SB&WRC Project

R&D Protocol – Prototype 2

September 2018

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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1. Introduction

The SB&WRC project aims at designing and producing 3 prototypes of thermal insulation materials for buildings, made from bio-based and waste-based raw materials. These 3 prototypes will be produced respectively from agricultural coproducts (wheat and corn stems) and textile waste (from duvets). Developed materials should have a carbon footprint which is at least 25% lower than that of conventional insulants, such as glass wool or rock wool. The overall objective of this project is to propose new solutions, using waste and agricultural co-products, to reduce CO_2 emissions of the construction industry and to preserve natural resources.

This document presents, as a first step, the methods of testing and characterisation of the textile waste material selected in Work Package 3 for the production of prototype 2, namely: duck feathers and polyester. A physical characterisation of these raw materials was carried out in order to determine their water contents, their densities, their water absorption as well as their characteristic temperatures. Work package 5 focuses on the production and characterisation of prototype 2: an insulant based on polyester waste or duck feathers. In this context, this document presents in a 2nd time, the manufacturing procedure of this prototype and then its thermal characterisation protocol in climatic chambers.

2. Characterisation of raw materials

2.1 Bulk density

Bulk density was determined by using helium pycnometer (AccuPyc 1330_ micromeritics). This method enables the precise measurement of the sample's volume. It consists in introducing helium into a reference chamber with a known pressure and then allowing it to expand into the chamber containing the sample. The drop in pressure in the reference chamber is then measured. The sample volume may then be determined according to Mariotte's law:

$$V_s = V_c - \frac{P_2 - P_a}{P_1 - P_a} V_2$$

whereby:

- P_1: gas pressure in the reference chamber (Pa);
- P_2: gas pressure in the expansion chamber (which contains the sample) (Pa);
- P_a: atmospheric pressure (Pa);
- V_2: expansion volume (cm^3);
- V_c: chamber volume (cm^3);
- V_s: sample volume (cm^3).

Bulk density is then given by the following equation: $\rho_b = \frac{m_s}{V_s}$; with ρ_b being the density and m_s the sample's mass.

2.2 Water content

The test consists in drying the sample in a proofer at a temperature of 40°C until the mass stabilises. Water content corresponds to the registered loss of mass. It is calculated according to the following equation:

$$W(\%) = \frac{M_w - M_d}{M_d} \,.100$$

With M_w being the mass of the wet sample and M_d the mass of the dried sample.

2.3 Water absorption

This test is derived from an experimental protocol developed by the RILEM TC 236-BBM group. The procedure used to measure the water absorption of the different materials is as follows:

1. Dry the sample at 40°C until a mass variation lower than 0.1% is obtained over a 24 hours period;
2. Immerse completely a plastic micro-perforated bag in water;
3. Place and attach the bag in a centrifuge and let it turn for 30 seconds at 500 RPM, then note the bag's mass;
4. Weigh the mass (M_0) of the material and place it in the bag;
5. Immerse completely the bag filled with the material in water for 5 minutes;
6. Take the bag out of the water, place it in the centrifuge and let it turn for 30 seconds at 500 RPM;
7. Weigh the spin-dried bag and note the mass M_1 (5 min);
8. Repeat steps 5, 6 and 7 for other samples for different immersion durations;
9. Calculate the water absorption according to the following equation:

$$M(t) = \frac{M_t - M_0}{M_0} \,.100$$

2.4 Characteristic temperatures

Characteristic temperatures are determined by means of a Netzsch differential scanning calorimeter DSC STA 449 F1 apparatus, under nitrogen flow, using an aluminium crucible. The samples are maintained at 20°C for 5 min and then heated up to 500°C at a rate of 20°C.min^{-1} (dynamic scan).

3. Production of mini-prototypes

3.1 Introduction

The University of Brighton (UoB) were responsible for developing eight 'mini-prototypes' measuring 300x300x100mm. These prototypes were constructed primarily from the waste bedding material gathered in partnership with Veolia UK at their HWRS in Worthing Sussex UK in October 2017. Results of this process were posted on the Construction 21 website. In summary the material that was gathered comprised bedding in the form of duvets and pillows. Here is a brief summary

- Veolia segregated pillows and duvets entering Household Waste Recycling Site for a week - 3,000 litres – 52 items.
- University assessed composition and status.
- Stuffing either: polyester (75%) or natural feathers (25%).
- Covers: Mix of polyester and cotton in variable amounts or occasional polypropylene.
- Status: On observation 50% of sample seemed in good quality – potentially reusable.

3.2 Construction specification of mini-prototypes

The University of Brighton team has over 30 years experience in the UK construction industry. Drawing off this, we endeavoured to design the mini-prototypes, which may be suitable as insulation in timber framed housing in the UK and France, so that the construction systems would mimic the types of material often used in this sector. The polyester material was always detailed to perform as a non-load-bearing insulation quilt, however we did develop a rigid board to house loose feather comprising the very same feathers compressed together and stuck with Jesmonite.

We have set out below a description of each of the eight 'mini-prototypes' that were delivered to the laboratories of our colleagues at ESTIC Caen on 27th April 2018.

