

Innovative pre-fabricated components including different waste construction materials reducing building energy and minimising environmental impacts (InnoWEE)

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Abstract. InnoWEE is a four-year project (from 2016 to 2020) financed by the European Community that involves ten partners from different European countries, as Greece, Italy, Belgium, Romania, Slovenia, Spain and Poland. The aim is to use the waste materials coming from construction and demolition processes of buildings and include them into a geopolymeric matrix with the purpose of producing prefabricated panels for different applications. Construction and demolition waste (CDW) materials with suitable characteristics have been selected to develop high performance geopolymeric panels for building walls envelopes and radiant panels for indoor walls and ceilings with low environmental impact. Field tests will be carried out in different sites in Europe characterized by different climatic conditions to check the simplicity of the installation procedure and the performance of the panels in terms of energy efficiency and environmental impact.

1. Introduction

In Europe, the construction sector is one of the major consumers of natural resources, so it is necessary to focus on the building industry to limit consumption and waste of energy. When referring to “construction sector”, all phases, starting from the supply of the material up to the disposal and recovery activities, should be considered. A more appropriate use of materials should ensure a greater contribution to the reduction of the environmental impact. It is therefore interesting to consider the potential reuse of construction and demolition waste (CDW) materials, possibly by looking for innovative solutions that also reduce building energy consumption.

2. The InnoWEE Project

2.1 Strategy

The main objective of InnoWEE project [1, 2] is the development of an optimized reuse of CDW materials

producing high add value prefabricated insulating and radiating panels to be used in energy efficient buildings, being based on:

- Recovery, selection and disassembling of CDW that will be characterized and eventually treated to yield suitable raw materials to be used for production of prefabricated components.
- To develop a new high performance prefabricated insulating geopolymeric panels for building walls envelopes and radiating panels for indoor wall and ceilings with low environmental impact, low embodied energy, low CO₂ emissions, high thermal performance. Panels will be fabricated recycling cement, bricks, mortars, glass and wood reaching at least 30% of CDW.
- To use an integrated design process and a holistic approach for the whole life cycle of the materials and components in order to obtain products that are cost-effective, competitive, robust, reliable and low maintenance.

- To create practical and sustainable building solutions easy to install and to integrate into building design, that meet the requirements of all the current standards. Moreover, the needs of the stakeholders that strongly influence the market have to be taken into account.
- To evaluate the new panels performance in the demo-sites characterized by different climatic conditions.

The project is structured in 7 work packages (WPs) (Fig.1) with the main aims of each WP described in the following:

WP1: To identify, to categorize and to analyse in labs the CDW typologies collected in Europe; To adapt them to the production lines; To identify and update the existing European and national standards, codes and guidelines; To establish the performance indicators for the new materials; To evaluate the environmental performance analysis (LCA); To develop a preliminary business model.

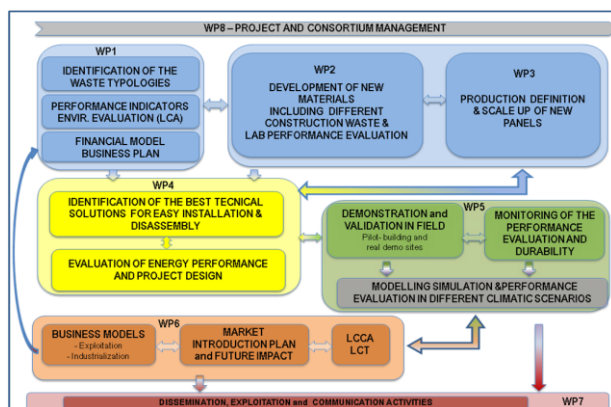


Fig. 1. InnoWEE project structure

WP2: To define the design of geopolymer binder; To develop and to assess the physical/mechanical characteristics of the prototypes of new eco-friendly insulating façade and radiating panels.

WP3: To define technical design and plants step of geopolymer components; To upscale eco-friendly insulating façade and radiating panels; To produce small scale of panels for demo site applications; To assess industrial production.

WP4: To identify the best solution for an easy installation and disassembly of panels based on architectural and costs evaluation; To optimize the solutions by modelling the energy performance of the different solutions; To elaborate the project designs for each demo building.

