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Project acronym: THINFRAME

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Funding Scheme: FP7-SME-2013

Final Publishable Summary Report

Thermal performance analysis and comparison through simulations of different window profile geometries incorporating foam and PCM

PROJECT COORDINATOR: TECNOLOGIAS AVANZADAS INSPIRALIA
PARTNERS:

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REPORTING PERIOD: from 01/08/2014 to 31/05/2015
PROJECT START DATE: 01/10/2013

Table of Contents.

Table of Figures.

1 EXECUTIVE SUMMARY.

THINFRAME aims to develop PVC profiles filled with the newly formulated thermal insulating foam manufactured in a single step during the extrusion process. This PVC profile will serve to produce highly insulating window frames. THINFRAME will comply with the most stringent national regulations on thermal insulating properties as required by national and local building codes.

The European Commission has set specific targets by 2020, known as the 20/20/20 targets, meaning the reduction of energy consumption by "20%, CO2 emissions by 20% and providing 20% of the total energy share with renewable energy. Three European legislations are pushing the construction and, as a result, window industry to achieve the above-mentioned goals.

Windows are responsible for about 30-50% of the heat loss through typical building envelopes, depending on the size and distribution in each building. Even though today's windows are considerable efficient, the heat loss per area through windows is still much greater than trough building walls and roofs.

The thermal efficiency of a window unit depends on the properties of both glazing and frame. While substantial effort has been made to improve glazing's performance, technical improvements on frame's properties are still needed as 30% of heat loss takes place through the frame. The best performing frames are made of plastic (polyvinylchloride, PVC) but window industry needs further development in the use of thermal insulating materials and their processing.

The THINFRAME project has been designed to address the above needs. The consortium encompasses the whole supply chain; including: FAPES Srl (Italy), a window manufacturer; Polinter S.A. (Spain) devoted to the production of plastic profiles for windows; Rossi Stamp Srl (Italy), an extrusion tooling and equipment manufacturer; and PCM Products Ltd. (UK), a producer of thermal insulating materials.

After two years of intense research and development efforts, the outcomes of the project have been materialized into the following project results:

- A novel foam formulation that will be prepared from a mixture of polystyrene (PS) and polyethylene (PE) filled with a Phase Change Material (PCM) in order to increase the energy efficiency of the frame.

- An in-line processing method for production of foam filled PVC profiles by co-extrusion of the internal foam core (PS/PE/PCM) and the external PVC layer.

- A profile and window structure with improved thermal insulation optimized for the European market.

The above results are considered highly innovative and are expected to contribute with the following benefits to the European windows profiles market:

- Improved thermal insulation properties. With an improved U-value of the frame below 0.90 W / (m2 K), THINFRAME technology will allow windows manufacturers comply with the most strict European regulations.

- Production by in-line co-extrusion, together with the outer layer of PVC, allowing the European frame and window manufacturers to lower their costs (up to 20%) and simplify their manufacturing processes.

- Cost-competitive price (below 200 €/unit) when compared to currently available high insulating alternatives, that show prices above 300 €/unit.

2 SUMMARY DESCRIPTION OF THE PROJECT CONTEXT AND OBJECTIVES.

In the context of the THINFRAME project, we are addressing the European window industry that is facing increasingly stringent legislation in thermal insulation requirements.

In order to overcome these problems, the THINFRAME project had as main objective the development of a new window frame insulation, representing a cost-effective and enhanced thermal solution able to compete with existing systems of lower insulation properties.

The main objective was to achieve an insulating foam material made of polystyrene (PS) and polyethylene (PE) filled with a Phase Change Material (PCM). The profile is then processed in-line with the PVC profiles made by extrusion; thus providing: easier adaptation to current production methods, lower heat losses, improved energy efficiency of buildings and cost-effective solution able to compete with lower insulation properties PVC systems.

