MORE-CONNECT
Development and advanced prefabrication of innovative, multifunctional building envelope elements for MOdular REtrofitting and CONNECTions
(No. 633477)

D5.3 Prototypes of prefabricated modular renovation elements

H2020-EE-2014-1-PPP (EE-01-2014)

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1 Introduction

The objective of work package 5 is the testing, pilot implementations and demonstration in real settings, as well as in industrial settings (demonstration of production), as in practice (demonstration and testing of the developed modular renovation elements both in real settings as in real life learning lab (RLLL) settings. The testing and demonstration in practice will be organised on six locations:

- Czech Republic (RLLL setting for in deep testing)
- Denmark (full real setting)
- Estonia (full real setting)
- Latvia (full real setting)
- The Netherlands (full reals setting and RLLL setting for in deep testing)
- Portugal (partial real setting)

The work package comprises 6 tasks of which this deliverable presents the results of **Task 5.3 Prototypes of prefabricated modular renovation elements**.

Building on the outcome of MORE-CONNECT task 2.2 this task concerns the actual manufacturing of the prototypes of the prefab renovation elements by the participating MORE-CONNECT producers. This means prefab renovation modules for markets in: The Netherlands, Latvia, Estonia, Czech Republic, Denmark & Portugal.

Task leader: Cenergia.

Other participants industry: BJW, WEBO, Matek, ZTC, Invela, Innogie & Darkglobe.

The content of this deliverable is constituted by two parts:

1. A word part which reports the outcome of the tasks. This part hold a country by country report in a standardized format following these headings:
    - The production process with photos of the elements with comments about the details/components
    - Details about the production, e.g. amount, production time, etc.
    - Testing and quality control – referring to the requirements defined in D2.1 (thermal characteristics)

2. A PowerPoint part which can be used for the presentation of the results at international and international conferences, workshops and webinars.

This PowerPoint part can be downloaded from the project website and it is also added as an abbreviated version after the word report as an appendix.

2 Czech Republic

2.1 The production process

In Czechia the prototypes were designed by CVUT. The cores of the prototyping modules were produced at RD Rýmařov (documented in Fig. 7.1 in D2.2) and then transported to CVUT-UCEEB, where the CVUT team took them and added extending installation elements such as the air ducts with specially 2D cut thermal insulation, piping, electric installations and the layer of soft thermal insulation to fill the gap between the wall of an existing building and the modules' structural core (see slides 7-9).

Fig. 1 Slide 7: Two samples – one full scale prototype and (left) one full-scale mock-up of the upper part of a façade element (right).

2.2 Details about the production

The production of the modules' core was made using standard production lines at RD Rýmařov, where they normally produce panels for prefabricated timber family houses. The specific production times of the core module were not tracked, but it took several hours and multiple workers participated on the production as the module was moving through the production line. The addictions of technology parts were made at CVUT-UCEEB were crafted on-site in the testing hall over a longer period of time. The speed of the process was not the key parameter at that stage, but the major concerns were technical feasibility, reliability of construction details and ease of future production (see slides 16-17).

Fig. 2 Slide 17: Testing of prototypes of air inlets, custom made boxes for control systems and mock-up of an existing window opening (testing of airtight connection

2.3 Testing and quality control – referring to the requirements defined in D2.1

Various properties of the produced prototypes were tested.

First of all, we have tested the feasibility and ease of assembly of the modules on the anchors and one to each other, including connections of air ducts, wiring and piping. A preparation of anchors and of the "bottom" panel is in slide 7. Slide 8 shows a preparation of the air ducts' connectors before assembly. The slide 9 documents fixing of the fast connectors on the inbuilt pipes. Slide 10 shows how we have used the hall crane to simulate assembly on construction site to test loading of one panel on the other. In slide 11 are two figures showing how we pushed the wiring of the control system, sensors and internet through the prepared protecting pipes. Slides 12 and 13 document a test of navigation of the hanging module to its precise position in order that the air ducts' connectors fit in the proper position. The moments just before the final contact of the modules are documented in slide 14 and the final fit is in slide 15. Slide 16 shows the assembly and fastening of the top anchors that hold the

module in place.

