Highly Sustainable and Effective Production of Innovative Low Cost Vacuum Insulation Panels for Zero Carbon Building Construction

Final Report Summary - VIP4ALL (Highly Sustainable and Effective Production of Innovative Low Cost Vacuum Insulation Panels for Zero Carbon Building Construction)

Executive Summary:
The aim of the VIP4ALL project was to generate for the building sector a real and cost-effective VIP alternative solution, specially designed for the energy efficiency goals of major EU building renovation actions and able to provide superior thermal insulation for building retrofit activities at real competitive and affordable prices.

A comprehensive work programme has been carried out for the successful development of VIP4ALL products, starting from the understanding of scientific needs for superior thermal insulation to identification/characterisation and novel nano-modification of appropriate natural/renewable materials, hence to numerical/experimental compositions and manufacturing of VIP4ALL, and finally to upscale...
hence to numerical/experimental compositions and manufacturing of VIP4ALL, and finally to upscale production of VIP4ALL and its performance in use in building demonstration. VIP4ALL composite core has been novelly formulated with hybrid scale-sized structures for both facilitating the production and ensuring sufficient thermal performance of VIP panels in practices. In addition, a side-stream development has also been carried out to explore exterior in-situ encapsulation of VIP for much robust operation and application. Many significant outcomes have been achieved, including the processing technologies, sustainable functional VIP4ALL core materials/systems, VIP4ALL thermal insulation panels with thermal properties similar to those of fumed silica, performance database, and simulation tools for composition and performance design. Additionally developed new thin exterior encapsulating cork surface layer could make new VIP4ALL much more user-friendly, e.g. easier to handle during stock, transportation and installation on-site, as well as protective, with less restriction regarding puncturing and consequent loss of performance, and this technology could also be applicable to conventional VIP panels.

VIP4ALL (Figure 1) aims to be recognized for their excellent thermal insulation properties (achieving lambda value 7mW/mK) at thickness smaller than 1/3 conventional air-filled insulation for the same R-Value. Apart from the excellent thermal performance, VIP4ALL products gather equal acceptance as standard VIPs regarding its design and fire resistant capabilities for building application (Class Bs1d0).

With a thickness between 3 and 4cm, VIP4ALL products could reach minimal thermal conductivities at common pore pressures, comparable to commercial VIPs for building applications and an expected lambda of 10mW/mK after 25 years under ambient conditions, and about 15mW/mK after 50 years, still providing much superior thermal insulation than any other conventional material used in the building market.

VIP4ALL project was funded under FP7-SME - Research for the benefit of SMEs (No. 606037). The project consortium includes the Garcia Rama Ltd, Spain; Va-Q-Tec Ltd, Germany; Sofalca Ltd, Portugal; Nordisk Perlite Ltd, Denmark; IPN, Portugal and Brunel University, UK. The VIP4ALL project is completed and the consortium is now proceeding to the next stage of industrialization of the technology and commercialization of the VIP4ALL products. In lieu of highly appraised outcomes from the final evaluation meeting and the significant potentials expected beyond the scope of the VIP4ALL project, the consortium is also exploiting more extensive development and hence collaborations.

Project Context and Objectives:
While the world is experiencing a strong demand for the measures of energy savings, today still around 40% of energy consumption and 36% CO2 emissions in Europe are directly related to the construction sector, due mainly to inefficient insulation materials and systems. On the verge of a major European building retrofitting action that must be put into practice within a deep economic crisis, inevitably traditional thick and cheaper insulation products are still the first consideration since the best state-of-the-art solution, Vacuum Insulation Panel (VIP) is unaffordable for the majority of homeowners and householders. The building sector has to overcome the biggest dilemma of coping with high mandatory levels of energy savings, at reasonable costs, but without losing considerable areas of living space due to the application of retrofitting insulation.

VIP4ALL project aimed at developing a true technical and cost-effective VIP solution by using natural minerals and/or renewable organic by-products as low cost VIP core materials through careful microwaving and doping with just minor amount of the expensive fumed silica (Figure 2). The composite core has a hybrid scale-sized structure that enables the overall reduction of the pore size, thus being less strict to the vacuum conditions. Besides its eco-friendly status, this hybrid core solution could not only cut its final price by more than 50% but also guarantee a similar thermal performance as the commercial VIP panels under moderate vacuum levels. Complementary, VIP4ALL panels' design was even improved by...
panels under moderate vacuum levels. Complementary, VIP4ALL panels’ design was even improved by the development of a thin cork protecting surface layer, making VIP4ALL much more user-friendly to stock, transport and to handle during installation and other mechanical impact resistance.

VIP4ALL products were specially developed to be the material of choice for the retrofit market, where low cost and living space area savings are as important as the need for outstanding insulation ranks, something that neither traditional nor the today’s state of the art European products can fully answer to. VIP4ALL products achieve thermal conductivities below 8mW/mK and are technically comparable to conventional ones with cores made of fumed silica or aerogel, but at a more acceptable cost. VIP4ALL project brought to the market a new generation of highly sustainable and energy efficient solution for low budget renovation actions, creating an exceptional opportunity for SMEs (>99% in EU building sector) to increase their competitiveness before the current dominant US and/or Asian companies seize this market, which represents around 9% of European GDP and a total workforce of 25 million jobs.

Main objectives of the VIP4ALL project were to:

Scientific Objectives
- Effectively control and understand VIP technology;
- Fully understand the role of the constituents that compose VIP core and envelope, and the processing parameters (vacuum level and air/moisture tightness) upon the properties of the final product along its service life time (ageing effect);
- Efficiently derive new VIP4ALL by using natural and renewable raw materials for optimal thermal, environmental and mechanical performance.

Technological objectives
- Develop new enhanced multi-level VIP core systems from low cost natural mineral resources and organic renewable/recyclable resources to replace standard high cost materials currently used;
- Refine the low cost VIP4ALL processing technology, up-scale it from a laboratory testing environment to a large industrial production;
- Combine the best technical properties with the least embodied energy necessary for the lowest production cost commercial manufacturing of VIP4ALL;
- Develop simulation tools that can successfully aid the development of the best VIP4ALL composition and core networking structure;
- Design VIP4ALL with the integration of traditional building materials and different envelope systems, and assess their thermal insulation performance, energy savings skills and payback times.