To achieve these objectives, the technical work during the whole of the project was aimed to:

- Prepare protective structures for the PCMs to stabilize them at temperature above 200ºC avoiding the leakage and degradation of the PCM all through the foam they are located.
- The selection of PCM materials with resistant properties to the window profile extrusion conditions.
- The incorporation, by compounding, into a polymer matrix, particularly but not limited to Polystyrene.
- The use of such compound to formulate and produce, via extrusion, of a foam of controlled and tuned cell size; therefore, obtaining optimal mechanical and thermal properties.
- Co-extrude at the same time a PVC profile and the above described and formulated PS compound, being the latter foamed filling all empty cavities inside of the former, in one single step.
- The resultant profile having and optimized geometry and resulting in all its performances compliant with the windows market certifications.

Moreover, it was necessary to study the microencapsulation of PC M by inorganic materials, to study the foaming process and the co-extrusion conditions as well as to calculate the thermal performance of different assembled geometries of window profiles. Also, the optimization of the performance and the energy efficiency of existing window frame foams has been studied to establish the most suitable concentration of foam components to have a defined and homogeneous cellular structure. A new foam formulation has been configured with better thermal qualities which are compliant with European standards of the building sector. The main physical properties of the produced foam has been measured.

The works carried out towards the development achieved include the establishment of mathematical models to compute the thermal performance of window frames containing foams and PCMs and their influence on the thermal efficiency of buildings. This results showed the real improvement in Energy Efficiency that the THINFRAME project is pursuing to achieve.

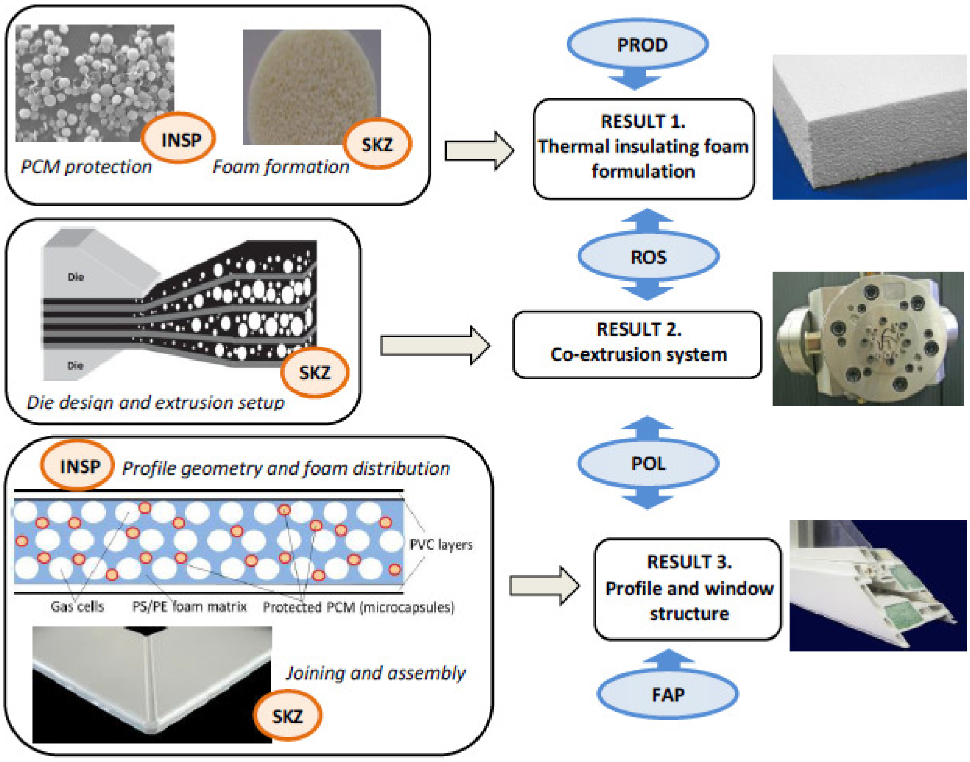

Figure 1. The Thinframe Results

3 DESCRIPTION OF THE MAIN SCIENTIFIC AND TECHNICAL RESULTS / FOREGROUND.

3.1 Main Scientific results.

The scientific results comprised several areas:

1. The understanding of the impact of encapsulation technologies of PCMs on its mechanical and thermal resistance. That involved the separately and jointly study of the resistance of the PCMs and the capsules made of different materials and manufactured in various ways.