Fig. 3 Slide 16: Fixing the top anchor

Besides the assembly, we have made a 2D modelling of heat transfer through the modules including a thermal simulation of the air ducts in the façade to be sure that the heat losses associated with the fact, that the system is located "outside" the building. It turned out, that the R-value of the core modules is higher compared to the original wall of the existing building and thus the air ducts are not "outside" of the building, but rather inside the building envelope and the heat losses to the exterior would be safely below two percent of the transported heating energy.

In the development team was present expert on fire safety who posed various questions on the fire safety of the solution of the air ducts in the façade elements. Based on the discussion we at first simulated and then conducted a fire test in our fire testing facility to prove or disprove validity of the doubts. We have tested one element, that simulated the worse possible scenario of fire that goes up in flames in the exterior corner of a building equipped with our MORE-CONNECT solution. There were four air ducts build in the façade elements simulating the modules fitted together in the inner corner and there were sets of temperature sensors built in the structure. We started a standard test fire and monitored the rise of temperatures on the surfaces and within the structure and in the air ducts. The fire test correlated with the simulations and showed, that there was no damage of the timber frame, no spread of fire above 0.5 m and temperatures in the air ducts stayed below 20 °C after 30 minutes of fire and thus there is no fire risk for the MORE-CONNECT solution in the scenario under investigation (see slides 18-23).

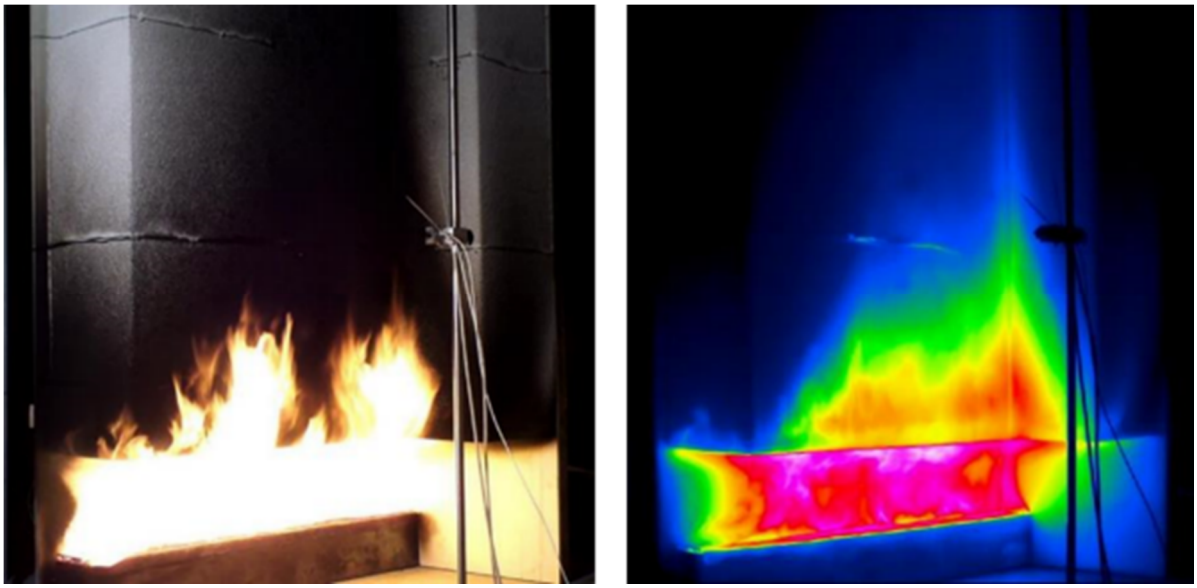


Fig. 4 Slide 20: Test in fireLAB

3 Denmark

In Denmark two products/construction concepts have been further developed in the MORE-CONNECT project:

- The company Innogie (new name: Ennogie) has developed a roof consisting of solar cell panels. Innogie is a company specializing in innovative use of solar energy with special attention to power adequacy, design and profitability for the consumer. Within the More-Connect project Innogie has developed several prototypes of its Solar Energy Roof - in particular concerning methods of mounting and flashing details to create a customer and installer driven plug-and-play solution.
- The company Invela has developed a new robot platform ready to perform many different types of task on-site or in prefab on large surfaces and areas. Specific in the pilot case performing decoration of externally insulated external walls carried out by a robot, programmed directly from Revit drawing and working on 120m² gable wall. Invela has through its work with developing a new solution for prefab manufacturing of façade elements gone from thoughts around the traditional factory prefab solutions using different types of materials and automations to gain further value and benefits, herein the generating of a new company called Robot At Work. Robot At Work aims at getting a scalable intelligent robot solutions on the building site and collaborating with the craftsmen doing the actual work precise and with less hazards involved.

