SB&WRC Project

Installation Report: University of Bath's Building Research Park

May 2019

Abstract of the project

The SB&WRC *(Sustainable Bio&Waste Resources for Construction)* project, an undertaking of more than two years, aims to conceive, produce and test three innovative, low-carbon, thermal insulation materials from agricultural co-products and recycled waste. The project is supported by the development program Interreg VA France (Channel) England and its budget, estimated to be 1.8M€, is co-financed by the ERDF (European Regional Development Fund) for 69% (1.26M€ contribution).

This project, led by Nomadéis, is carried out by a cross-channel partnership which gathers academic research laboratories, private research and consulting companies, manufacturers and professional non-profit organisation of the building sector:

- Nomadéis;
- Veolia Propreté Nord Normandie;
- University of Bath;
- Ecole Supérieure d'Ingénieurs des Travaux de la Construction de Caen (ESITC Caen);
- Construction21;
- UniLaSalle;
- University of Brighton;
- Alliance for Sustainable Building Products.

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Table of Contents

1. Presentation of the facility

Two series of field demonstration tests were carried out to evaluate realistic performances of the prototypes. In the first series, large panels were installed at the University of Bath's Building Research Park (BRP) within the Large Environmental Chamber (LEC) (Figure 1). The second series of field tests, for Prototype 3, were carried out at the University of Brighton's Waste House (WH) (Figure 2).

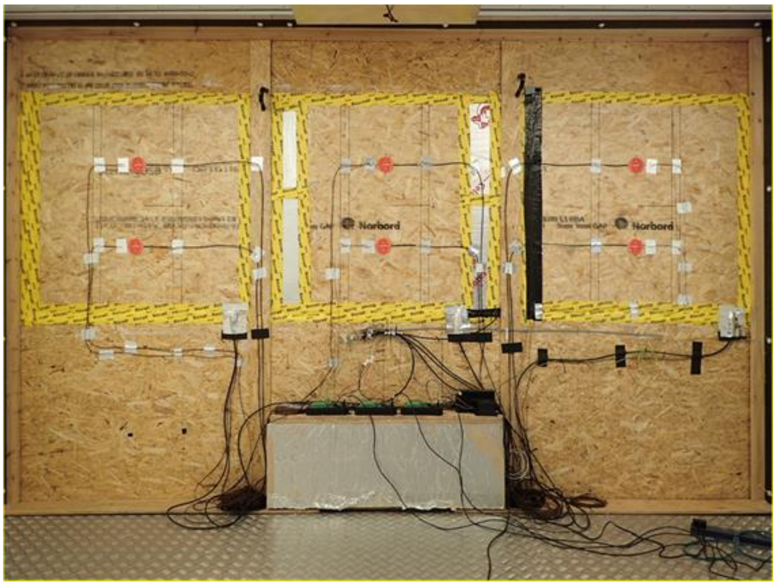


Figure 1: All three prototypes installed in the LEC at the University of Bath's Building Research Park. (Straw, Maize pith, and Duvet from left to right)

Figure 2: Prototype 3 installed in the Waste House, University of Brighton (prototype 3 on top and agricultural bale on bottom)

The first series carried out in the LEC consisted of three 1.1 m2 panels, representative of in-situ timber framed walls, were each filled with one of the proposed insulation materials. To measure their performance, each panel was fitted with Campbell Scientific CS215 Temperature and Relative Humidity Probes through their thickness at their centre lines.

The nominal 150 mm deep panels were placed into corresponding apertures within LEC facility. Campbell Scientific HFP01 Heat Flux Plates and CS215 Temperature and Relative Humidity Probes along with additional T-style thermocouples were located on the exterior surfaces (Figure 3) as well as centrally within each chamber. The programming and data storage were accomplished using a series of Campbell Scientific CR6 Measurement and Control Dataloggers.

