Deliverable D2.3
Prototyping best performing new eco-friendly radiating panels for indoor applications

Grant Agreement number 723916
Project acronym InnoWEE
Project full title INNOvative pre-fabricated components including different Waste construction materials reducing building Energy and minimising Environmental impacts
Due date of deliverable 31/03/2018
Lead beneficiary CNR-ITC
Other authors CNR-ISAC, CNR-ICMATE, RED, ZAG, TEC, PIETRE

Dissemination Level

<table>
<thead>
<tr>
<th>PU</th>
<th>Public</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>Confidential, only for members of the consortium (including the Commission Services)</td>
</tr>
<tr>
<td>CI</td>
<td>Classified, as referred to in Commission Decision 2001/844/EC</td>
</tr>
</tbody>
</table>
Document History

<table>
<thead>
<tr>
<th>Version</th>
<th>Date</th>
<th>Authors</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>05/03/2018</td>
<td>CNR-ITC</td>
<td>Creation of the document</td>
</tr>
<tr>
<td>2</td>
<td>12/03/2018</td>
<td>CNR-ICMATE</td>
<td>Improved draft</td>
</tr>
<tr>
<td>3</td>
<td>13/03/2018</td>
<td>CNR-ITC</td>
<td>Inclusion of preliminary results of thermal performance</td>
</tr>
<tr>
<td>4</td>
<td>14/03/2018</td>
<td>TECNALIA</td>
<td>Addition of requirements for historical buildings</td>
</tr>
<tr>
<td>5</td>
<td>15/03/2018</td>
<td>Pietre</td>
<td>Revision</td>
</tr>
<tr>
<td>6</td>
<td>16/03/2018</td>
<td>CNR-ITC</td>
<td>Version sent to reviewers</td>
</tr>
<tr>
<td>7</td>
<td>17/03/2018</td>
<td>CIRCe</td>
<td>Addition of notes about the design of fastening systems</td>
</tr>
<tr>
<td>8</td>
<td>28/03/2018</td>
<td>MB</td>
<td>Revision by first reviewer</td>
</tr>
<tr>
<td>9</td>
<td>29/03/2018</td>
<td>AMS</td>
<td>Revision by second reviewer</td>
</tr>
<tr>
<td>10</td>
<td>29/03/2018</td>
<td>CNR-ITC</td>
<td>Version sent to Coordinator</td>
</tr>
<tr>
<td>11</td>
<td>30/03/2018</td>
<td>CNR-ISAC</td>
<td>Approved and submitted version by the Coordinator</td>
</tr>
</tbody>
</table>

Disclaimer

This document is the property of the InnoWEE Consortium.

This document may not be copied, reproduced, or modified in the whole or in the part for any purpose without written permission from the InnoWEE Coordinator with acceptance of the Project Consortium.

This publication was completed with the support of the European Commission under the Horizon 2020 research and innovation programme. The contents of this publication do not necessarily reflect the Commission’s own position. The document reflects only the author’s views and the Community is not liable for any use that may be made of the information contained therein.
# Contents