So, the report will cover the production of both these products/systems.

3.1 The production process

3.1.1 Ennogie

Working within the MORE.-CONNECT project Ennogie has refined the production process and

Fig. 1 Early prototype of the Innogie solar cell roof on a single family house near Odense, DK

Fig. 2 Innogie PV-prototype installation in Haderslev, DK

3.1.2 Invela

The new building solutions are being produced with the Robot At Work solutions and most importantly by using a tablet graphic user interface (GUI) for working onsite with scalable robots.

When developing the robot solution for onsite work, Invela/Robot at Work found it very important for the craftsmen onsite to be able to control the solution with great ease and without the need of much training. Therefor a tablet/smatphone control interface was essential and was developed alongside the whole development of the actual 3D façade solution to be tested in More-Connect.

This GUI is now the key product of Robot At Work and can control and be used in more and more applications for robotics. Described in short it allows the building constructors to generate small working packages from the drawings of the building and to post-process them through the “black box” in Robot At Work, and then deliver these packages for onsite work to perform specific tasks. This is very unique and one of a kind software for construction work.

Below some photos of the work that has been performed in the developing process and tested onsite in some cases is shown.

Fig. 4 Rendering with spraygun and pump and 3D printing on a wall

Fig. 5 Complete prototype of insulated wall with robot made decoration and robot applied finishing.

3.2 Details about the production

3.2.1 Ennogie

As the product was further developed and the experience of laying a roof with the PV-roofing elements has grown the speed of the laying process increased and at the final installation of the app. 400 m² PV roof on the Danish pilot project the time spent for installation was down to 180 person hours.

3.2.2 Invela

For Invela two development tracks has been in focus: The most important is to be able to cover a large area with with one robot – to avoid using time on moving the robot from place to place and the speed of the operation. For the carrying out of the work on the Danish pilot project the robot covered 120m² – it took two hours to install the robot and one hour to take it down again. The actual painting time by the robot was 25 min. This would be the same whether it should paint a logo or the whole gable wall (avoiding the windows) in one colour. The programming task took around 20min and the task was started only by the push of one bottom on a smartphone onsite.

3.3 Testing and quality control

3.3.1 Ennogie

Production of components: Main suppliers do comprehensive QA activities before shipping products to Innogie. PV panel supplier doing 100 % automatic test of each PV panels, (e.g. efficiency, insulation, visual inspection). Supplier of mechanical components conduct on each delivery of steel rails test measurement by means of a test gauge to ensure correct shape of the steel rails order / delivery. Installation on–site: Visual inspection of all PV panels Visual inspection of all steel rails. Control measurement of each batch regarding steel rails. Only instructed employees are in charge of manufacturing of Innogie roof panels and cables.

During installation, the installers are responsible for ensuring that the work is done according to the guidelines.

As soon as the micro inverters are connected to the internet Innogie will start to receive data from the installation. This data will reveal if anything in the system is not working properly.

3.3.2 Invela

This Quality Control is divided in two, the responsibility of the craftsman working on-site and the building planner, who makes the actual tool paths directly from the drawing. The craftmen needs to make sure that the working tool and the material used is mounted correctly and is ready for use. The building planner needs to make sure that the drawing is precise and that the tool paths for the robot is as they should be, so they perform correctly onsite.

The new feature when using the robot is, that it can be used to remind the craftsman through the interface about specific task used for Realtime or later QC. This means both task that he can do alone or control but also the option where it is necessary to take measures or photo’s real time on the fly when the robot is working. This could be temperature of the surface, material used, time to clean tool for maintenance etc.

4 Estonia

4.1 The production process

AS Matek (with go-operating Estonian lead partner Tal Tech) was designing, producing and assembling insulated timber frame elements (wall and roof) to renovate soviet time 5-storie apartment building into nZeb building.