Technical Objectives

Develop VIPs with:
- Low thermal conductivities: less than 8mW/mK (thermal conductivity of the centre of panel (Kcop), using pore pressures lower than 100 mbar), comparable to standard VIP solutions;
- Life-time expectancy of at least 50 years under standard and typical environmental conditions of temperature and ambient vapour pressures without losing significant thermal performance;
- Thicknesses lower than 30 mm or lower than one third of conventional air-filled insulation of the same R-Value;
- Acceptable fire resistance performance for building application (at least Class B2).

Economic and Societal Objectives
Economic and Societal Objectives
- Develop VIP4ALL with reduced production costs: cutting up to 50% the costs of the conventional silica VIPs, making VIP4ALL capable of competing in terms of price with standard fibre and polymer insulation products;
- Achieve high energy saving ranks by combining outstanding insulation properties with 50% of the conventional VIP payback time;
- Offer a new product (VIP4ALL) to the retrofitting sector, capable of saving 5 (at least 3) times more living space compared to conventional fibre insulation products;
- Achieve sustainable construction by using at least 50% of low energy renewable materials for VIP product;
- Play an important market role in ambitious renovation programmes, helping both SMEs producers and end-users re-launch their activity and aid their economic recovery process.

Project Results:
Project Outcomes
Many significant outcomes have been achieved, these include a novel generation of vacuum insulation panels (VIP4ALL), their formulations, manufacturing technologies, performance in use and the simulation software developed to predict the thermal responses of different core compositions and VIP4ALL panels in combination with other building materials.

The development of the VIP4ALL products covered the following main steps:
1) Identification and modification of low cost, natural, open pore core materials with low pore size, able to efficiently reduce gas conduction at moderate vacuum levels;
2) Experimentally and numerically design of compositions and development of manufacturing technologies of VIP4ALL core systems;
3) Identification and evaluation (of gas and water permeability) of envelope foils with the highest barrier properties, allowing the VIP4ALL panels to have the necessary long service life of above 25 years for building purposes;
4) Production in lab and upscale in commercial production line of VIP4ALL;
5) Additionally design a protective skin made of ecological, natural and renewable cork thin layers able to keep the vacuum panels safe against mechanical damage without losing thermal performance.

The VIP4ALL Insulation Material
The final VIP4ALL product is constituted with a special grade of pure lightweight mineral powder as core material, with very fine powder distribution and low pore sizes, wrapped in vacuum with an envelope of superior barrier properties. A permanent frame technology was developed to confer regular, square-shaped edges to appropriate panels fitting. Moreover, an advanced version is the encapsulated VIP4ALL panels with an innovative, eco-friendly thin cork surface layer. The encapsulated version VIP4ALL allows a safer and better handling and installation on-site, while giving protection against puncturing and consequent loss of performance. The VIP4ALL insulation products and their technical characteristics are summarised in Figure 3.

Project Development and Achievements
Main achievements
All the objectives of VIP4ALL project have been successfully achieved. Main achievements related to the project results can be summarised as follows:
Result 1: Sustainable functional core systems for insulation products: The project has fully achieved the development of novel hybrid core VIP solutions by using low cost wood residues and siliceous lightweight materials as core system with low cost, natural, open pore core materials with low pore size, allowing the VIP4ALL panels to have the necessary long service life of above 25 years for building purposes.
development of novel hybrid core VIP solutions by using low cost wood residues and siliceous lightweight
powders doped with controlled amount of fumed silica, in which some of these compositions present even
better thermal conductivities than those of pure fumed silica for gas pressures up to 10mbar.
Result 2: VIP4ALL thermal insulation vacuum panels: It was developed and industrialized a new
generation of vacuum insulation panels with thermal properties similar to those of fumed silica, but based
on a cheaper natural and sustainable lightweight mineral. The panels can be processed with a new
encapsulation cork layer for better handling and mechanical protection. The following picture (Figure 4)
shows the main features achieved:
Result 3: VIP4ALL processing technologies: An efficient method combining microwave pre-treatment and
vacuum impregnation method was developed for multiple core restructuring possibilities and raw materials
pre-treatment. The results can provide an effective dispersion of fumed silica nano powder in a
hierarchical network of the larger open pores of the organic and inorganic hybrid formulations.
Result 4: VIP4ALL composition and performance simulation software: A software was developed to
predict the thermal behaviour of the different core compositions and pore structures not only at material
level, but also capable of foreseeing the final product thermal performance. Software outcomes provide
important and useful fundamental basis for material researchers and manufacturers to formulate VIP4ALL
products as well as its thermal performance prediction in multicomponent building systems.

Apart from the achievements related to the project results defined in DOW, the consortium has also
carried out complementary tasks which have allowed us to reach the following outcomes:
• New surface protection system, which is not only applicable to VIP4ALL novel solution, but also for the
  conventional VIP panels;
• Promoted cluster integration since VIP4ALL has become a member of the EU Advanced Material and
  Nanotechnology Cluster (AMANAC) within the “Insulation Materials”
• Produced training material for future knowledge
• Promoted VIP4ALL on multiple platforms (congresses, fairs, magazines, flyers, posters, internet, etc.)