Publishable summary .................................................................................................................................................. 4  
List of Figures .............................................................................................................................................................. 5  
List of Tables ................................................................................................................................................................. 7  
Abbreviations ............................................................................................................................................................... 7  
Symbols ......................................................................................................................................................................... 8  
Introduction .................................................................................................................................................................... 9  
1 General features of radiant panels ........................................................................................................................... 10  
  1.1 Radiant ceiling elements .......................................................................................................................................... 10  
  1.1.1 Geometry .......................................................................................................................................................... 10  
  1.1.2 Piping and connection system ............................................................................................................................ 11  
  1.1.3 Design and assembly of piping system on EPS panels ....................................................................................... 12  
  1.1.4 Installation system ............................................................................................................................................. 13  
  1.2 Radiant wall elements .............................................................................................................................................. 13  
  1.2.1 Geometry .......................................................................................................................................................... 13  
  1.2.2 Insulator ........................................................................................................................................................... 14  
  1.2.3 Stamping of WG panels featuring a channel pattern .......................................................................................... 14  
  1.2.4 Piping system and assembly on WG panel .......................................................................................................... 15  
  1.2.5 Pipe connection system ........................................................................................................................................ 15  
  1.2.6 Fastening system ................................................................................................................................................ 16  
  1.3 Surface textures, colours and multifunctional coating ........................................................................................... 16  
2 HDG and WG binder .................................................................................................................................................... 17  
  2.1 Thermophysical properties of geopolymer materials used ...................................................................................... 17  
  2.2 Preliminary fire tests on WG ................................................................................................................................... 18  
  2.2.1 General aspects .................................................................................................................................................. 18  
  2.2.2 Experimental results .......................................................................................................................................... 19  
  2.2.2.1 Calorific value .............................................................................................................................................. 19  
  2.2.2.2 Cone calorimeter method .............................................................................................................................. 20  
  2.2.2.3 Conclusions and next steps ............................................................................................................................ 22  
3 Tested production methods for radiant panels ......................................................................................................... 23  
  3.1 Radiant ceiling elements ........................................................................................................................................... 23  
  3.1.1 Method 1 – Bottom casting + stamping ................................................................................................................ 23  
  3.1.2 Method 2 – “painting” + stamping ....................................................................................................................... 24  
  3.1.3 Details of casting box for method 1 and 2 ............................................................................................................. 25  
  3.1.4 Method 3 – top casting + rolling .......................................................................................................................... 25  
  3.1.5 Details of casting box for method 3 ..................................................................................................................... 26  
  3.1.6 Preferred casting method for radiant ceiling panels .......................................................................................... 27  
  3.2 Radiant wall elements ............................................................................................................................................... 27  
  3.2.1 Method 1 – “painting + stamping” ....................................................................................................................... 27  
  3.2.2 Details of the casting box for method 1 ................................................................................................................ 27  
  3.2.3 Method 2 – separate casting of HDG and bonding to WG ................................................................................ 28  
  3.2.4 Details of the casting box for method 2 ................................................................................................................. 29  
  3.2.5 Assembly of piping system on WG panel ........................................................................................................... 31  
  3.2.6 Preferred casting method for radiant wall panels ................................................................................................ 32  
4 Assessment of prototypes ............................................................................................................................................ 33  
  4.1 Radiant ceiling elements .......................................................................................................................................... 33  
  4.1.1 Visual inspection of panel defects ......................................................................................................................... 33  
  4.1.2 Thermal performance of panels ............................................................................................................................. 34  
  4.1.2.1 Numerical simulations ..................................................................................................................................... 34  
  4.1.2.2 Apparatus for the thermal performance measurement .................................................................................. 35  
  4.1.2.3 Procedure for the thermal performance measurement .................................................................................. 38  

30/03/2018
4.1.2.4 Results of the thermal testing ........................................................................................................ 39
4.2 Radiant wall elements ............................................................................................................................. 43
  4.2.1 Visual inspection of defects ............................................................................................................... 43
  4.2.2 Thermal performance ...................................................................................................................... 44
5 Design of the anchoring system ............................................................................................................. 45
  5.1 Radiant ceiling elements ...................................................................................................................... 45
  5.2 Radiant wall elements .......................................................................................................................... 46
6 Requirements for Historical Buildings ................................................................................................. 47
  6.1 Historic Buildings’ definition ............................................................................................................... 47
  6.2 Intervention limits to be respected or considered in Historic Buildings. ........................................... 48
  6.3 Matrix evaluating the suitability of the RADIATING PANELS to Historic Buildings ....................... 49
  6.4 Considerations on the applicability of the RADIANTING PANELS to Historic Buildings ................. 50
  6.5 Analysis on the applicability of radiating panels in the Virtual Demo Cases of INNOWEE .......... 50
    6.5.1 Private House in Piazzola sul Brenta (Padua, Italy) ....................................................................... 50
    6.5.2 House in the settlement of Parikia in Paros (Greece) .................................................................. 50
    6.5.3 Historical Residential Building (Bucharest, Romania) ................................................................. 51
    6.5.4 Two blocks in Txurinaga neighbourhood in Bilbao (Basque Country, Spain) ............................... 51
Conclusions .................................................................................................................................................. 52
References .................................................................................................................................................... 53
Publishable summary

Deliverable D2.3 “Prototyping best performing new eco-friendly radiating panels for indoor applications” presented the numerous steps that led to the laboratory assessment of real scale panels, starting from the assessment of geopolymer mixtures.