The main task was produce large ready finished external wall and weather proof roof elements.

Prototypes of prefabricated elements was developed by Tal Tech and AS Matek. There were 4 main issues wich needed to be handled which will be described later.

In AS Matek there was produced:

- external wall element for 5-storie apartment building
- external wall elements for ventilation chamber on roof
- roof elements for 5-storie apartment building

Wall element construcion (from inside): compensation mineral wool; vapour-barrier; timber frame 45x195+45x70, insulated with mineral wool; wind-barrier mineral wool board; vent.battens; facade board

Roof element construcion (from inside): OSB board; timber frame 45x195+45x145, insulated with mineral wool; underlayment; vent.battens; plywood; 2xSBS

Into wall and roof elements there was installed ventilation pipes in AS Mateks factory. Steel brackets were assembled under wall elements. Plastic windows were used.

Special attention was needed to assembling insulation and make elements airtight.

Fig.1 Production of More-Connect Estonian pilot

4.2 Details about the production

AS Mateks factory production took 1,5 months, during that time 6 different types of elements, all together 197 external wall and roof panels were produced for 5-storie apartment building.

Element production was very difficult and time consuming because there were many unusual materials for AS Matek. Special attention and high accuracy were needed for façade board assembly and for steel brackets.

Fig.2 Appr. 3x10m external wall element

Fig.3 Installing SBS to roof elements

4.3 Testing and quality control

Before element technical design there were tested 4 main issues at AS Matek:

1. How to fill element joints PU-foam (how PU-foam acts in different conditions)
2. How to install and insulate ventilation pipes into external wall element
3. How to connect ventilation pipes to each other between elements
4. How to hang elements with steel bracket to existing building

Fig.4 PU-foam between wood in a different condition

Fig.5 Installing and insulating ventilation pipes into external wall element

Fig.6 Connecting ventilation pipes to each other between elements

Fig.7 Hanging elements with steel bracket to existing building

During the production Tal Tech installed 2 wall and 2 roof sensors to monitor building when it is in use.

Quality control check:

- Monitoring materials and certificates, including moisture in timber
- Assembling material according manuals and project data
- Transport package and identification

5 Latvia

5.1 The production process

Prototypes of prefabricated modular renovation elements were developed by Riga Technical University and ZTC LTD and then produced by external company selected based on public procurement. The prototypes included different sealing options and external finishing solutions.

Fig. 1 Slide 56: Demo samples were produced to test their durability and to evaluate possible installation solutions

5.2 Details about the production

Overview of production process is available here https://youtu.be/bo7BxMEi3zM . Prototypes were ready in 2016. The panel fasteners and connectors were tested in RTU premises. The production took 2 weeks.

Fig. 2 Slide 57: Evaluation of joints sealing options and test of panel connections

5.3 Testing and quality control – referring to the requirements defined in D2.1

In order to prevent air circulation between exiting wall and panel the following materials were analyzed: Sealing tape (1); Mineral wool (2) and soft sealing tape (mineral wool) (3), see fig. 3. Taking into account the external wall vertical deviations, it was decided to use mineral wool sealing tape. Regular sealing tape doesn't ensure necessary air tightness level due to its bending and twisting. Mineral wool doesn't ensure full filling of air gap due to the vertical deviation of the wall.