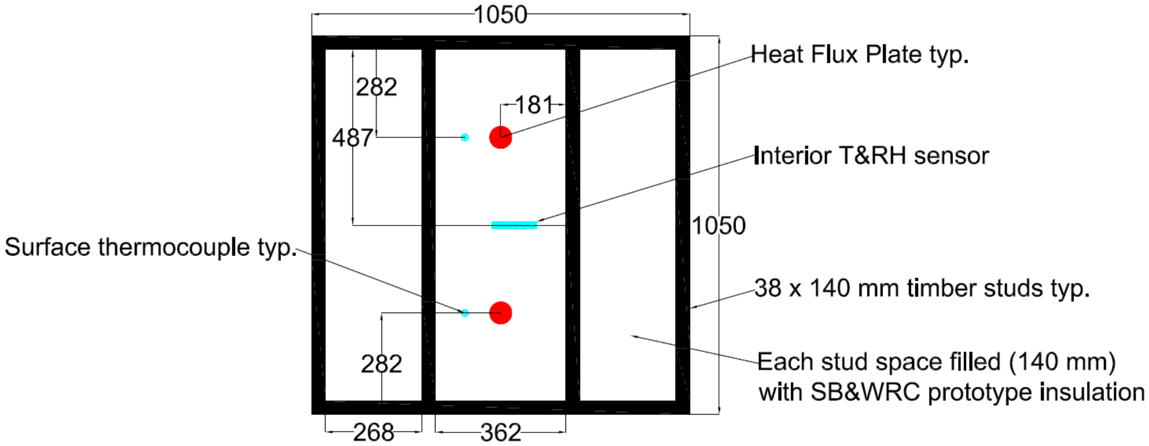


Figure 3. Schematic of the panels for use in the LEC with sensor placement

A second series of field tests, for Prototype 3, was carried out at the University of Brighton's Waste House (WH) comparing the performance of the oriented straw prototype with an equal wall thickness of agricultural baled straw. The reinforced column (RC) design of the WH is such that provisions for various infill materials may be facilitated. This is further accommodated by the infill section being broken down into framed "cassette" style sections. These cassette sections are essentially in-wall cabinets in which various insulation materials may be placed. In this case one of the original cassettes holding a combination of VHS and cassette tapes, was utilized for the evaluation of the oriented straw prototype. The location of the straw prototype was selected in the South East corner of the first-floor office and centrally along the eastern wall of the building as indicated in Figure 4 below.