VIP4ALL outcomes according to project objectives
Scientific Objectives: All the scientific objectives were achieved by the formation and consolidation of
specific know-how on materials properties and vacuum technology necessary for the final product
specifications. The role of each material component (core and envelope) and factors affecting the
performance of material (aging effects) were assessed and understood. The investigation for alternative
ecological and cheaper core materials than the commercially used fumed silica was carried out following
all the requirements.
Technological Objectives: Final scalable VIP4ALL products were achieved, with and without protective
skin, fully attending the necessary material specifications for successful use in building applications.
Around 250 panels were produced in an industrial environment, meaning that a successful scale-up work
plan from lab to industry was accomplished. VIP4ALL panels contain natural low cost inorganic powders
as core material and behave similarly to the commercial ones for moderate vacuum conditions. Simulation
tools were developed and were able to predict the thermal response of several compositions in study and
the integration of the end product with other building elements.
Technological Objectives: All the critical objectives of the project linked with the technical compliance of
the new developed VIP4ALL product were accomplished or even exceeded, clearly attesting the potential
of VIP4ALL solution created for the building sector. The following table (Table 1) shows how the features
of VIP4ALL faced with project goals.
Economic and Societal Objectives: Analysis of the cost effectiveness was done taking into account the
costs per mass of the core material, its density and its mean thermal conductivity. For the evaluated
Costs per mass of the core material, its density and its mean thermal conductivity. For the evaluated VIP4ALL with the core density of 285 kg/m³, costs/mass of 0.30 €/kg and a mean thermal conductivity of 7mW/mK, the specific cost of 0.60 €W/m4K was calculated. For a comparison, the specific cost of fumed silica is 1.75 €W/m4K. It means that more than 50% reduction cost on the core material was achieved by the VIP4ALL project using the alternative core systems. Taking into consideration a global perspective that can include the service life performance of VIP4ALL and fumed silica panels, a cost advantage for VIP4ALL is envisaged to be around 30%, turning VIP4ALL panels a much more appealing product of choice for the building market. This reduction in cost is particularly important when it comes to deal with retrofitting actions. Spacing savings around 4 to 5 times can be guaranteed by VIP4ALL products, when compared to conventional insulation materials for the same thermal performance, as it is clearly presented in the graph below (Figure 5):

Milestones achieved
A list of 4 milestones was initially defined and linked to the expected project results, covering important technical events in the project work plan that had to be accomplished. The following table (Table 2) shows the forecasted milestones and how they were verified at the end of the project.

The following section summarizes the major activities, development and outcomes accomplished in the RTD work packages of the project.

WP1 - Preliminary Research: Definition of relevant scientific concepts
Traditional and state-of-the art and future thermal building insulation materials targeting energy efficiency were reviewed and reported under this WP, as well as summarized the most common building solutions, either for new and old buildings across Europe. The high insulation materials currently available on the market can be applied in almost every space or component that need to be insulated, but the nature and performance of each one targets them to be more suitable for specific applications, being either for exterior and interior wall insulation (in new or retrofitted buildings), roofs, floors and also for some special applications, like doors or prefabricated elements. The advantages and drawbacks of each thermal insulation materials were reported, as well as a comparison of some of their properties and requirements, namely thermal conductivity, mechanical strength, fire resistance, durability, costs and environmental impact ranks, among others. The development of an enhanced understanding concerning modern building systems, their thermal insulation needs and current materials/systems diversity (including standards, building codes and regulations), focusing particularly on the refurbishment market.

Based on an extensive literature review, this WP has covered not only a comparison between the performance of traditional insulation materials versus VIPs, as well as the physical fundamentals involved in vacuum insulation, with special focus on the importance of gas conduction in VIP’s thermal conductivity. Different composition spectrums were evaluated (including fumed silica, aerogels, PU, glass fibres, etc.) for VIP core materials, both for building insulation (Figure 6) and appliance and packing applications, stating their performance ranges, advantages and drawbacks, as well as diverse types of commercial barrier envelope foils available, describing their skills to avoid the permeability to atmospheric gases and water vapour during the insulation lifetime, up to comprising factors affecting VIPs performance, like thermal bridges and ageing effects.

Following a description of VIP production technology, a picture of current VIP’s building uses and construction examples studied, covering different application fields like facades/walls, roofs, floors and sandwich elements. Complementary, the cost of VIP building integration was primarily approached, as well as current VIP performance standards, application drawbacks, service life and installation concerns. Finally, apart from the developments expected for VIPs and advance insulation materials in a near future
Finally, apart from the developments expected for VIPs and advance insulation materials in a near future, an introduction of VIP4ALL approach of using low cost materials for the construction of VIP core is given, summarizing the properties of mineral and organic powders proposed, their role as standard building insulation materials and the achievements made so far regarding their integration in vacuum insulation technology, thus defining important inputs needed for simulation tools and further product development.

WP2 - Raw materials characterization and components processing definition

This WP was reserved for the identification, testing, characterization and technical comparison of the many proposed natural/renewable inorganic/organic materials anticipated towards the selection of the best ones to be used for the core of the novel VIP4ALL panels, as well as the identification of the best commercial envelope solutions for product development aiming defining VIP4ALL composition and associated industrial production technology.

Two groups of low cost, environmental friendly inorganic and organic materials were select as total or partial substitutes for fumed silica, commonly used in VIP’s cores (Figure 7). The natural and processed organic granules considered in this work are industrial wastes. Their re-use is in agreement with the nowadays sustainability agenda, which simultaneously demands energy conservation alongside the use of low impact materials to reduce the consumption of raw materials, prevent greenhouse gas emissions and, consequently, global warming. Regarding the mineral options, two special fine grades, with particle sizes lower than 100µm, were anticipated.

Complementary, another two natural siliceous powders with even finer particle sizes were considered and characterized. The assessment to the main chemical, physical and thermal characterization of these materials is then reported in this deliverable and compared to commercial nanoparticle fumed silica, already used in VIP’s cores.

Specific particle size fractions of two types of lightweight minerals and organic powders were then selected for being the most suitable raw materials, based on whole set of characteristics such as low bulk density (between 0.18 and 0.3 g/cm³) and initial moisture content, good thermal properties, the best open porosity ranks and overall ease of evacuation during VIP processing. At this stage, the different scales of particle and pore sizes were considered to allow the construction of effective VIP4ALL hybrid core nano structures, including also the possibility of partially using fumed silica. In order to accomplish the goals of this WP and to pursue with the laboratory developments expected for WP3 and WP5, new vacuum chambers and sealing machines were built by IPN (Figure 8) and acquired to produce lab trial samples at ultimate vacuum levels below 10-2mbar and test the new core systems. At this stage, a new dedicated high precision thermal conductivity measurement equipment was also built, exclusively to assess the thermal properties of VIP4ALL samples. The extensive laboratory characterization of the VIP4ALL core candidates has included, among others, X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FT-IR), particle size distribution by laser diffraction (DLS), real density, particle specific surface area evaluation (BET), pore size distribution by Hg porosimetry and N2 adsorption, SEM morphology analysis, initial moisture and moisture adsorption evaluation by Dynamic Vapour Sorption (DVS) analysis, thermal conductivity, determination of the apparent core density and materials easiness of evacuation.