   The result was the understanding of how the capsule can sustain the extreme compounding technologies, and how that property can be tuned by adding several layer of different materials: the final result was a twofold encapsulated material having a melamine-formaldehyde layer which was covered by a second one made of Silica. The PCM encapsulated had net thermal storage capacity equivalent to the total mass contained in the capsules, which proved to be stable to repeated heating/cooling cycles.

   The in detail results were:

a. The selection of the specific PCM according to the confinement strategy for minimal external volume changes, PCM handling and compatibility with the foam formulation. The Protection through microencapsulation to improve heat transfer flux due to a greater surface contact area and cycling stability by reducing phase separation. That resulted in Obtaining microcapsules size <20µ with a core/shell >70wt% via:

   i. The identification and selection of the material strategy for PCM confinement for maximum efficiency of the thermal storage properties.
   ii. Design of an encapsulating shell to make it compatible with the host polymer matrix thereby not preventing the transformation process of the polymer foam during extrusion in terms of the final piece's mechanical properties.

b. An obtained PCM structure compatible with the PS foam making a full characterization of the main physic-chemical properties of the prepared PCM structures.

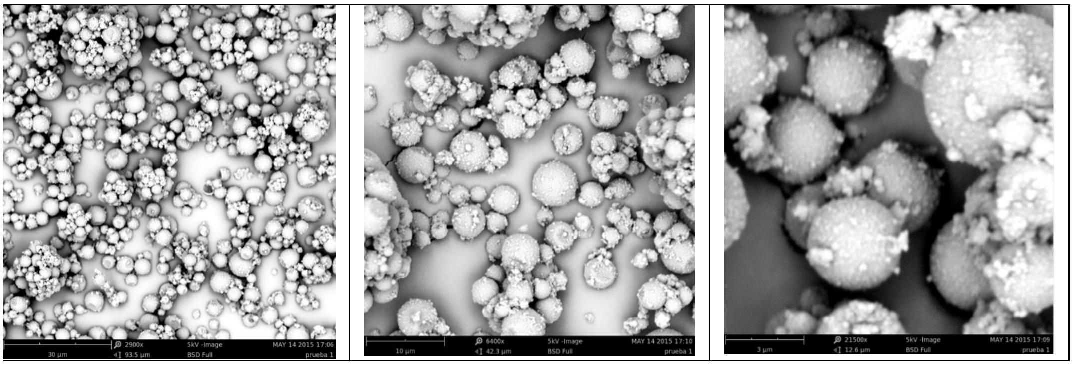

Figure 2. Twofold encapsulated PCMs.

2. The understanding of the interaction of the capsules inside of the polymer matrix (thermal behavior): the capsules mainly were compounding resistant. In such a case they had little impact into the foaming process (in case of Chemical foam). They distribute evenly both into the PS compound and into the Foam. In the foam, the capsules were mainly found on the surface of the cells, having little impact in the cell walls and strouts. In the case were a small part of capsules were broken (5-to 15%) it was some impact in the rheology of the PS melt, the melt strength was reduced. That issue, in some cases, did not affect by far the foaming process and in some samples, it was even positive, helping the foam to fill all gaps inside the PVC profiles, the compatibility of the PS foam and the PVC was increased. However that benefit, such issue had to be controlled due to the loss of the thermal properties of the released PCMs and risk of control list of the foaming process.