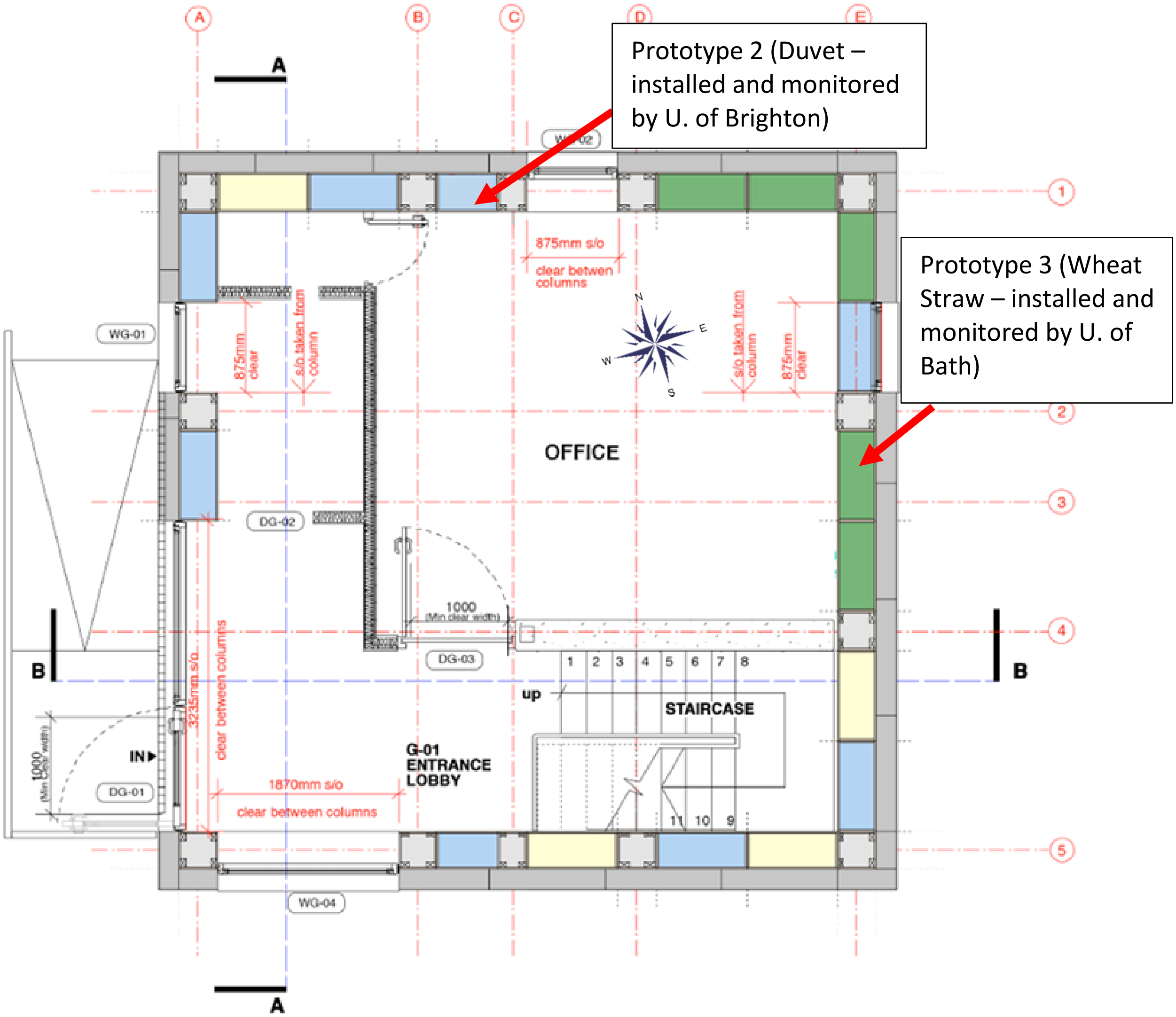


Figure 4: Planview of the WH indicating location of prototype install

Data acquisition was achieved in this phase by implementing TinyTag View 2-TV-4505 Sensors for initial temperature and relative humidity through the thickness of the wall. The second phase implemented Campbell Scientific HFP01 Heat Flux Plates and CS215 Temperature and Relative Humidity Probes along with additional T-style thermocouples. These sensors were used in combination with a Campbell Scientific CR6 Measurement and Control Datalogger complimented by an AM16/32B Relay Multiplexer;

2. Issues encountered

Through the demonstration activities, a variety of issues were encountered. Initially, translating traditional agricultural bale formation into a laboratory produced oriented straw bale on a smaller scale provided a significant challenge. The mechanics of wheat straw when compressed into bale form is not universally scalable. Determining the ideal pressure and bale size was a challenge from the beginning and was constantly refined throughout the project. Several prototypes were created during the project until a stable bale formation could be repeated on a consistent basis.

Additionally, construction and equipment failures along the way contributed to lengthening the overall timeline of the testing. The laboratories at the University of Bath have undergone a series of retrofitting and construction of new letting facilities which provided limited access to equipment at times, delaying the overall project. As the LEC replicates severe weather conditions, the operating equipment is pushed to perform under extreme conditions and therefore required maintenance and repairs during the tests performed. These delays accumulated to add an additional 6 weeks to the testing timeline.

In terms of straw supply, while abundant, the harvesting and use of traditional baling equipment result in bales of mixed composition and straw quality and is something that would need to be addressed in future developments.

3. Measurement of performance

3.1 Experimental conditions

Test 1

The first phase testing completed at the University of Bath's BRP was conducted within the LEC. The LEC provided controlled temperature and relative humidity conditions representative of winter, summer, and extreme climatic variations. As such the *in-situ* thermal and hygroscopic properties of the three Bio & Waste based prototype insulating materials could be simultaneously evaluated side by side. Each panel is identical in construction as previously described and shown in Figure 3.

The LEC program was initiated and a 24-hour settling period was established, with the chamber temperatures set to 20 °C and 0% RH, to ensure all panels were conditioned equally. The various programs representing the different climatic conditions ran consecutively, only stopping for chamber maintenance or repair. Each program was monitored throughout its duration.