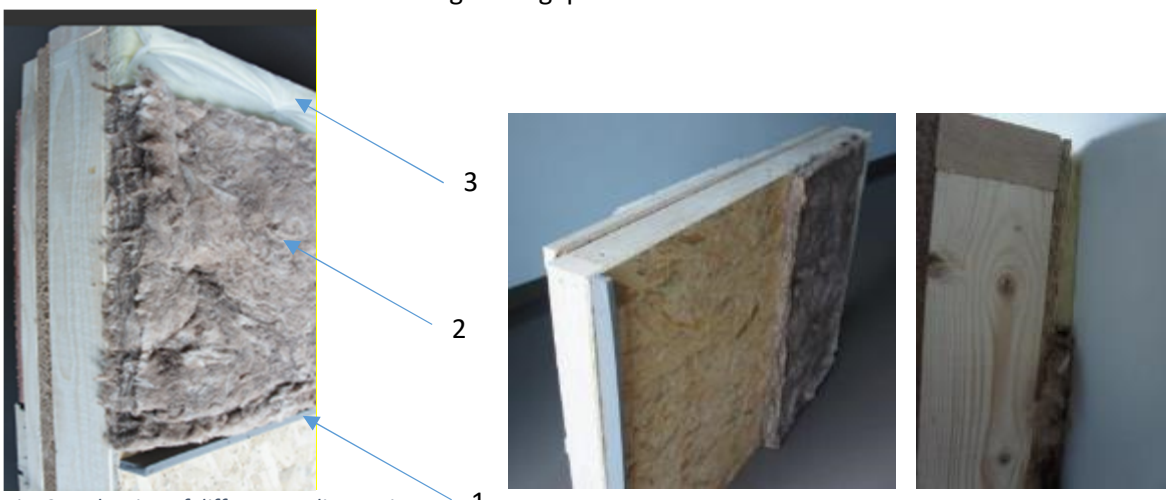
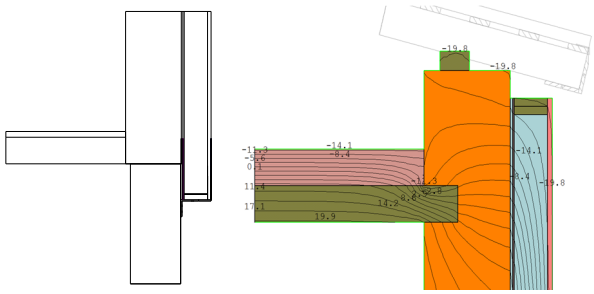


Fig. 3 Evaluation of different sealing options

The thermal bridge values and temperature distribution was analyzed for main junctions. In comparison to widely used rendered facades modular wooden frame facades should have higher rate of thermal bridges. It was found out that non-insulated wall edge has 4.6% higher heat losses in comparison to insulated edge. The critical point is external corners where extra losses are by 12% higher in comparison to rendered façade solution. Comparison of thermal bridge values is shown in table below.



a) .DXF model b) THERM model

Fig. 4 Evaluation of thermal bride effect

Table 1 Comparison of thermal bridge values

Type of thermal bridge	External Ψe W/(m·K)	Internal Ψi W/(m·K)	Classic rendered facade
			Internal Ψi W/(m·K)
Basement/stem wall	0.37	0.4	0.3
External corner	-0.09	0.1	0.05
Wall/attic slab	0.14	0.30	0.24
Panel joint	0.02	0.05	0.00

Panel thermal characteristic were analyses in order to obtain U-values and moisture growth.

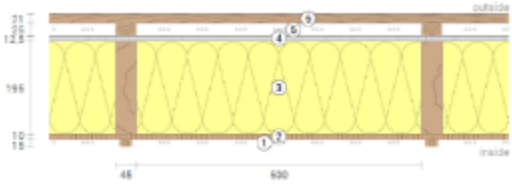
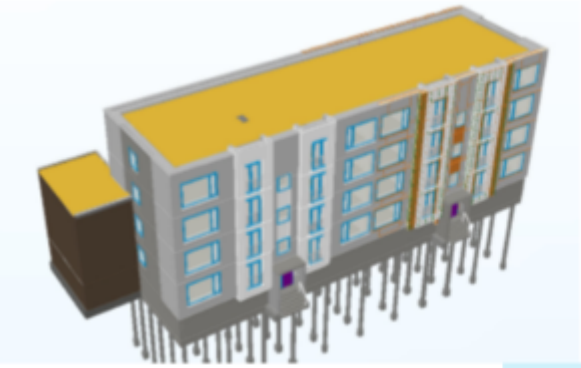


Figure 5 Evaluation of thermal characteristic

6 The Netherlands

6.1 The production process

For the renovation of the Dutch demonstration project Presikhaaf Arnhem the prefab elements were designed by WEBO. BIM models were made for the buildings which were used for the further design and production of the elements.