   The in detail results were:

c. The understanding of the foaming process, allowing the evaluation of the conditions of formation of PS foams, basic kinetics and methodology of polymer foaming as well as the influence of the foaming agent and PE as a method for controlling the cellular structure of the insulating foam. Considering a concentration of chemical blowing agent below 10% and a cell distribution of 2-15cells/ µm.

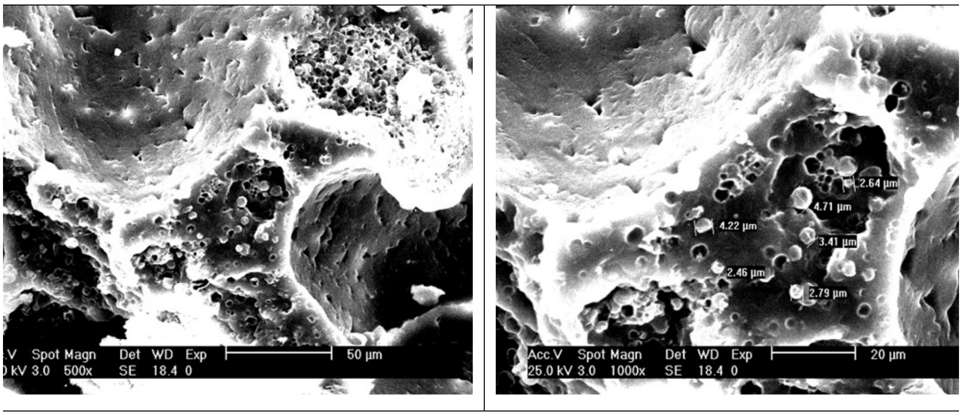

Figure 3. Twofold encapsulated PCMs dispersed into a Polystyrene matrix (compound after several processing cycles).

d. The definition of the co-extrusion conditions, correlating the foaming of PS with the physical behavior of extruded PVC. This will assure that the two flows of component materials (insulating foam and outer PVC layer) are compatible and that the stability of the profile is maintained.

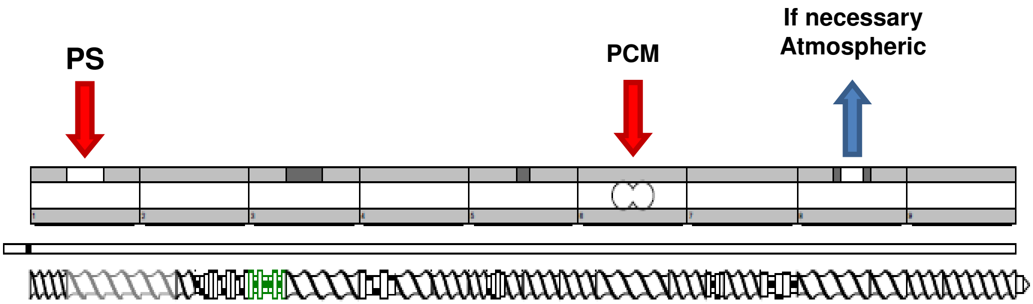

Figure 4: Screw configuration for PS compounding.

3. The optimization of the performance and the energy efficiency of existing window frame foams has been established defining the most suitable concentration of foam components to have a defined and homogeneous cellular structure.

4. The works carried out towards the development achieved; include the establishment of mathematical models to compute the thermal performance of window frames containing foams and PCMs and their influence on the thermal efficiency of buildings. This results show the real improvement in Energy Efficiency that the THINFRAME project was pursuing to achieve.

5. A new foam formulation has being configured with better thermal qualities which are compliant with European standards of the building sector. The main physical

properties of the foam produced have been defined and tested to adequate the results of testing to the thermal insulating materials sector.

6. The study of the rheology behavior of the PS formulated compound, its foaming kinetics and mechanisms , together with the understanding of the PVC own rheology (flow behavior), allowed the design of the a new co-extrusion tooling.