Test 2

The second phase testing completed at the University of Brighton's Waste House (WH) evaluated two forms of straw bale construction within an existing environment. As the walls at the WH have a depth near that of a traditionally constructed agricultural straw bale structure; a single 1000 mm (long) by 450 mm (wide) and 350 mm (high), with the baling twine laying lengthwise, was cut along its length to reduce its width to approximately 300 mm. The cut agricultural bale was then inserted on its end into the lower portion of the cavity in the WH oriented, so the straw was parallel to the heat flow. The upper portion of the cavity was then filled with two layers of the 350 mm (long) by 150 mm (wide) by 150 mm (high) oriented straw bale prototypes. These bales were placed in the cavity, so the straw was perpendicular to the heat flow. This set setup was then instrumented for temperature, relative humidity, and additionally heat flow during a second series of the phase. Each series was in place and monitored for at least 4 weeks. During each phase, the room was in use by the students and faculty at the university.

3.2 Experimental results

Test 1

The recorded data from the LEC was evaluated based on environmental phases as shown in Table 1 below.

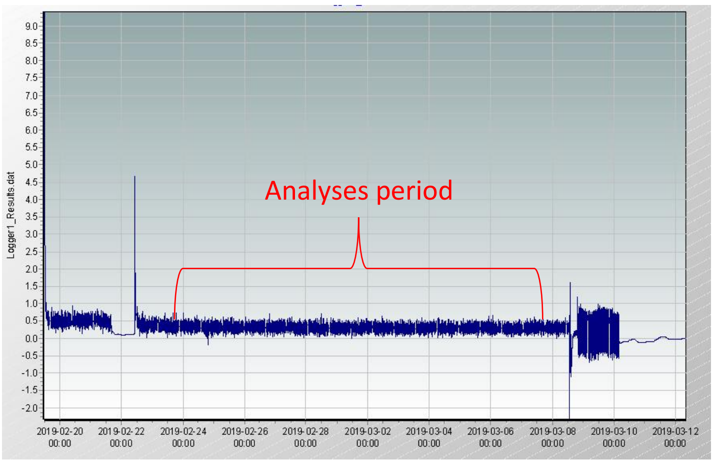
Table 1: LEC settings

Phase	# days	Start	End	Indoor		Outdoor	
		Date	Date	Temp. (°C)	RH (%)	Temp. (°C)	RH (%)
Phase 1	17	19/02/2019	08/03/2019	10	0	30	0
Phase 2	18	08/03/2019	26/03/2019	21	70	5.0 – 12	61 - 88
Phase 3	11	26/03/2019	06/04/2019	21	50	28	48

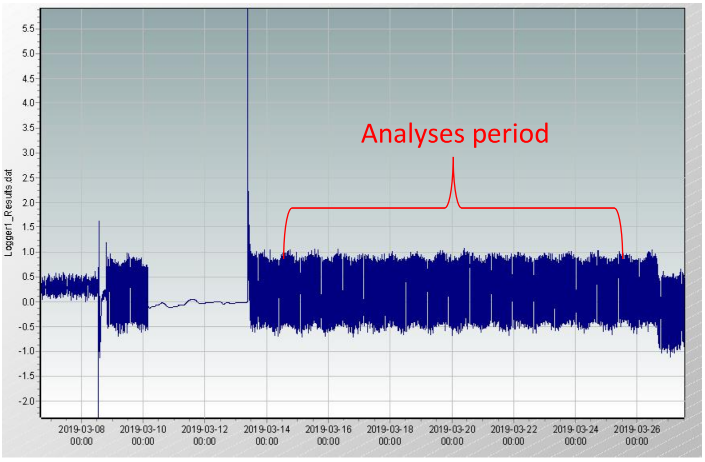
The data from the LEC was continuously recorded throughout the duration of the testing period. During the testing, there were power outages and equipment malfunctions that disrupted the testing procedure. Therefore, all periods within 12 hours of these events were excluded from analysis as shown in Figure 5a-c. Table 2 provides a summary of the calculated U-values for the first three testing periods of each prototype.