BIM

PRESIKHAAF ARNHEM

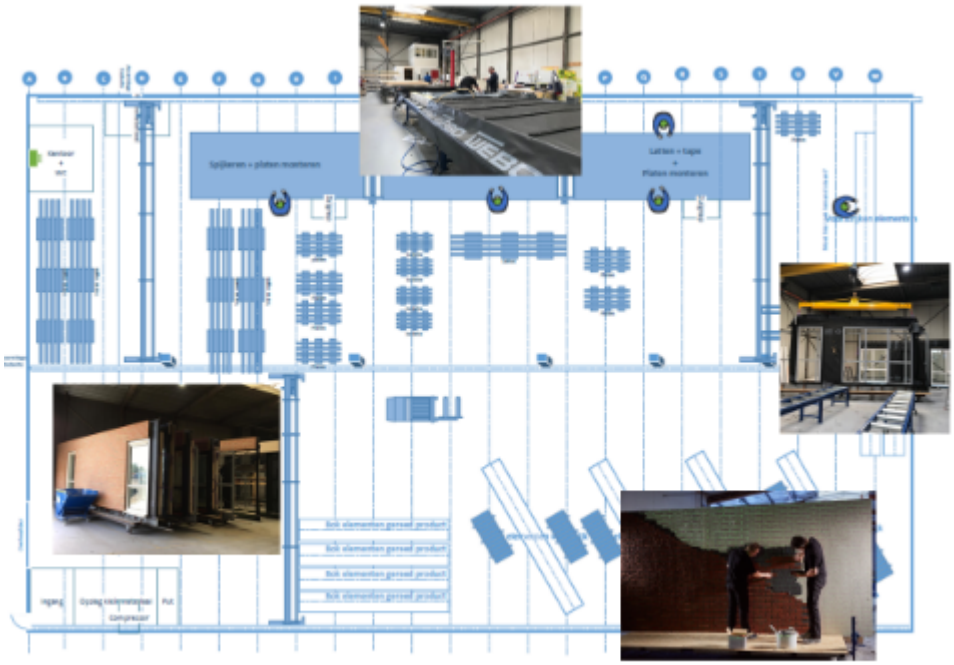
As WEBO is already active in the production of prefab facades it was not necessary to design and construct specific prototypes for this project. The façade solutions for Presikhaaf were based on previous, tested, prototypes, however, further developed with typical MORE-CONNECT elements like embedded ducts in the elements, click and span connections etc.
Webo presented the façade solution to the client which was decisive and the client prescribed WEBO as preferred supplier
For the design process WEBO was taking into account:

- Application of a high level of thermal insulation,
- high level of airtightness, to be controlled and proven by blower door measurements
- certified industrial production,
- integrated ventilation ducts in the prefab elements
- finishing and cladding included in the prefab elements
- geometrics (laser scanning, point cloud),
- design-for-manufacturability (BIM, 3D design),
- integrated product delivery including on-site installation, short lead time on-site <10 days,
- portfolio of successful completed projects

6.2 Details about the production

WEBO has now made over 5000 wall elements. However, one of the problems is that the product is so innovative and simple that potential clients do not believe in it. In such cases WEBO is inclined, and the problem lies with WEBO. Still this 'problem' is solved by adapting the client demands, doing concessions on their own product. Better would be the strategy: 'we have developed a product, this is it, this is what you get, this is how it works. The modular system must be applied as such, and we must not adapt to the traditional process of the contractor.'

The production lines, used for the manufacturing of the façade elements looks like this:



6.3 Testing and quality control – referring to the requirements defined in D2.1

Before the production of the prefab elements following tests and assessments were made:

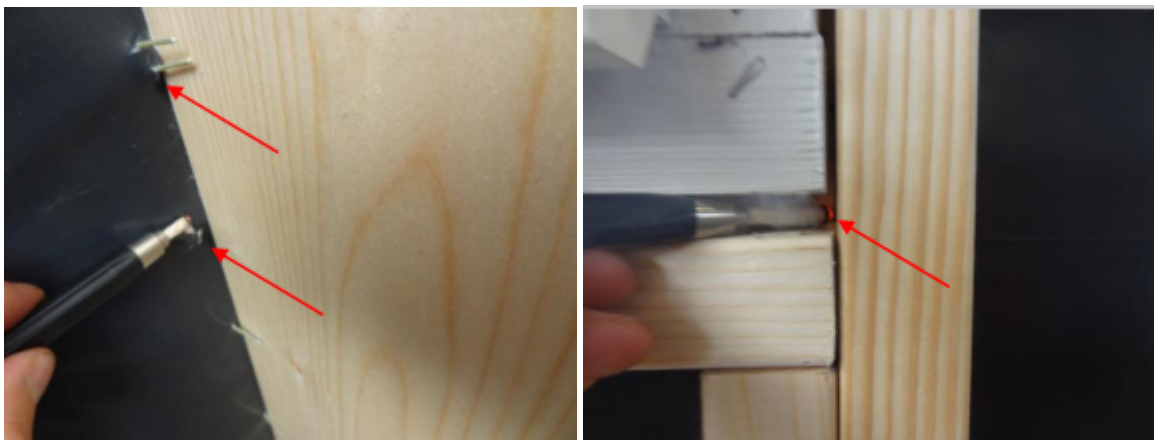
- Airtightness measurement of a prototype of a standard prefab façade element in a test box
- Building physical assessments of the details of the window frames and connections with the prefab façade elements.

The airtightness measurements had both qualitative and quantitative purposes.

Qualitative: although airtightness measurements in test boxes cannot be compared with measurements in real buildings, these measurements can give a good indication if the elements have the potential to achieve a good airtightness of the renovated envelope. The airtightness measurements indicated that the prototypes were suitable to achieve a high level of airtightness.

Quantitative: the airtightness measurements have been used to detect weak points and air leakages in the façade elements.
Conclusions of these tests were that:

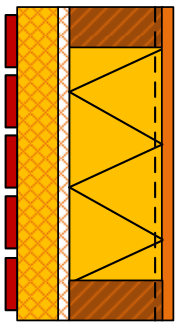
- A n_{50} value of the building envelope between 0,5 and 1,0 should be feasible
- The frame sealings have a very good performance
- Weaker points are the connections between the window frames with the façade elements and the staples that are used for installing the foil.
-



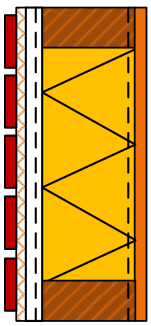
The goal of the building physical assessments of the details of the window frames and connections with the prefab façade elements is to see to which extension these details are weak spots in the total thermal performance of the facade elements. Therefor thermal bridge calculations have been executed. These calculations showed that these details did not introduce weak spots and that the solutions are suitable for passive house renovation.

The WEBO prefab façade elements have been improved after its application in the Presikhaaf project. The EPS on which the brick slips are glued is replaced by battens and cement fiber board. This has some advantages with respect to:

- Guarantee on wind and waterproofing in the long term in case of mechanical damage
- Improvement fire protection
- Production efficiency (simplification)
- Improvement production efficiency: 'in line' process developed
- Improvement quality management system: every single wall element checked and marked with a 'approved' sticker, according to the quality management system



-Fermacell 12,5mm
-Vapor-tight foil
-Wood structure 38x286mm
-Insulation (stone wole)
-OSB
-STO insulation
-Brick slips



-Fermacell
-Vapor-tight foil
-Wood structure
-Insulation
-Water retaining, vapor-open foil
-Battens (air cavity)
-Cement fiber board
-Brick slips

7 Portugal

7.1 The production process

The developed prefabricated modular solution in Portugal comprises a wood frame, an internal/external cladding made of Coretech® sheets and a filling material of polyurethane foam (Figure 1). The module has a total thickness of 120mm and a density of 19.7 Kg/m^3. It was produced with 2.55 m in height and 1.00 m width. In Figure 2, the assembly of the prototype is shown before the filling of the insulation layer. The polyurethane foam is injected only when the other components assembly is complete. Figure 3 shows the detail of the male-female system designed for the connection of several panels.