Following this study, three single material and four multi-material compositions were proposed to be tested as VIP4ALL hybrid core systems and evaluated further in the research plan (W3 to WP5). This selection has included an appraisal of primary cost effectiveness study of the proposed compositions, based on raw materials price and processing costs combined. Complementary, from a set of 4 types of commercial envelopes (Figure 9), all having extremely high barrier properties against gas/vapour transmission, two foil
envelopes (Figure 9), all having extremely high barrier properties against gas/vapour transmission, two foil systems were selected for further VIP4ALL R&D tasks and development. This assessment has included the laboratory appraisal of moisture transmission rates and as well as mechanical and quality testing. Finally, a preliminary evaluation of the usage of cork sheets for VIP4ALL panel encasing was undertaken, with very encouraging results obtained, proving the ability of cork envelopes to provide the necessary mechanical protection for VIPs without the losing much thermal efficiency.

WP3 - Modification of natural renewable raw materials for VIP4ALL

This WP has covered the study and reporting of a comprehensive database and corresponding prototypes of the original and restructured core materials proposed for VIP4ALL, with a systematic account of from the parameters of the original raw materials, including from macro, micro, chemical compositions, physical properties of size distribution, particle size, density, moisture content, moisture sorption behaviour, porosity and original thermal conductivity, to the restructuring technologies, to the restructured materials with the networks performance.

The outcomes have addressed the overall objective of WP3 and reflected significant amount of the experimental work carried out to restructure the novel proposed powder materials in conjunction with fumed silica. The compiled work has provided many major achievements, being the main one the development of a properties database of which served as a vital base for the understanding of the restructuring processes and resulted restructured systems for the possible development of VIP4ALL in WP4 and WP5. The developments towards the modification and beneficiation of the natural raw materials were made through multi-mode microwave technology and induced steam pressure to facilitate the hybrid construction of VIP4ALL cores and to develop nano to macro pore network systems and their filling by inorganic particles (e.g. silica fume) towards optimal thermal performance (Figure 10 and Figure 11).

Many important outcomes have been achieved, including the definition of different modification stages and consequent restructuring pore size/intrusion levels capable of been generated and their relationship with systematic processing parameters. A comprehensive database and corresponding prototypes of the original and restructured core materials proposed for VIP4ALL have been compiled and documented. It was concluded that while the microwaving processing was not sufficient to attain the dispersion of fumed silica (requiring a supplementary and efficient carrier, e.g. air water or other suspension.), on the other hand, it can be very significant on the modification of the organic powder pore network systems and quite effective upon changing open porosity levels of the lightweight mineral formulations, both useful for later evacuation easiness during VIP production and for the suppression of gas conduction inside the system.

WP4 - Production, materials and product performance simulation

This WP intended to develop simulation models and fast working tools, not only to predict the thermal behaviour of different nano-, micro-, meso- and macro structures possible to envisage for the VIP4ALL cores (material level), but also to forecast VIP4ALL product final thermal performance and design their combination with current building systems.

Eight different VIP core systems have been modelled and the VIP parameters are generated. Its outcomes provide most important and useful fundamental basis for material researchers and developers and manufacturers to formulate VIP4ALL products for building construction. The modelling of thermal behaviour of VIP’s core materials was first generated preliminary unit sub-models, starting from the individual pore systems within the nanostructured core materials and including important parameters affecting thermal insulation performance such as solid conduction, gas conduction and radiation. By using a unit cell model, the unit area (unit cell) of the cross-section of porous material was represented as an assembly of small finite element mesh in which each element can be classified as either void or solid.
assembly of small finite element mesh in which each element can be classified as either void or solid (Figure 12). Afterwards, a comprehensive global (Macro-scale) heat and mass transfer model was developed based on the heat mass transfer program FPRCBC-T developed by BRUNEL (Figure 12). A comprehensive appraisal of the developed modelling work has confirmed that the calculated thermal conductivity of VIP had good agreement with tested results in which the maximum variation between predicted and tested results has been within 5%. This numerical model was developed not only to be capable to simulate multiple component systems, thus able to calculate the thermal conductivity of the VIP’s core materials and compare it with the laboratory evaluation made in WP7. Moreover, it was possible also to predict the overall thermal performance of the final VIP4ALL panels and modelling multi component building systems (U-values) and the ones installed for the demo activities under WP8.

WP5 - Product composition and manufacturing technologies
WP5 was especially planned to study and evaluate different formulations for VIP4ALL core systems, taking the outcomes of WP2 and WP3 as starting point. The main objective was then to develop an economically viable method to produce low cost hybrid core materials systems, focusing on manufacturing steps and optimized processing parameters, so that the formulation for VIP4ALL could be ready for the scale up in WP6.

Recommendations for the use of VIP products in buildings were discussed at this point, covering the most important stages for handling VIPs, during the fabrication of components and systems, and also during transportation, handling and direct installation on site. Under this context, an extended work was held towards the development of a novel cork encapsulation system that could efficiently protect the VIP4ALL panels without being too much detrimental for the overall thermal performance of the panels. This way a new cork lamination process was selected, using thin cork sheets of 3 to 5mm, and their interfacial bonding with the panels metalized envelop tested and secured.

Apart from the definitions of materials, pre-treatment set-ups and selection of the most suitable techniques for restructuring core materials and products preparation (including drying), the definition of a new internal structural frame box for the VIP4ALL panels was also envisaged at this stage, along with the envelope preparation and definition of evacuation and sealing parameters.