Table 2: LEC results

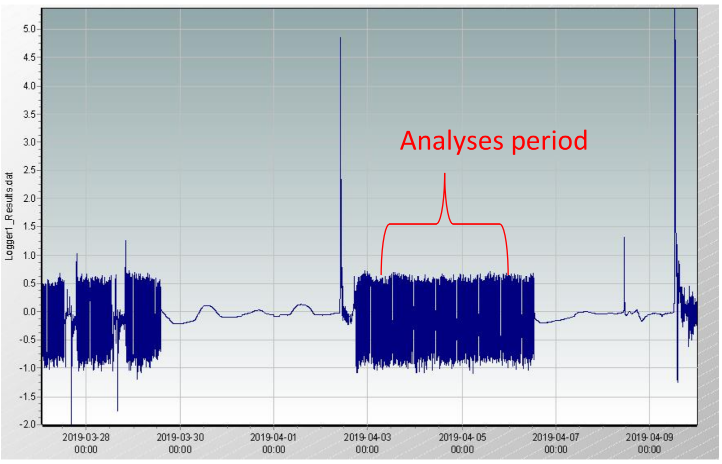
Prototype	Description	U-value (W/m2K)		
		Phase 1	Phase 2	Phase 3
Prototype 1 (Maize pith)	6 layers each having approximately 22 - 25 mm thickness. Gaps filled with broken pieces of the "board"	0.272	0.223	0.287
Prototype 2 (Duvet)	3 layers folded and stapled to each side of the stud bay	0.282	0.237	0.277
Prototype 3 (Oriented straw)	Stacked bundles each 150 x 140 mm (height x depth). Gaps filled with loose straw	0.321	0.263	0.326



a. Phase 1 (representative Heat Flux graph)



b. Phase 2 (representative Heat Flux graph)



c. Phase 3 (representative Heat Flux graph)

Figure 5. Example of observed heat flux

Test 2

The three locations monitored by the TinyTag sensors are represented in the graph in Figure 6. These radial graphs represent the various stages of temperature and RH through the thickness of the insulation with respect to time (rotating counter clockwise).