WP5: To install the selected solutions in the 4 buildings: a pilot site, a new building, an existing one and a historical buildings; To evaluate the performance and durability in field respect to energy, durability and comfort; To monitor the compliance with national/European standards, codes and guidelines; To compare the innovative products with the traditional in

terms of installation time and costs; To define the performance in a large European scenario.

WP6: To define production and installation method for a large scale application, capital costs of ownership, final business plan with respective risk assessment and sensitivity analysis of data; To evaluate the costs performance during the whole life cycle (LCCA); To develop Exploitation plans for different European markets centred in SME interests, Life cycle thinking (LCT) during the whole life cycle.

WP7: To build up and maintain a web site and widely disseminate the outcomes towards stakeholders; To promote the project among academic population, governments, policy makers, designers and engineering, energy efficiency social housing; To define a training plan; To develop training material and training of end-users; To ensure knowledge exchange and easy communication among the partners, as well as between partners and stakeholders

3. Development of InnoWEE products

3.1 Prefabricated ETICs panels

As opposed to conventional systems that are assembled on-site, in InnoWEE a new type of prefabricated ETICs was proposed. It consists of prefabricated insulating panels composed of an outer geopolymer layer and an inner EPS layer (Fig.2). The panels can be installed easily and fast, and they are extremely eco-friendly by using low CO₂ emissive geopolymer technology and recycling of large amounts of CDW (50% weight of the geopolymer binder). The panels are rectangular with a staggered layout, to facilitate the connection of adjoining panels and have a weight of 18Kg/sq m Substitution of individual panels can be done and easy end-of life recycling is guaranteed by their easy dismantling. The thermal resistance of the panels has been measured in laboratory, according to the EN 12667 standard, obtaining a value of 2.04 m²K/W-1 at 10 °C.



Fig. 2. InnoWEE ETICs panels: scheme (left) and panels produced in pilot production (right)

3.2 Ventilated façade panels

An innovative lightweight ventilated façade panel has been developed made by bonding an outer high density geopolymer (HDG) layer to an inner wood-geopolymer

panel (WGP), thus providing light weight and mechanical strength. The panels are squares with a side sizing 59.5 cm and could be installed on supporting structures using the most common anchoring systems with a weight of 9 Kg/panel. The panels have been designed to withstand the most demanding seismic and wind loads in European countries.



Fig. 3. InnoWEE ventilated façade panels: scheme (left) and prototype panels (right)

3.3 Radiant panels

Radiant systems are designed for highly efficient low temperature heating and high temperature indoor cooling. The radiant panels have been designed and fabricated both for ceiling and wall application (Fig.4). Contrary to common plasterboard based radiating panels the InnoWEE panels are easy to dismantle and recycle due to the absence of gypsum in their formulation. The panels layout is a square of size equal to 59.5 cm that allows an easy mounting on common indoor ceiling systems that are designed for 60 by 60 cm tiles.



Fig. 4. InnoWEE radiant ceiling panels: front and back views

4. Pilot production of InnoWEE products

By moving forward, transforming R&D concepts and results into commercially viable processes for any product, the scaling up with the aim of a pilot plant plays an essential role in this process. Therefore, an efficient, economical, easy to operate production process of the HDG panels was designed by adopting with the minimum possible modifications the capabilities, infrastructure and equipment of an existing Pilot Plant (Technology Upscaling Pilot Plant - TUPP) in AMS facilities (Fig. 5).

The main objectives which have to be fulfilled simultaneously are:

- Optimize the process operating parameters;
- Evaluate the effects of recirculating process streams;

- Obtain process information necessary to specify and design the full scale plant;
- Test process control systems and procedures;
- Test construction materials;
- Optimize the equipment design;
- Obtain sufficient information to prepare detailed and reliable estimates of capital and operating costs, and as well as a reliable economic evaluation;
- Gain operating experience and train the personnel that will operate the full scale plant;
- Identify hazards in the process and ensure safety in design and operation, including the disposal of waste;
- Produce a reasonable amount of geopolymer panel for their evaluation on demo sites.



Fig.5. Pilot plant (TUPP) facilities used for InnoWEE upscale production of HDG panels

The basic flow sheet of the modified – for the purposes of InnoWEE- pilot plant (Fig.6), includes:

- Processes identification ;
- Processes duration ;
- Equipment that will be used ;
- Utilities that will be needed ;
- Auxiliary processes involved ;
- Personnel involvement ;
- Production's prerequisites ;
- Design specific requirements ;
- Design "influencers",
- Possible Health&Safety issues,
- Quality Assurance Plan identification,
- Production cut-off points,
- Possible remedies on failures.