Preliminary assessment to hybrid VIP core production consisting on the usage of the mineral and organic powders substitutes, along with and fumed silica, was done with the formulations proposed on WP2. Blends containing from 1% up to 50% fumed silica along with natural raw materials were characterized in terms of their thermal conductivity behaviour in function of pore pressure (Table 3).

Following the evaluation of preliminary results, prototype panels as large as 30x30cm with 2.5 cm thickness were created to have defined shapes, with parallel sides and right-angled edges, with the use of permanent frames provided by frame boxes (Figure 13). A final density of about 285kg/m3 was selected for the best composition, while guaranteeing the shape stability of the panels after atmospheric loading. CaO powder was also involved in paper and used as drier to be placed inside the panels. Pressure levels as low as 0.05 mbar could be achieved at production with this new enhanced composition, using the available laboratory vacuum and sealing chambers. By the means of using a va-Q-check device, it was possible to access the increase of the gas pressure rate being in the order of 1 mbar/year at laboratory temperature and humidity conditions for the metalized foils used.

Also with the help of va-Q-tec, accurate measurements concerning the influence of internal gas pressure over the lambda values were possible to be realized (Figure 14 and Figure 15). In this study, the characteristic half-value pressures for each core composition were calculated and evaluated its relation with each system pore size distribution. At this point the initial lambda value of 7.2mW/mK was considered...
WP6 - Industrial production up-scaling

After the many laboratory developments made at this point using small sized lab samples, the goal of this WP was to scale up and test the VIP4ALL production in industrial environment and evaluate the feasibility of a large-scale production. Moreover, this scale up should be decisive to attest future product performance capabilities and to generate prototype products for technical approval and the assessment of project objectives compliance (WP7) and to secure on-site demonstration activities to be held in WP 8. Under this context, a large number of different sized VIP4ALL were produced at Va-Q-tec premises according to the previous procedures and findings following WPs 2-5 (Figure 17). Different properties and their relationships that determine the thermal performance of VIP4ALL have been taken into account to optimize the formulation and production. Interim assessments of the produced VIP4ALL have also been carried out. Single mineral core compositions has been used for VIP4ALL industrial trial production, which has been made at the existing production line that the company owns for manufacturing their traditional fumed silica core VIPs. It was considered that a prior drying of the mineral powders should be more favourable for the quality control of the VIP products, especially the one such as microwave drying that could be most efficient and effective. Special processing considerations were taken in terms of panels shape and thickness controls. The data interpretation also helped to optimize processing parameters for future full industrialization of the product and large scale commercialization of VIP4ALL.

These production tests have include the manufacturing of 200 large direct-filled panels with pronounced flanges and nominal sizes of 600 mm x 500 mm x 40 mm and 30 smaller frame-boxed regular shaped panels, sized 400 mm x 360 mm x 40 mm (nominal) with special barrier envelope films (Figure 18). The proposed mineral powders were chosen as core material for the industrial prototype VIP4ALL panel production, with addition of CaO2 at 5 and 10% by weight as a dryer and pressure sensors were include inside for future vacuum level verification. Complementary to the scale up activities and to confirm product quality control, a set of preliminary laboratory characterization tests were performed with the prototype samples being manufactured, in order refine or redefine future composition or processing set-ups. This way and at the end of production, representative panels were tested and crucial parameters in VIP4ALL thermal performance determination, such as gas pressure, density, type of core material and envelop, pressing force, mixing ratio and duration were all carefully and globally evaluated, enabling a better understanding of the VIP4ALL formulation and performance. Average lambda values were tested around 6.5-7.0mW/mK right after sealing for direct filled panels, and initial gas pressures around 0.5 mbar. On the other hand, the enhanced framed and regular shaped panels had thermal conductivity at 10°C of 5.5 mW/mK, for initial gas pressure of around 0.1 mbar (Figure 19), meaning that both scale up activities were inside the project technical objectives.

Knowing the importance of ageing and that the thermal performance of the VIPs will degrade as moisture and gas permeate through the barrier envelope of the panels, besides the evaluation of thermal resistance right after production (and the corresponding initial gas pressure), the research team endorsed the making of accelerated ageing experiments to forecast future VIP4ALL quality performance. The evaluation of the gas pressure increase and thermal performance during life time of VIP4ALL panels were assessed.
gas pressure increase and thermal performance during life time of VIP4ALL panels were accessed periodically during four months in samples stored in a climate chamber at 50°C and 70% RH (Figure 20). The study of the air and water permeation of different envelop foils were also performed under those conditions, allowing to establish a rank among them. Also these tests have included the evaluation of smaller sized panels produced in laboratory having different commercial foils types in order to predict which ones would be best for product compliance. The best foils have presented a Pair below 12 mbar./m².year and PH2O as low as 2.5g/m².year. The foils used to produce the VIP4ALL prototype samples had an intermediary performance among all type of envelope barriers. The frame boxed VIP4ALL panels made at va-Q-tec presented the lowest increase on pressure and thermal conductivity of 0.9 mbar/year and 1.1mW/m²K.year respectively, under accelerated aging conditions. For these panels, an expected λ ~ 10 mW/mK after 25 years under ambient conditions was estimated and λ ~ 15 mW/mK after 50 years, thus able to provide superior thermal insulation than any other conventional material used in the building market.

WP7 - VIP4ALL technical performance
The major goals of this WP were to evaluate VIP4ALL thermal performance and fully describe and characterize the technical properties of the novel insulation solution to be used as a building material. Also, VIP4ALL product technical compliance was made through performance tests to assess the fulfilment of the project’s technical objectives. This evaluation has included issues such as thermal resistance, length, width, thickness, squareness, flatness and apparent density, behaviour at compression, behaviour at fire and ageing. Whenever possible, European test standards and certified and reference exterior laboratories were chosen to characterize VIP4ALL.

The main outcome of this WP was the realization that it had been possible to develop an exceptional new insulation product at lower costs than the current VIP ones. The VIP4ALL VIP (Figure 21) having the new proposed mineral core material and a novel structural frame inside have presented a final density of 285 Kg/m3 and an average lambda value of 7mW/mK (corresponding to a R-Value of 5,18 m²K/W, for a nominal panel thickness of 40mm), according 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”. Also, only a small detrimental variation on thermal performance was registered by the encapsulated VIP4ALL panels, using a thin (3mm) cork protective layer.