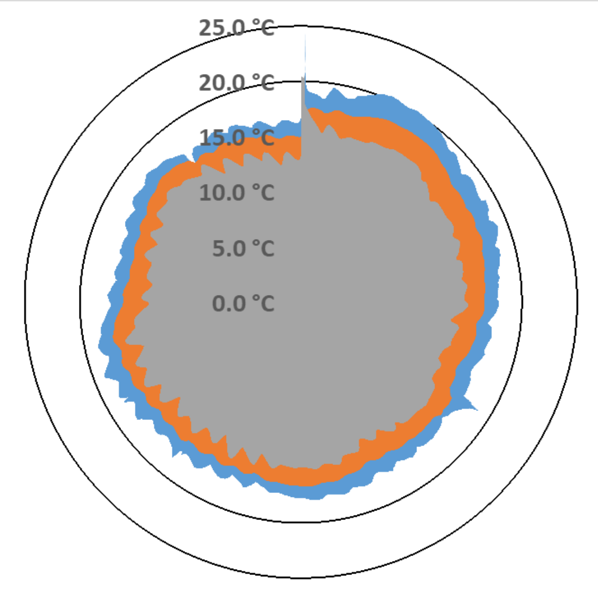
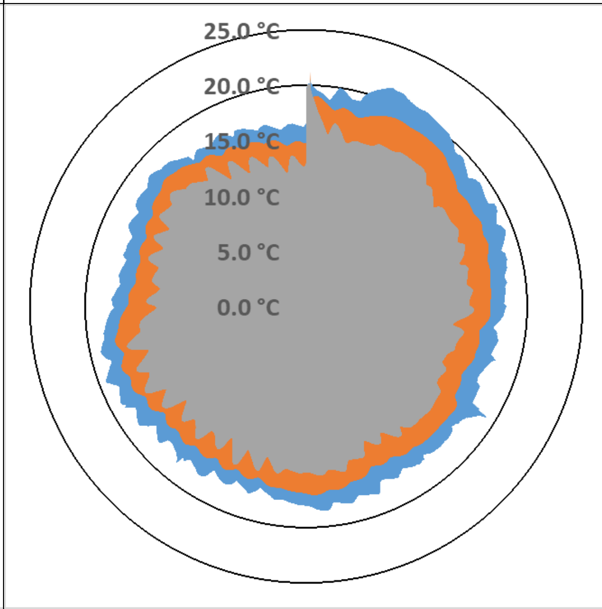
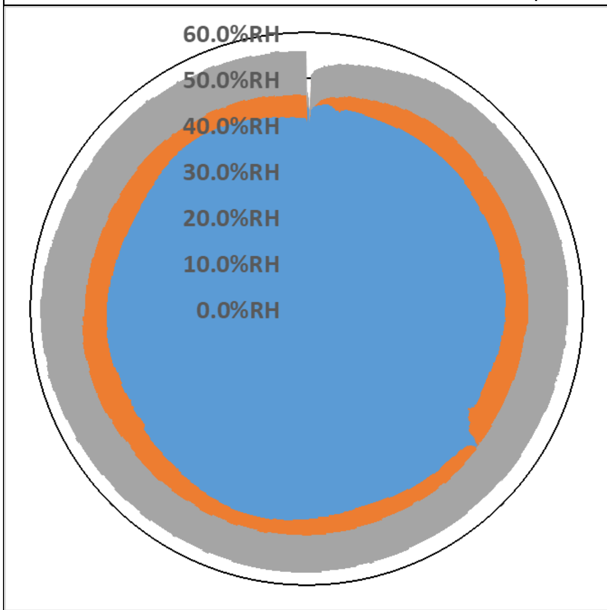
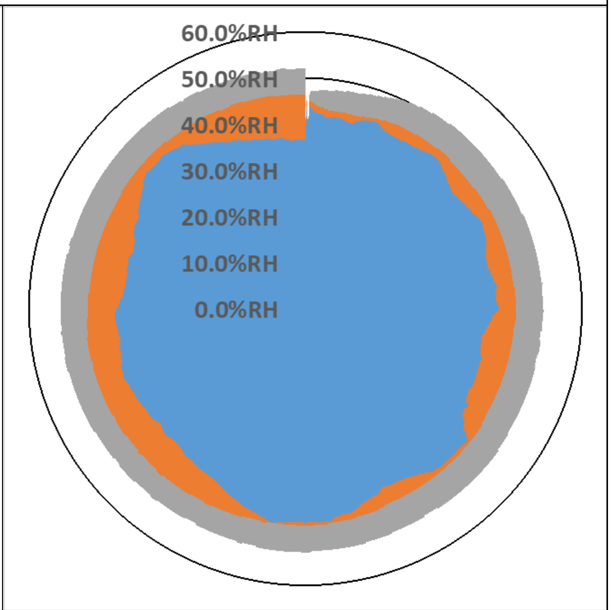
<table>
<tr><td>Agricultural straw bales</td><td>Protoyope 3 – Oriented straw bales</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Temperature variation</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Relative Humidity variation</td></tr>
<tr><td></td><td>Interior face of insulation</td></tr>
<tr><td></td><td>Centre of wall cavity</td></tr>
<tr><td></td><td>Exterior face of insulation</td></tr>
</table>

Figure 6. Temperature and RH through the wall cavity

It can be seen that while both versions of straw insulation had similar performance, the Prototype 3 bales fluctuated more and retained less moisture.

The second phase deployed heat flux plates to investigate potential *in-situ* λ-value variations. To facilitate the installation of the heat flux plates, a thin layer of rapid setting grout was applied centrally to the uneven surface of each of the straw sections. Unfortunately, the grout interfered with the results, likely influenced by the absorption of moisture, delayed curing, or inadequate surface contact.

4. Conclusions

Echoing the initial results from the testing of the raw materials and Prototype 3, the oriented straw performed only slightly below that of the industry standard of mineral wool as did all the prototypes. In the LEC demo, the maize (Prototype 1) performed marginally better than the duvet and straw prototypes (Prototypes 2 and 3 respectively) as related to thermal transmittance. It is only in the presence of continuing elevated humidity that Prototype 1 falls slightly below that of Prototype 2.

The field demonstration at the Waste House (WH) reinforces the earlier presented findings of the improved benefits of orienting the straw against the elements (perpendicular to the heat flow).

These demonstration programs have provided evidence to the viability of the three prototypes insulating potentials. More detailed long-term research is recommended to capture full structure and air quality performance.

The SB&WRC project is part of the Cross Border European Territorial Cooperation (ETC) Programme Interreg VA France (Channel) England and benefits from financial support from the ERDF (European Regional Development Fund).