The prototyping phases required an extensive work that allowed identifying the main issues related to the manufacture of real scale panels, and addressing them to the maximum extent feasible in a laboratory production.

Suitable sizes and geometry of both radiant wall panels and radiant ceiling panels were selected by taking into account also numerical simulations, with the aim of optimizing their production, installation and thermal performance.

Geopolymer mixtures were further tuned to meet the needs of the pilot-plant production, especially in terms of fluidity and open time, and to improve the behaviour against issues highlighted by real scale prototypes, mainly due to panel warping and shrinkage cracking.

Various casting options were tested to select the most suitable for serving as a base for the scaled-up production, which finally were those labelled as “bottom casting + stamping” for the radiant ceiling panel and “separate casting of HDG and bonding to WGP” for radiant wall panels.

The assessment of panels was carried out first by visual inspection and qualification of structural and processing defects to select the most appropriate binder formulation and panel casting method. Laboratory tests were performed to evaluate the thermo-physical properties of the geopolymers and the thermal performance of prototype radiant panels.

Fire properties of prepared materials were assessed by two testing methods for small samples: determination of calorific value and the cone calorimeter method. Moreover, single burning item small-scale testing and a simulation of the test results was used for estimation of SBI criteria.

For both radiant wall and ceiling panels, a suitable fastening method was selected and designed, in order to prove their potential compliance with building regulations in force. Moreover, a commercial pipe connection system was selected, compatible with the produced panels.

Finally, proper insulating materials, appearance (textures and colours) and dedicated requirements for historical buildings were discussed as well.
List of Figures