7. In addition, the study of the foaming and thermal stability of the co-extruded materials gave the understanding of the melt flows of the materials and the limit in the processing conditions, allowing in turn, the initial selection of the equipment and the design of the optimal processing conditions.

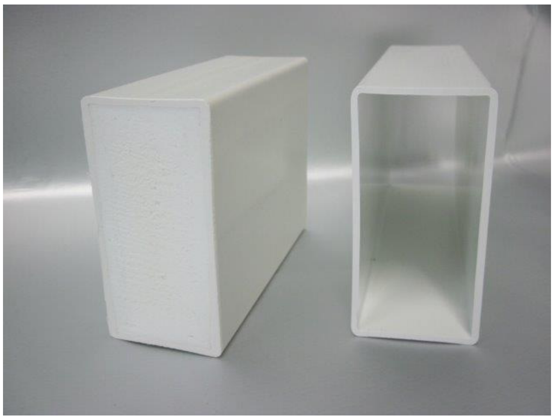

Figure 5. PVC with foamed PS, process developed by SKZ.

3.2 Main Technical results.

The final window profile involved the combination of several technologies:

- Foam with improved thermal (Insulation) and mechanical properties (mechanical properties added to those of the profile).
- Foam with additional thermal heat storage capacity by having encapsulated PCMs.
- A proprietary pultrusion technology that allows the PVC reinforcement to a level equivalent to that of those of Aluminum frames. Allowing extra light performance with improved insulation PVC frames; by eliminating thermal bridges as the metallic frame need to confer stiffness to the window assembly is removed.
- The manufacturing of the THINFRAME window profile is a "One step manufacturing process", integrating all its constitutive elements in a steady and continuous process. It has the following advantages:
    - Low overheads and low manufacturing cost.
    - Technology resultant of the merge of existing technologies which can be easily implemented in the current manufacturing industry of window, door frames, transoms / beam profiles.
    - Controlled manufacturing quality.
    - Intimae interaction of all the constitute elements providing optimal enhance of the overall performances (insulation, thermal and mechanical).
    - Optimal savings regarding residues.
    - Easy Recyclability. The constitutive elements could be separated, post treated and recycled.

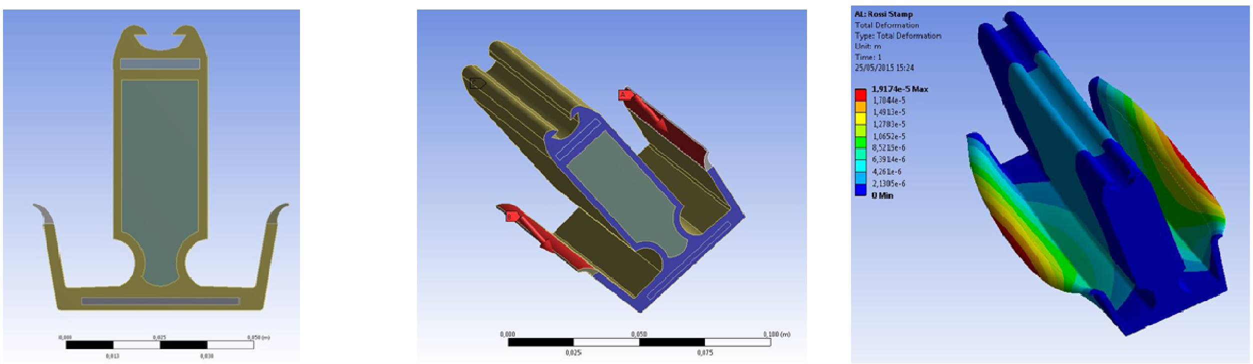

Figure 6. Rossistamp PVC profile - filled with PS foam reinforced with glass fiber.