Complementary it was possible to conclude inside this WP, an extensive physical characterization of the novel VIP solution, concerning the determination of technical issues such as length, width, thickness, squareness and flatness of prototype VIP4ALL panels (according EN 822, EN 823, EN 824 and EN 825). Under this work plan, it was also recognized that the VIP4ALL panels present excellent mechanical performance - pressure load at 10% compression of about 300 kPa, following EN 826, meaning a much better than the one of silica VIPs). Moreover, VIP4ALL panels could attain sufficient fire resistance and a B class classification according EN 13501-1 Fire classification of construction products and building elements, when placed in-between a building solution comprising an external 10mm OSB board and an interior 12mm gypsum drywall panel (Figure 22).

Finally, with the help of accelerated ageing tests performed inside controlled climate chambers (50°C/70%RH conditions), during 4 consecutive months (joint activity with WP6), it was possible to conclude that the latest VIP4ALL envelope/core panel system was only susceptible to minor increases of internal pressure and thermal conductivity under accelerated conditions, corresponding to an expected increase in λ of around 10mW/mK, after 25 years under ambient environment and operational conditions.
Increase in $\lambda$ of around 10mW/mK, after 25 years under ambient environment and operational conditions. With the outcomes of this WP it was possible to prove and assure VIP4ALL quality and technical merits under laboratory testing conditions, providing all the technical information (product datasheet) needed for future large scale production and market acceptance.

WP8 - Demonstration of VIP4ALL integration in buildings
After the comprehensive laboratory characterization of VIP4ALL in WP7, a more representative demonstration of VIP4ALL’s thermal performance made in a real operational environment has been undertaken. The main objectives of the demonstration of VIP4ALL integration in buildings were therefore to plan, design and perform the insulation works with the help of demonstration sites, in order to test, evaluate and validate the VIP4ALL solution.

To accomplish these objectives a design adaptation and work execution of VIP4ALL installation was performed by IPN at their Demo Park, in Coimbra, Portugal (Figure 23), during the last month of the project. For the purpose it was used two perfectly identical lightweight wood mock up houses, one completely insulated with VIP4PALL panels (covering all walls, roof and floor), and the other one (control cell), using a conventional cork insulation of the same thickness for comparison purposes (40mm for wall applications and 30mm for roofs and floors).

In order to attest VIP4ALL thermal performance and foreseen its energy efficiency capabilities for building applications, a combination of monitoring and thermal regulation systems were installed in both demo houses, capable to register and control several parameters related with their thermal behaviour. These included, among many, an exterior complete weather station, numerous thermal sensors measuring all sides of the house’s envelope (thermocouples and heat flux ones) (Figure 24) and two identical heat ventilation control equipments, installed inside each demo house in order to keep the same stable indoor comfort temperature around 22°C. This way, differences in energy consumption registered for both demo houses could be directly related to the building envelope thermal profile and, consequently to the performance of each insulation system installed. All instruments were monitored by a main computer workstation unit.

Ultimately, the energy consumption of both houses was individually measured (in kWh and KgCO2) and the total energy cost (in Euros) compared.

Along all the measuring period performed so far (still an ongoing test), differences over the maximum/minimum temperatures and correspondent heat flux variations registered inside the walls of both demo-houses have been consistently found (Figure 25), clearly attesting a better insulation performance given by the VIP4ALL solution, which is able to provide a much more efficient thermal barrier for the testing envelope. Much bigger heat flux losses and gains through the envelope towards or from the outdoor were verified by the control house using conventional insulation, thus inducing the need for the electrical heat ventilator to turn “ON” over much higher frequency and amplitude regimes, than the ones registered for the VIP4ALL demo house, in order to maintain an indoor temperature stable around the preset level (22°C).

To corroborate this evidence, a preliminary comparative statistical analysis was made in function of time, by evaluating differences between the indoor and the outdoor temperatures of both demo building structures, and the corresponding heat fluxes passing through both South oriented test walls (in W/m2). Estimation of the thermal resistance (R-Value) according to ASTM C1155 (Standard Practice for Determining Thermal Resistance of Building Envelop Components from the In-Situ Data) have resulted in 3.26 m2K/W and 1.24 m2K/W, respectively for VIP4ALL demo house and for the control one using conventional cork insulation, already clearly attesting significant differences between both insulation...
Conventional cork insulation, already clearly attesting significant differences between both insulation systems. Nonetheless, higher R-Values differences are expected to be recorded in the near future, by substituting the current VIP4ALL panels installed (produced in the early stages of project development), for the latest ones, developed with the frame case technology, capable of providing panels with perfect regular edges, able to fit and be much better joined, thus less prone to thermal bridging effects and to formation of irregular void gaps in-between consecutive panels which can be highly detrimental for the overall thermal performance of the installation. Still, even under this conditions, a distinctively insulation performance was already possible to observe, which was also possible to confirm experimentally, by comparing for the same period the levels of energy spent by both demo houses while trying to maintaining a stable indoor temperature of 22°C. Noticeable, the values registered were 29.8 kWh for the VIP4ALL’s house in comparison to 39.0 kWh for control one, which represented energy savings of about 30%, when using VIP4ALL panels under and during the conditions of the present study.

Finally, the outcomes of this WP also include a comprehensive report on VIP4ALL handling and installation procedure instructions, including recommendations regarding the right conditions for panels storage, handling cautions, levelling and substrate conditions for installation, bearing framework needs, the use of proper fixing materials and tools, compatibility with other building materials, compliance check procedures, etc. (Figure 26).

In conclusion with the activities made under this WP it was possible to provide an overall assessment of VIP4ALL innovation and demonstrate its superior merits for building applications.

Potential Impact:

The Construction and Insulation Market Overview
It is clear that the insulation market is on a verge of a new era, claiming for higher performance solutions and where more demanding legal and durability requirements are setting the political agenda for future developments. This way, the call for novel insulation systems is been driven by the arising of green and net-zero energy buildings (nZEB).