Figure 1. Sketch of radiating ceiling panel (a), with a section of the tube embedment (b) and a real-scale prototype (c)................................................................. 10
Figure 2. Shaping of EPS insulator: (a) CNC-milling of EPS; (b) finished shaped EPS insulator including channel for piping accommodation and slots for piping entry/exit towards the back side of the panel........................................................................................................... 11
Figure 3. (a) Pipes exiting on the rear side of the insulator; (b) panels with piping connected on backside.................................................................................................................. 11
Figure 4. Candidate connectors from the Uponor “Quick&Easy” system to connect the piping............ 12
Figure 5. (a) Sketch of used spiral pipe design; (b) figure of the reference panel Uponor Teporis 1200×1000 .................................................................................................................. 13
Figure 6. (a) Sketch of the pipe inside the EPS channel according to the “suspended” geometry; (b) sketch of the MDF clamps used to mount the piping................................................................. 13
Figure 7. (a) CNC machining of the clamps; (b) MDF clamps ready for use; and (c) piping mounted in suspended geometry inside the channel of an EPS panel.......................................................... 13
Figure 8. (a) Example of false ceiling; (b) commercial false ceiling mounted in the Pilot Demo House in Padua (Italy), intended to be partially replaced by InnoWEE radiating panels.............. 13
Figure 9. Radiant wall system: (a) sketch of the WG+HDG radiant part; (b) prototype with the insulation layer............................................................................................................................. 14
Figure 10. (a) Hydraulic press used for shaped WG panels for radiant wall panels; (b) casting box with mould insert to define the channel pattern on WG panel; (c) even spreading of the WG mixture inside the casting box; (d) compression of the panel; (e) demoulded WGP with stamped channel pattern to accommodate the piping ......................................................................................... 15
Figure 11. Painted WGP with mounted PEX-a piping system..................................................................... 15
Figure 12. Example of fastening of the radiant wall panel with screw and washer ..................................... 16
Figure 13. Calorific value (PCS value) of the three materials. PCS value of dry wood are about 15 to 20 MJ/kg................................................................................................................................. 20
Figure 14. Heat Release Rate – HRR (a), and Total Heat Release – THR –measured with cone calorimeter method at 50 kW/m² of heat flux .......................................................................................................................... 21
Figure 15. Total Smoke Release – TSR (a), and (b) time to ignition and flame duration measured with cone calorimeter method at 50 kW/m² of heat flux ................................................................................................. 21
Figure 16. Photo of the three samples after the test with CONE calorimeter method at 50 kW/m² of heat flux .................................................................................................................................................. 21
Figure 17. Calculated SBI parameter THR60° (a), and calculated SBI (EN 13823) maximum parameter FigRA (b) for three materials, tested with Cone calorimeter method at 50 kW/m² of heat flux ................................................................................................................. 22
Figure 18. Steps of the “bottom casting + stamping” production process .................................................. 23
Figure 19. Photographic sequence of the “bottom casting + stamping” production process ................ 24
Figure 20. Details of EPS panel preparation necessary for the “bottom casting + stamping” production process .................................................................................................................................. 24
Figure 21. Steps of the “painting + stamping” radiant panel production process ...................................... 24
Figure 22. Photographic sequence of the “painting + stamping” production process ................................ 25
Figure 23. Example of casting box for “bottom casting + stamping” ........................................................... 25
Figure 24. Steps of the “top casting + rolling” radiant panel production process ........................................ 26
Figure 25. Photographic sequence of the “top casting + rolling” radiant panel fabrication process.......... 26
Figure 26. Example of casting box for “top casting + rolling” method ..................................................... 27
Figure 27. Steps of the “painting + stamping” production process for HDG+WGP radiant wall panels .... 28
Figure 28. Photographic sequence of the “painting + stamping” process for HDG+WGP radiant wall panels .................................................................................................................................................. 28
Figure 29. Details of the casting box for a 8 mm thick HDG panel to be coupled to a 15 mm thick WG panel (the 70 x 70 cm² cover plate is not shown) .................................................................................................................. 29
Figure 30. Schematic steps of the “freestanding HDG plate” casting process (steps 1 to 6) and the subsequent bonding to WG panel with mounted piping (steps 7-8)................................................................. 30
Figure 31. Photographic sequence of the “top casting + rolling” of the “freestanding” HDG plate ........ 30
Figure 32. Example of final HDG+WGP radiant panel, with cross-section exploded for demonstration purposes .................................................................................................................................................. 30
Figure 33. Details of the casting box for a 8 mm thick HDG plate to be used with a WGP 15 mm thick (the 70 x 70 cm² cover plate is not shown) .................................................................................................................. 31
Figure 34. Procedure for mounting the piping system on WGP: (a) painting with a waterproof commercial varnish; (b) fixing of the pipes with hot-melt adhesive at selected points; (c) finished WGP panel with mounted piping; (d) masking of WGP edges with masking tape before the casting or bonding of HDG .................................................................................................................................................. 32
Figure 35. Two-dimensional section of a radiant panel........................................................................ 34
Figure 36. Parametric temperature profiles at the exposed HDG side (λ geopolimer of 0.84 W/m·K) ...... 36
Figure 37. Parametric temperature profiles at the exposed HDG side (λ geopolimer of 0.89 W/m·K) ...... 36
Figure 38. Thermal dummies during a radiant ceiling test ........................................................................... 37
Figure 39. User interface (basic version) of the custom data acquisition software. The two hydraulic circuits are named “G” and “P” respectively ................................................................. 37
Figure 40. Installation of three geopolymeric radiant panels ........................................................................ 40
Figure 41. Results of the steady state cooling measurement for ceiling panels ............................................ 40
Figure 42. Results of the steady state heating measurement for ceiling panels .......................................... 41
Figure 43. Thermographic images of the panel in heating mode ................................................................. 41
Figure 44. Thermographic images of the panel in cooling mode ............................................................... 42
Figure 45. Thermal images of the panel after 5 minutes (a), 10 minutes (b), 30 minutes (c), 60 minutes (d) from the beginning of the test: inlet temperature is equal to 16°C .................................................................................. 42
Figure 46. Results of the transient measurement for ceiling panels ........................................................... 42
Figure 47. Basic commercial false ceiling with omega profiles (a), cold formed hat omega-section (b) ... 45
Figure 48. Example of commercial aseismic false ceiling suspending structures – www.atena-it.com ....... 46
Figure 49. Possible scheme of fastening for radiant wall elements and possible fasteners ................. 46