In more concrete terms, the THINFRAME solution can contribute to achieve an Integrated and Cost-Effective solution to lower heat loss through window frames by using the described innovative technology able to**:**

- Improve thermal insulation properties, with U-value of the frame around 0.86W / (m_2 K) making it easier to comply with the most recent member states' legislations.
- Produce by an in-line co-extrusion together with the outer layer of PVC manufacturing process, allowing the European frame and window manufacturers to lower their manufacturing costs (up to 20%) by simplifying the process of manufacture.

- Get a cost-competitive price (below 200 €/unit) when compared to currently available high insulating alternatives, that show prices above 300 €/unit.

The results above are possible, because THINFRAME project has developed PVC plastic profiles filled with newly formulated thermal insulating foam manufactured in a single step during the extrusion. This PVC profile serves to produce highly insulating window frames. Thinframe complies with the most stringent national regulations on thermal insulating properties as required by local building codes.

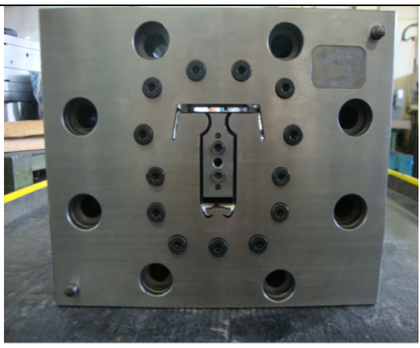

Figure 7. Final assembled Co-extrusion die.

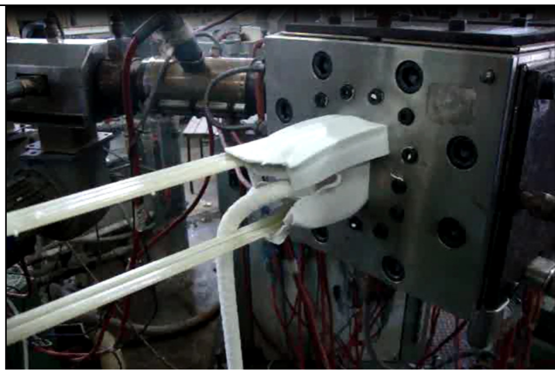

Figure 8. Detailed picture about the pultrusion system, Rossi Stamp proprietary technology. A, Glass fibber passing throughout the die during the co-extrusion of PVC-PS foam.

The Thinframe solution consists of a PS-based thermal insulating foam formulation as a safe alternative to PU involving the following developments:

- Selection of foaming agents and foaming technology as a means of controlling cellular structure,
- PCM protected structures produced by microencapsulation of organic PCM with an inorganic layer in order to increase the thermal efficiency of the foam through thermal storage: preparation of protective structures for PCMs: Stabilization of PCM at temperature above 200ºC and foam density in between 50kg/m3 up to 250 kg/m3 (improved mechanical properties) with a thermal conductivity λ <0.04 W/(m.k) (not in case of high-density foam of ρ=200kg/m^2 → λ=0.057W/mK) and a PE content <5%wt.

Additionally, for the cost-competitive production of PVC window frames with high insulating properties, it has been necessary to develop a method based in the extrusion process. The most suitable method is the use of a co-extrusion process of the PVC and the insulating foam formulation that was able to fill the cavities of the profiles. This development required a careful design of the die and the adjustment of co-extrusion system.

The in detail results were:

- The Optimization of the foaming process: Foam formulation with controllable cellular structure (distribution of 2-15 cells/mm) and thermal insulation value around 0.04 W / (m K).

- The compatibilisation of the foaming process with in-line extrusion of PVC profiles. Co-extrusion Die with maximum pressure difference of 50 bars and temperature difference not higher than 10ºC between PVC and foam.
- Design of a frame structure for windows and other material used in construction Transom /beam, using the Thinframe co-extrusion pultrusion reinforcement profile manufacturing technology.

Table 1 U-values comparison with the final properties

FRAME	Current FAPES	Steel removed	Foam final strand	Foam final profile
U-value, W/m2K	1.38	1.01	0.82	0.86
% improvement	-	27%	41%	38%
% to reach theoretical optimal value	98%	44%	18%	23%

Figure 9. Final industrial profile. PVC glass fibber reinforced, PS foamed inside.