The latest existing European policy initiatives have been mainly targeting energy efficiency, such as the Energy Performance of Buildings Directive (EPBD), obliging Member States to set minimum requirements on the energy performance, for both new and existing buildings. This directive mandates all member countries to enhance their building regulations and introduce energy certification schemes, to have new and retrofit net-zero energy buildings by 2020, aiming to reach a 20% reduction in Greenhouse gases emissions by 2020 and a 20% energy savings by 2020. These reductions are crucial since the building sector accounts for 42% of the EU’s energy consumption and approximately 35% of all greenhouse gas emissions. Special focus is given to construction activity in the residential building market as it consumes 26% of the total energy.

Improving the energy performance of buildings is also a cost-effective way of fighting climate change and also a way for creating job opportunities, particularly in the building sector. Latest figures from 2013 state that the EU Building and Construction sector accounts for approximately 10% of the EU’s GDP, employing more than 32M people with a turnover of €1.27 trillion, representing around 7.5% of total European employment, 28.1% of industrial employment and around 23% of the total world production in the construction sector. The European construction sector comprises roughly 1.9 million construction firms, being the majority of them, SMEs.

Currently there are about 210 million buildings in the EU which give approximately 53 billion square meters of usable indoor space. Under this context, adding new and improved insulation systems (such as VIP4ALL) is expected to be relevant for 40 to 60% of the building stock during 10 years, depending on
VIP4ALL) is expected to be relevant for 40 to 60% of the building stock during 10 years, depending on building age and climate zone. This represents a huge market, just in Europe, claiming for new and better solutions like VIP4ALL to arise, not to mention the 7% increase of the present building stock that it is expected to take place during the next 10 years. Many of these type of buildings, mostly from the 60's, 70's and 80's, having low architectural interest and being known by their poor insulation ranks, could benefit immensely with a more affordable superinsulation solution like VIP4ALL.

While global insulation market (Figure 27) was worth USD 37.94 billion in 2013, the growing insulation demand in residential and non-residential applications are expected to be the main driving force for the insulation market growth in the next 10 years, boosted by government initiatives, lunched to promote energy efficiency and sustainable development. Residential construction is expected to gain revenue share by 4.93% up to 2020.

Building energy savings is probably the main reason why Europe is considered the most mature insulation market (Figure 28), having the highest consumption per capita in the world (hugely competitive), but also the most stringent building codes in terms of energy efficiency. The total market for thermal insulation products in Europe stood at just under 234.6 million m3 in 2014 (7.4 million tons). This equates to an approximate market value of €11.5 billion, from which around 2/3 of sales are coming from the residential building segment which accounted for over 50% of the total revenue.

Biggest players in the global market are all European, including Isover, Saint-Gobain, Knauf and Kingspan. Plastic foams, mineral wool and fiberglass products dominates the market. This supremacy is based on a high level compatibility with minimal expenses and installation problems which help gain mass approval from consumers over other materials. It is also expected to witness fastest growth of fiberglass next seven years, at a CAGR of 9.1% from 2014 to 2020. On the other hand polymer insulating foam materials such as EPS, elastomers and polyethylene used for acoustic and thermal insulation in residential, commercial and industrial applications are expected to grow at a CAGR of 8.6% until 2020. However being downstream derivatives of crude oil, the price of oil poses severe restraints to plastic foams market.

The total demand of thermal insulation products is estimated to reach 213 million square meters by 2017. It is expected that this growth in the next few years will be mainly driven by the most stringent standards and legal requirements in terms of efficiency and sustainability of insulation materials, led by Germany, Netherlands and United Kingdom.

Traditional solutions such as mineral wool, glass wool, flexible elastomeric foams, rigid foams, polyethylene, and cellular glass cannot ensure the required insulation capabilities, due to the limitations of the material characteristics. Latest developments on superinsulation materials like the ones proposed by VIP4ALL seek to reduce energy losses in buildings, thereby lowering the level of energy consumption. This will also contribute to decreasing the EU’s energy import dependence. Anticipated final properties for VIP products indicates possible to reduce the U-value of the walls and roofs in a building renovation, from 2.0W/(m2*K) to 0.2W/(m2*K) and reach Passive House and NZEB energy efficiency standards. This reduction could be achieved with VIP4ALL products allowing for a cost-effective renovation without losing too much living space areas.

The increasing demand for high performance insulation in buildings (provided by VIPs and aerogel materials) is then expected to be a major force to drive the growth of the insulation market, with the superinsulation segment forecast to reach the market size of 24.900 million euros in 2020. However, due to the production process, performance, price and environmental impact of current solutions, major challenges/opportunities are not being fully addressed by companies trying to enter this market with novel solutions. This is why one of the major concerns of VIP4ALL was to be able to reduced significant the price
This is why one of the major concerns of VIP4ALL was to be able to reduce significantly the price of such solutions (VIPs), an objective that was possible to accomplish successfully by getting a cost reduction of over 50% in the price of raw materials and a global cost advantage envisaged around 30%, when compared to the current high-priced commercial VIPs. This price reduction will allow VIP4ALL panels to be a much attractive product of choice for the building market.

**Commercialization Plan**

VIP4ALL could be specifically positioned to appeal to our target customers with the following main characteristics:

- 5 to 7 times greater insulation than conventional materials e.g. XPS, PU, etc. If performance is the main driver here, VIP4ALL will be a superior consideration;
- A selling price of over 30% less than existing fumed silica based VIPs. If cost is the main driver here, VIP4ALL will be the better alternative for major cost savings;
- A 50-year lifetime performance guarantee with certified performance. If long time superior performance is the driver, VIP4ALL will succeed;
- Insulation thickness vs. performance is major issues in both refurbishment projects and densely populated urban areas. If saving space is the driver, VIP4ALL will the best option for the project;
- A less fragile VIP product that can be easily handled without being damaged. If handling and installation issues are relevant, VIP4ALL (encapsulated version with the cork laminate) will be superior over conventional VIPs.