30/03/2018 6
List of Tables

Table 1. Thermal properties experimentally determined on some geopolymeric compounds.......... 17
Table 2. Properties of tested WGP specimens .................................................................................. 18
Table 3. Fire resistance classification criteria .................................................................................. 19
Table 4. Results of calorific value tests .......................................................................................... 20
Table 5. Simulated SBI-data ............................................................................................................ 22
Table 6. Synthetic evaluation of radiant ceiling panel prototypes based on visual survey (N.A. = not available) .................................................................................................................. 22
Table 7. Results of the parametric simulations of the radiant panel in cooling mode......................... 33
Table 8. Sensors installed on the hydronic system ............................................................................ 37
Table 9. Sensors installed on the tested system and in the test chamber .......................................... 38
Table 10. Results of the steady state cooling measurement for ceiling panels .................................. 40
Table 11. Results of the steady state heating measurement for ceiling panels ................................... 41
Table 12. Synthetic evaluation of radiant wall panel prototypes based on visual survey (N.A. = not available) .................................................................................................................. 43
Table 13. Suitability matrix for InnoWEE solutions in case of internal applications ........................... 49

Abbreviations

CDW Construction and Demolition Waste
EoL End-of-Life
EPS Expanded PolyStyrene
ETICS External Thermal Insulation Composite System
EWP Engineered Wood Product
FA Fly-Ash
GPS Graphite PolyStyrene
HDG High Density Geopolymer
HDPE High Density PolyEthylene
HVAC Heating, Ventilation, and Air Conditioning
InnoWEE Innovative pre-fabricated components including different Waste construction materials reducing building Energy and minimising Environmental impacts
K-sil Potassium (K) silicate
LoW List of Waste
MDF Medium-Density Fibreboard (EWP)
MIP Mercury Intrusion Porosimetry
MK MetaKaolin
Na-Sil Sodium (Na) silicate
NMR Nuclear Magnetic Resonance
OPC Ordinary Portland Cement
PAH Polycyclic Aromatic Hydrocarbons
PAN PolyAcryloNitrile
PCB Poly-Chlorinated Biphenyls
PCS Gross calorific potential (Pouvoir Calorifique Supérieur)
PSD Particle Size Distribution
RHM Random Heterogeneous Material
SBI Single Burning Item
InnoWEE D2.3 “Prototyping best performing new eco-friendly radiating panels for indoor applications”

SEM
Scanning Electron Microscopy

SL
granulated blast furnace slag

SRM
Secondary Raw Material

TOC
Total Organic Carbon

VOC
Volatile Organic Compounds

WG
Wood Geopolymer

WGP
Wood Geopolymer Panel

XPS
Extruded PolyStyrene

Symbols

λ
thermal conductivity
[W kg⁻¹ K⁻¹]

ρ
density
[kg m⁻³]

ρᵦ
bulk density
[kg m⁻³]

ϕᵢ = Vᵢ/Vₜot
volumetric fraction of the iₘ component
[%]

C=ρcₚ
volumetric heat capacity
[J m⁻³ K⁻¹]

cₚ
specific heat
[J kg⁻¹ K⁻¹]

fₜ
compressive strength
[MPa, i.e. N/mm²]

fₑ
bending strength
[MPa, i.e. N/mm²]

fₑₒ
pull-off strength (adhesion strength)
[MPa, i.e. N/mm²]

fₑₚ
splitting strength
[MPa, i.e. N/mm²]

OP
open porosity
[%]

Rₑ
(cubic) compressive strength
[MPa, i.e. N/mm²]

Vᵢ
volume of the iₘ component
[m⁻³]

Vₜot
volume of the compound
[m⁻³]

WA
water absorption
[%]

30/03/2018