4 POTENTIAL IMPACT AND MAIN DISSEMINATION ACTIVITIES AND EXPLOITATION RESULTS.

4.1 Potential impact and use.

The need to comply with the increasingly stringent legislation in thermal insulation requirements for buildings in European countries is the main driver for the expected 30% growth by 2020 in the construction industry considering the public and private sectors. The European window and façade market stabilized in 2010, after overcoming hard 2009 due to the financial crisis and grew in 2010 by 0.4% to 125.8 million window units. About 80% of all buildings in Europe were built before the 1990s, at a time when most EU members had no energy performance-based requirements in their building codes. Therefore, the market is expected to continue sustained growth mainly driven by the increasing level of renovations (by more than 4% annual growth) in order to reduce the heating and cooling energy costs.

The European insulating materials market was estimated at €1.84 billion in 2008. For the decade 2005-2015 the estimated average annual growth rate is more than 4%, reaching a volume of 697.2 million units to 2015.

Regarding the exploitation plan, after the deep market analysis, the THINFRAME consortium strongly believe on the competiveness of our new technology, despite other new technologies in insulation market are emerging, like for instance new materials as the aerogels. In most of cases such technologies are very expensive versus THINFRAME due to both high cost of the raw materials and its industrial implementation for the window frame manufacturing process.

The THINFRAME technology is a clean and versatile one, based in raw materials of moderate price which, in addition, involves the elimination of complexity in the window frame profile design (which decrease the price by eliminating some detrimental elements for the insulation, i.e. the metallic reinforcement frame) but increasing the overall performance (insulation and mechanical). In addition to the opportunities of commercialization in the windows market, it can be foreseen other opportunities in the construction and equipment's protection market, by the design of tooling and formulations of coextruded panels (mainly based in XPS, but also potentially including others such as polyolefines, etc.) with layers of insulation materials with differentiated functionally (improved insulation and thermal repose materials, the latter containing PCMs disperse into a polymer matrix which in turn can offer mechanical properties (abrasion, resistance to compression, etc.) and aesthetical properties (color, gloss, printability, etc.).

4.2 Main Dissemination activities

The dissemination activities undertaken have been addressed to get the highest possible impact for the results achieved in the project, guaranteeing the maximum dissemination of the scientific results, coordinating the IPR protection strategy for the consortium and designing and developing the exploitation strategy. It also gathers all training activities devoted to ensure an effective knowledge transfer from the RTD performers for training of the SMEs partners. The dissemination activities included continuous communication with relevant stakeholders, maintaining the project website, presentations, publications, conferences, etc.