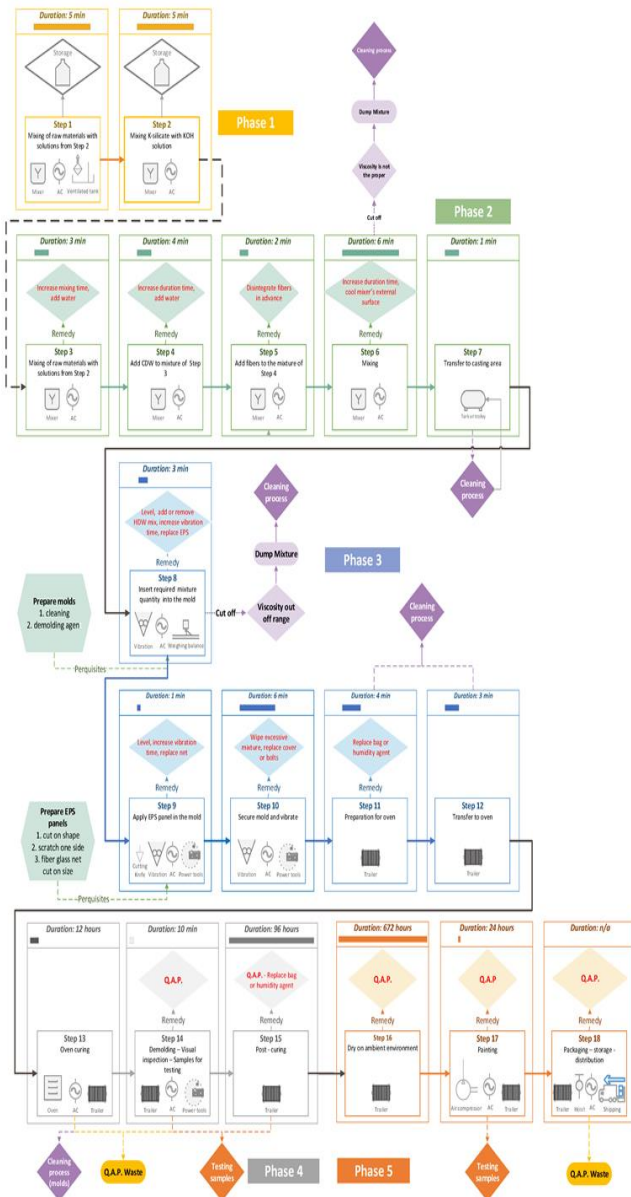


Fig.6. Flow sheet of pilot plant

Based on the outcomes of the preliminary design of the pilot plant and the modelling simulations, all the necessary modifications were conducted to the existing plant (TUPP). The ETIC and ventilated facade panels produced in the pilot plant are presented in Fig. 7.



Fig.7. Upscale production of InnoWEE HDG panels (ETICs and ventilated facades)

5. Technical evaluation of InnoWEE products

One of the goals of the project is also the establishment of the procedure for the evaluation of the newly developed products (fundamentals for attestation of conformity) in order to enable and support market introduction. Innovative products are often not covered by the scope of harmonised European Norms (hENs), which provide procedure for an assessment of technical requirements and placing construction products legally on the EU market (Construction Product Regulations or CPR) [4]. For such innovative products (where also products developed within InnoWEE belong), there are other procedures to enable the proper assessment of products (national /European Assessment procedure). For the purposes of the InnoWEE products assessment provisions of ETAG 004 [4] and ETAG 034 [5] were taken into account respectively for ETICs like and ventilated facade panels. The following characteristics of panels have been already tested or are still in progress [7]:

- water absorption (capillary test);
- water vapour permeability;
- freeze – thaw behaviour;
- bond strength (Fig. 8);
- impact resistance.



Fig. 8. Determination of bond strength (“pull off” test) on InnoWEE ETICs like panel

Based on the findings of Rilem TC DTA (Durability testings of alkali activated materials) which has set a series of methods for testing alkali activated materials (also geopolymer belongs to this group) regarding long term behaviour when exposed to severe conditions, also some parameter related to the durability have been tested or still being in progress [7]:

- determination of resistance to carbonation;
- alkali silica reactivity (Fig.9);
- sulphate resistance;
- resistance to freezing;
- resistance to freezing in the presence of de-icing salt.

