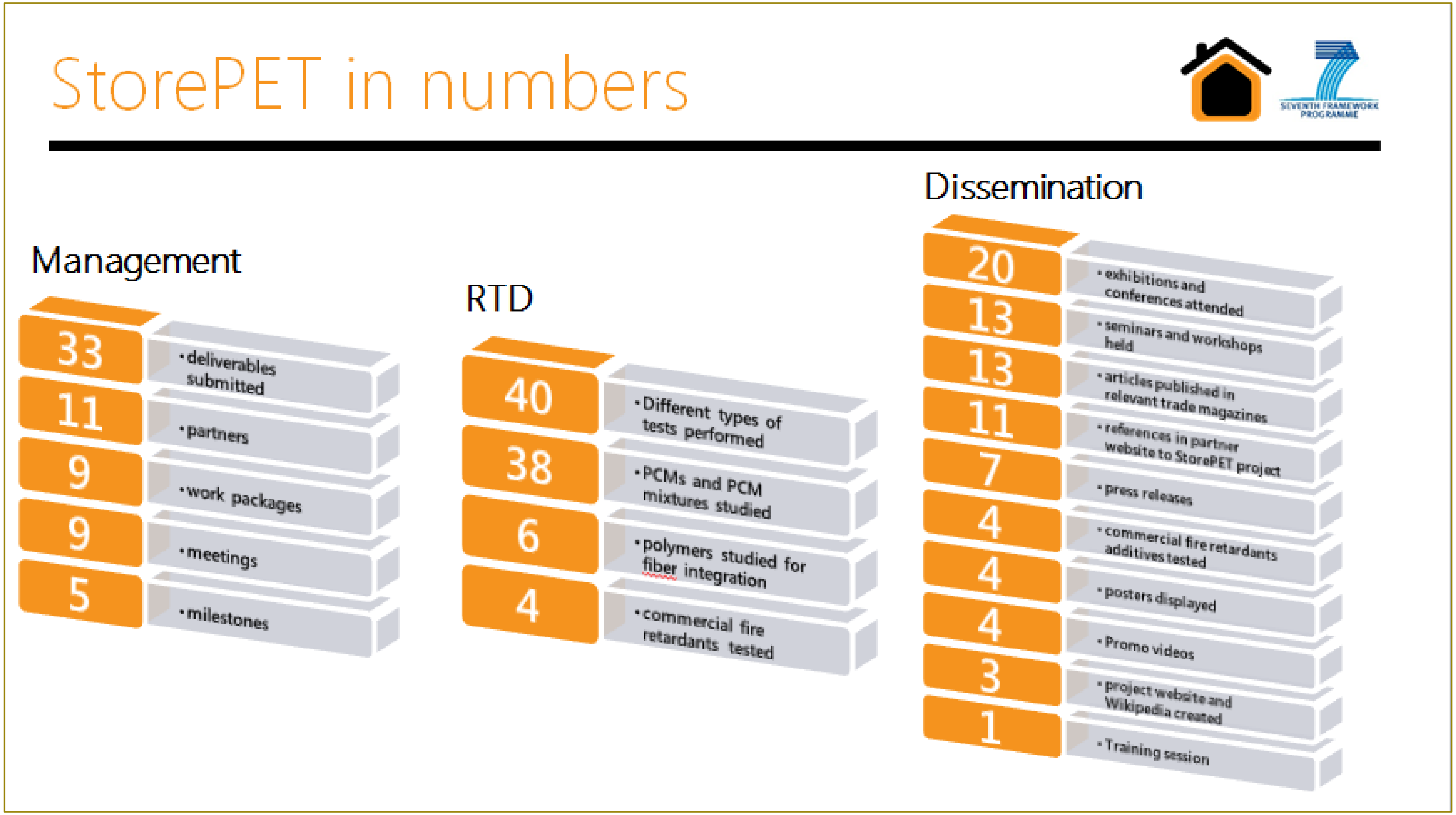


Figure 43: STOREPET in Figures