In that sense, the project web site is available at: www.thinframe.eu

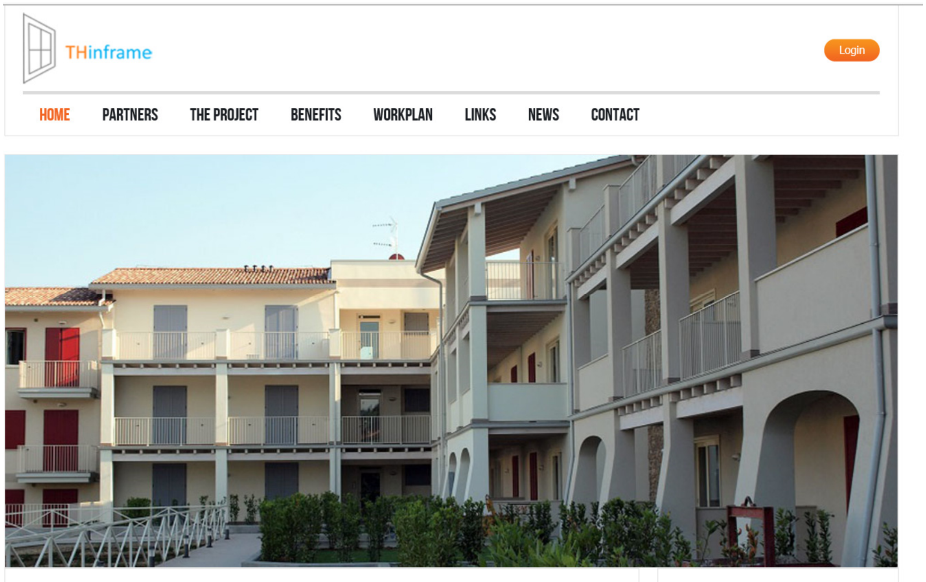

Figure 10. Thinframe Web Site.

The Wikipedia page and its publishable results have been submitted for approval to the Wikipedia administrators. On the other hand, the Project Video has been produced and is now available. The Video has been distributed to a number of media; including: the Project Web Site, YouTube, LinkEdin, Google+, etc.

www.thinframe.eu/the-project
www.youtube.com/channel/UCpafhzB_3sWAXL83qnAkpTw
https://plus.google.com/113601034871362252490/posts
www.linkedin.com/company/tecnolog-as-avanzadas-inspiralia-sl

Several actions were also followed in order to get the maximum distribution of THINFRAME results among the other companies involved in the window industry in different geographical areas. These activities were targeted to prepare the path for success during the different Exploitation phases. Among those activities several Show fairs were attended within THINFRAME activities:

- VETECO: (Madrid, May 2014) International Exhibition for windows and building elements.

- BATIMAT (Paris, November 2015). Next visit to BATIMAT. One of the biggest exhibitions in Europ
- BTA-FOODTECH: (Barcelona, April 2015
- HOST: (Milano, October 23 - 27, 2015
- EUROSHOP: (Dusseldorf, February 2014).
- K-Messe 2013
- Plast 2015. International Trade Fair for Plastics & Rubber. 26-30 Oct. 2017 Milan, Italy.

Other dissemination activities involved:

- The creation of a Thinframe project Linked-in group. A group was created in 2014: www.linkedin.com/grps/Thinframe-8155977/about?
- Participation in: The Brightest! Greenest! Buildings Europe 2015. (A carbon neutral virtual exhibition dedicated to Europe's most successful and greenest building projects and the green building solution contributing to their performance (www.brightestgreenestbuildings.eu/en/home).
- BUILD UPON aims to build a community: whose mission is to work with partners to co-create ambitious national renovation strategies to improve our existing buildings (Article 4, EU Energy Efficiency Directive).

BUILD UPON
Co-Creating Europe's National Renovation Strategies

Finally, but not less important the technology and its benefits was disseminated among the SMEs customers through commercial meetings, including physical visit to the experimental and industrial lines during part the manufacturing trials. Potential customer could see by themselves the technical advantages of the developed "One Step" co-extrusion pultrusion (reinforcement) foaming process at Rossi Stamp demo site and the Extrusion-foaming experimental process at SKZ site.

5 WEB SITE AND CONTACTS.

5.1 Members of the Consortium.

Partner	Short name	Web site	Country
TECNOLOGIAS AVANZADAS INSPIRALIA S.L.	INSP	http://www.inspiralia.com/	Spain
POLINTER SA	POL	http://www.polinter.com/	Spain
ROSSI STAMP SRL	ROS	http://www.rossistamp.com/index.php?lang=en	Italy
PHASE CHANGE MATERIAL PRODUCTS LTD	PROD	http://www.pcmproducts.net/	United Kingdom
FAPES SRL	FAP	http://www.fapes.it/	Italy
SKZ-KFE GGMBH KUNSTSTOFF-FORSCHUNG UND-ENTWICKLUNG	SKZ	http://www.skz.de/en/	Germany

5.2 Project Contact

For more information on the THINFRAME project please visit the project web site

www.thinframe.eu

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