Tests performed on panels from pilot productions confirmed that panels could be suitable for use as façade cladding. Capillary water absorption of panels after 24 hours was 1.8 kg/m^2 , and testing of frost resistance has confirmed that there was no cracks or other type of damage after 30 cycles of freezing–thawing on both types of panels. Coefficient of water vapour permeability, which is relevant for ETICs like panels, was determined to be 44. By incorporating a mesh into the panels also impact resistance was improved, and it is now satisfactory for being used in Zone II group what means they are suitable for zone liable to impacts from thrown or kicked objects, but in public locations where the height of the ETICS will limit the size of the impact. Some long term durability tests are still in progress.



Fig. 9. Determination of alkali silica reactivity resistance of InnoWEE ventilated panel

The evaluation of the InnoWEE products is focused also on the thermal performances of the materials. A set of thermal measurement [8] has been already conducted on material samples to determine:

- thermal conductivity with the Hot Disk method, according to ISO standard 22007-2;
- specific heat by differential scanning calorimetry, according to DIN 51007;
- density with the buoyancy method, according to ASTM C20.

The obtained values of thermal conductivity are very promising, especially for the use on the radiant panel. The HDG compounds could reach values over $1 \text{ W m}^{-1} \text{ K}^{-1}$ while the WGP compounds are in the range between 0.3 and $0.5 \text{ W m}^{-1} \text{ K}^{-1}$. Both intervals represent a significant improvement with respect to the standard plasterboard finishing, that has a thermal conductivity close to $0.2 \text{ W m}^{-1} \text{ K}^{-1}$. The specific heat is close to $1000 \text{ J kg}^{-1} \text{ K}^{-1}$ for the HDG compounds and higher for the WGP compounds (in the range of $1200 - 1500 \text{ J kg}^{-1} \text{ K}^{-1}$). The density is higher for the HDG compounds (between 1700 and 2000 kg m^{-3}) compared to the density of the WGP compounds, that varies between 1000 and 1500 kg m^{-3}). The density is significantly higher than the traditional plasterboard solution, but it is still in an

acceptable range regarding the final weight of the finished product, guaranteeing the manoeuvrability of the panels. The measurements are still ongoing to further optimize the compounds that have the better trade-off between thermal conductivity and density.

All these measurements have been used to study and define the layout of the radiant panels in order to optimize the heat exchange with the environment. Several thermal simulations, using the finite element method, have been conducted to investigate the impact on the overall thermal performance of geometrical and structural parameters of the system, such as piping layout, geopolymer conductivity and thickness, stratigraphy,

The radiant panels prototypes are under testing in a dedicated test facility at the ITC-CNR laboratory in Padova [9]. The laboratory is a controlled test room where radiant panels could be installed and connected to a hot and cold water generation system. The facility is provided with a dedicated data acquisition and control system, that includes also the thermal dummies required by the standards, as shown in Fig. 10.



Fig. 10. View of the thermal chamber during a radiant ceiling test

The facility allows the measurement of the steady-state thermal performance of panels, that is conducted with reference to the EN 14240 and EN 14037 standards that define the testing procedure for cooling and heating ceiling surfaces. Further measurements have been conducted to assess the transient thermal performances of the system, measuring the time constant of the panels. To verify the durability of the panels, a stress test with a repeated fast switching of the water supply temperatures has been performed for several weeks.

6. Conclusion

InnoWEE project is set up in the way that the feasibility of using CDW in geopolymer matrix is holistically assessed through subsequent phases: research and development, pilot production, and technical assessment. The research on materials led to the creation of three products: an ETICs system, a ventilated facade, and a

radiant panel. The developed products are under a wide range of testing procedures that are checking their mechanical, thermal, and durability performances. The first results show that the geopolymer properties are adequate for the creation of industrial components for the building industry. The test are still ongoing and are coupled with on-site installation of the products across different demo site in Europe, to further investigate the effects on energy efficiency and thermal comfort of the proposed solutions. Last but not least, process and final products are being evaluated also by life cycle assessment (LCA) and supported by market feasibility studies.

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