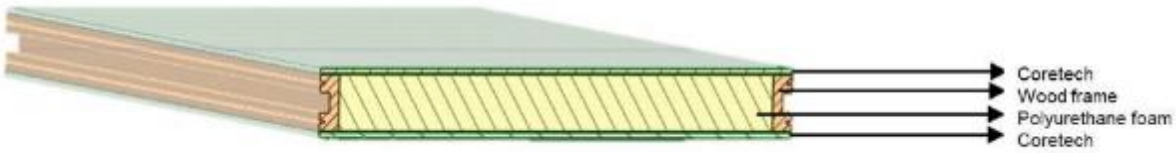


Figure 1 - Composition of the prefabricated panel

Figure 2 - Assembly of the prototype for the prefabricated module

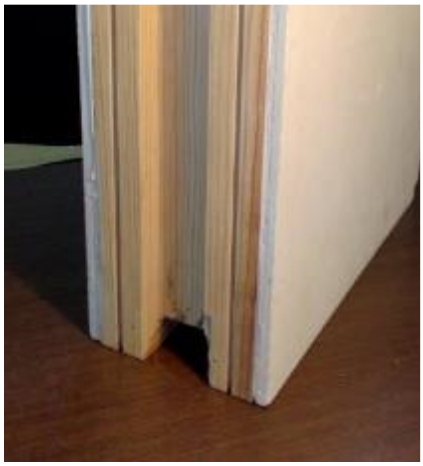


Figure 3 - Wood frame detail

7.2 Details about the production

A total of four prototype modules were produced. The production time for the final prototypes extended for four weeks.

The prototype manufacturing allows to assert the cost structure of the prefabricated panel process and implementation (Figure 4). The analysis indicate that the insulation material is the most costly, followed by the metal fixation pieces and the wood frame.

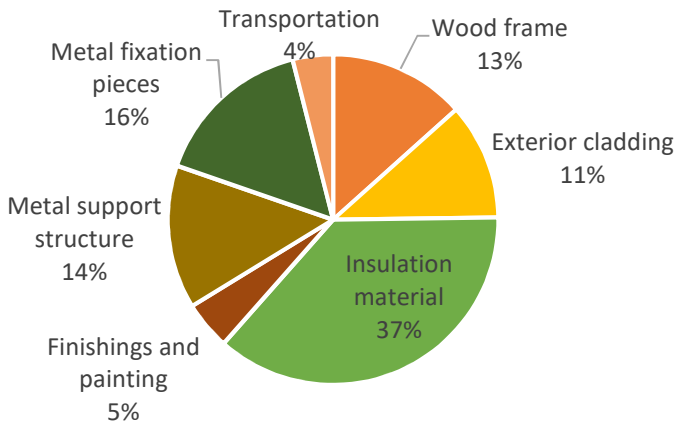


Figure 4 - Cost structure

7.3 Testing and quality control – referring to the requirements defined in D2.1

The prototypes were tested in laboratory using a thermal chamber (Figure 5) and through dynamical simulations, in order to optimize the insulation layer thickness, as well as different materials for this layer. The experimental work allowed to obtain valuable results regarding thermal characteristics, such as the differences between joints and current zones of the panel (Figure 6). Additionally, testing results from physical measurements of superficial temperature and heat flux indicated a U-Value of 0.31 W/m².K for the completed prefabricated panel.

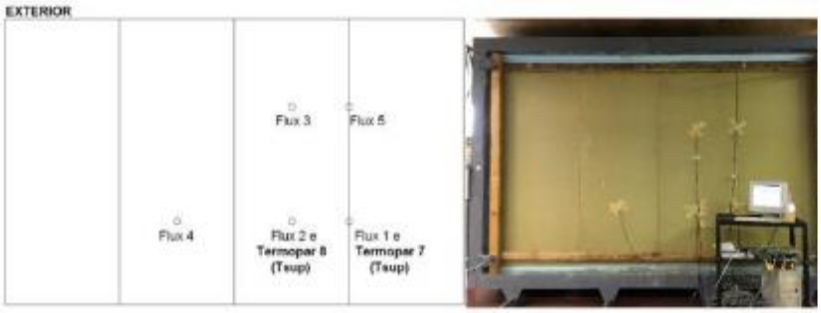


Figure 5 - Experimental setup of prototypes in thermal chamber

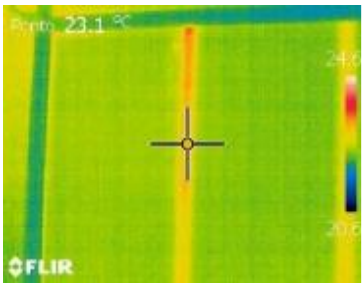


Figure 6 - Thermographic image of the panels