Our initial commercialization plan is to market VIP4ALL across Europe, being the markets with the highest demands the UK, Germany and the northern Europe countries. We have assumed that the refurbishment opportunity represents approximately 30% of the new buildings market. Our strategy is therefore to target the German market first, as we have an established customer base there through va-Q-tec channels. Va-Q-tec will also be the owner and solely producer of the new VIP4ALL solutions. Sofalca will be the supplier of the cork laminates and Nordisk the supplier of lightweight minerals for the future products based on the findings of the project, completing the supply chain.

Furthermore, VIP4ALL do not intend to target only Europe. Asia is also a big growing market. Their demand for insulation materials is predicted to grow at 9.4% per year up to 2016. The total market value stood at EUR 5 billion in 2011, with most gains in the coming years driven by rising construction and manufacturing output. A key driver will be new building codes that call for the reduction of energy consumption on building applications. Other key factors include the China’s rising urbanization, ongoing investment in office, commercial, institutional and other insulated structures as well as the improvement and replacement of insulation in existing buildings to raise energy efficiency. As China continues on the path to industrialization, demand in this sector will increase, too, in part as a result of governmental and private initiatives to reduce energy consumption and costs in many applications, apart from building ones (e.g. refrigerators, freezers and transportation equipment). Va-Q-tec, being a world leader manufacture of superinsulation solutions for these segments and with international presence already established channels, will be especially interested upon developing VIP4ALL oriented products also for these markets.

Meanwhile, regarding the building sector, market opportunities in southern Europe have greatest opportunities as markets in northern Europe are already quite saturated. This way, Garcia Rama will be the company allowed to commercialize/install the product in Spain and Portugal, having all SMEs agreed to form a joint-venture in order to commercialize the products based on the findings of the project. Through va-Q-tec it will be possible to provide the novel’s panel specifications to wholesale distributers identified in target markets. The distributers will then sell to installers in the construction industry. Relationships with customers will be maintained through the distributors. As said before, a standard
Relationships with customers will be maintained through the distributors. As said before, a standard geographical account management approach will be adopted. Throughout target European countries, we will establish a team of technical sales executives in local territories who will engage key decision makers in to continue the process of introduction, validation and employment of the VIP4ALL technology.

**Market Barriers**

VIP4ALL is a new type of products, consequently, there are a few market barriers to be addressed in order to realize market penetration, such as:

- **Lack of public acceptance** – conventional thermal insulation materials (e.g. PUR, EPS, XPS, fiberglass panels, mineral wool, etc.) have prevailed over VIP until recently, mainly due to their lower production costs and easiness of installation - VIPs requires market acceptance.
- **Lack of support for VIP in various European countries** (e.g. Southern European countries) – these barriers will be largely overcome by targeting countries which are accepting of the technology and historically have been first adopters of VIP technology. With the efforts from Garcia Rama it will also be possible to establish new markets.
- **Lack of full understanding and accessories for VIP in practices.** Unlike conventional insulation materials, VIP has unique characteristics; it requires many special considerations in its installation and in uses.

Table 4 shows a summarized SWOT analysis made for VIP4ALL market entrance.

VIP4ALL will offer a new product to the building retrofitting sector, capable of having exceptional thermal insulation ranks at small thicknesses (initial lambda value of 7.2mW/mK at 40mm thickness), reducing the space needed to comply with the new thermal efficiency regulations, thus contributing not only for indoor comfort, but also for the buildings valorisation. With a highly efficient and cost effective insulation solution (30% less than common VIP solutions), VIP4ALL can play an important market role in ambitious major renovation programs, thus helping both SMEs producers and end-users to enhance their activity and economic process.

In order to put this in practice, VIP4ALL has participated in a project proposal called “Blue Sky Cities” for the Horizon 2020 proposal that consisted of building large scale pilots based on modular systems for smart city solutions. The project was proposed to use VIP4ALL as next-generation systems with a more economical and viable cost and the highest efficiency.

While there is still no commercial production of the developed VIP4ALL solution, due to the specific needs and the investment of a new production line, the upscaling production and the performance database indicated that the developed products should be able to bring significant future revenues for the SMEs beneficiaries involved in the project, as well as important economic, societal and other impact across the Europe.

Many dissemination activities took place throughout the duration of the project, namely, the development of a project website, as well as numerous social media websites where the dissemination manager included updates regarding new outcomes and results from the VIP4ALL. VIP4ALL also appeared in several newsletters and it was promoted in several popular press media and several scientific papers were published. All partners have included information regarding the VIP4ALL project in their company and organization websites, as well as social network and numerous news regarding the project. The VIP4ALL product was presented in a large number of international fairs, conferences and workshops, showing the VIP4ALL developments and its results, always gathering a very welcomed and enthusiastic interest (e.g. Figure 29 and Figure 30).

A demo house was built at IPN facilities where the thermal behaviour and the energy efficiency of the VIP4ALL solution is still being currently monitored and compared against conventional insulation systems. The demo building also served for installation training actions and dissemination activities during the
The demo building also served for installation training actions and dissemination activities during the project duration. These activities are foreseen to continue onwards in the future (Figure 31).

Finally, VIP4ALL has become a full member of the European Advanced Materials and Nanotechnology Cluster (AMANAC cluster - Project reference: 636239) as a cluster project (Figure 32). The participating project cover a wide range of different technologies at the service of Energy Efficiency in Buildings with a special focus on the development of nano and advanced materials/systems and building components. In addition, the high participation of SMEs (36%) and large industries (27%) as partners of the 233 projects and the high number of countries represented within the Cluster facilitates the implementation and impact of the results during the post-project market launch stage at a European level.

List of Websites:

http://www.vip4all.com/

Susana Garcia Rama, Garcia Rama, Spain, susana@garciarama.com
Jorge Corker, Instituto Pedro Nunes, Portugal, jcorker@ipn.pt
Mizi Fan, University of Brunel London, UK, Mizi.Fan@brunel.ac.uk
Roland Caps, va-Q-tec, Germany, caps@va-q-tec.com

Last update: 27 June 2016
Record number: 184797