Mini Prototype Number	Size	Purpose	Insulation Material	Binder	Outer Material	Binder	Top Covering
1	300x300x100mm	General Tests	Feather	No	Feather	Marseille Soap foam	None
2	300x300x100mm	General Tests	Feather	No	Feather	Jesmonite	Breather Membrane
3	300x300x100mm	General Tests	Polyester	No	OSB Timber Board	n/a	Breather Membrane
4	300x300x100mm	General Tests	Polyester	No	OSB Timber Board	n/a	Featherboard Render. Waste agg in lime
5	260x70x12mm	Fire Tests	Feather	Jesmonite	No	No	No
6	260x70x60mm	Fire Tests	Feather	No	Feather	Marseille Soap foam	No
7	220x50x50mm	Fire Tests	Polyester	No	Breather Membrane	No	Breather Membrane
8	220x50x50mm	Fire Tests	Feather	No	Breather Membrane	No	Breather Membrane

In addition below are notes of the specialist materials used to bind the feathers, aggregates etc., used to manufacture prototypes 1,2 & 4.

2.2.1 Mini-Prototype 2 Version 1

Specialist Material: Outer-coating of feathers in a Marseille soap (foam) binder.

Method

- Dissolve 75ml of Marseille soap granules (UK supplier: www.mikewye.co.uk) in 1ltr of warm water.
- Use a mechanical whisk to create a dense foam
- Mix the foam with the feathers and 'laminate' into a mould (300 x 300 x 100mm). The foam will stiffen after 24 hours allowing the material to be lifted from the mould
- Allow 1 week for the material to dry

2.2.2 Mini-Prototype 2 Version 2

Specialist material: Featherboard material

Method

- Mix 1500g of Jesmonite powder with 600g of Jesmonite liquid (UK supplier: www.industrialplasters.com – Product: AC 100).
- Add 5 lts of dry feathers to the Jesmonite mix.
- Cast the mix into a mould (300 x 300 x 12mm).
- De-mould can be after 4hrs.
- Allow the material time to dry.

2.2.3 Mini-Prototype 2 Version 4

Specialist Material: Waste render

Method

- Pass the waste construction aggregate through a 5mm sieve
- Calcine oyster shells up to 1000C in a kiln to create quicklime
- Blend the aggregate and dry quicklime together at a ratio of: 3 aggregate – 1 lime
- Add water to the dry mix in order to slake the quicklime with the aggregate. There will be a hot reaction as the quicklime slakes.
- Add enough water to create a workable mortar. This produces a much better mortar than using pre-slaked lime materials.
- In the UK, this technique is known as a 'Hot - Mix' lime mortar
- Apply the lime render to the Featherboard
- Allow the render time to cure/dry

4. Characterisation of mini-prototypes

4.1 Thermal conductivity measurements

The measurements of thermal conductivities were carried out using a HFM (Heat Flow Meater) apparatus. The measurements are made in steady state by imposing a temperature gradient, thus, the heat flow circulates vertically, through the sample, from the hot plate to the cold plate (Figure 1).

The tests carried out were conducted at different average temperatures which are: 0, 10, 20 and 30 C.

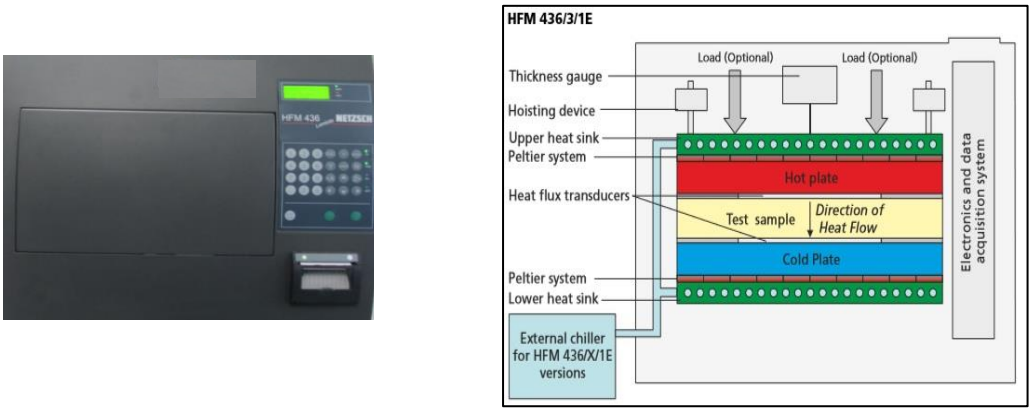

Figure 1: Device and measuring principle of HFM 436

4.2 Fire reaction tests

Fire reaction tests are conducted according to NF EN ISO 11925-2 standard. This test allows to determine the ignitability of a product by direct incidence of a small flame (2 cm of height). It consists in exposing the sample during 15 s to a flame and observing the ignition of the specimen and its damage.

5. Production of prototype 2

Prototype 2 is an insulating material made of textile waste from duvets (polyester) associated with an OSB timber board. It will be used for internal insulation for walls. The targeted thermal conductivity is equal to 0.06 W.m-1.K-1. This value can be reached by changing the density of polyester.

The manufacturing of the prototype consists in:

- The assembly of OSB timber pieces to form the box;
- Filling the OSB timber box (Figure 2) with polyester.

The dimensions of the prototype depend on thermal testing and they are 2000 x 2000 x 100 mm.

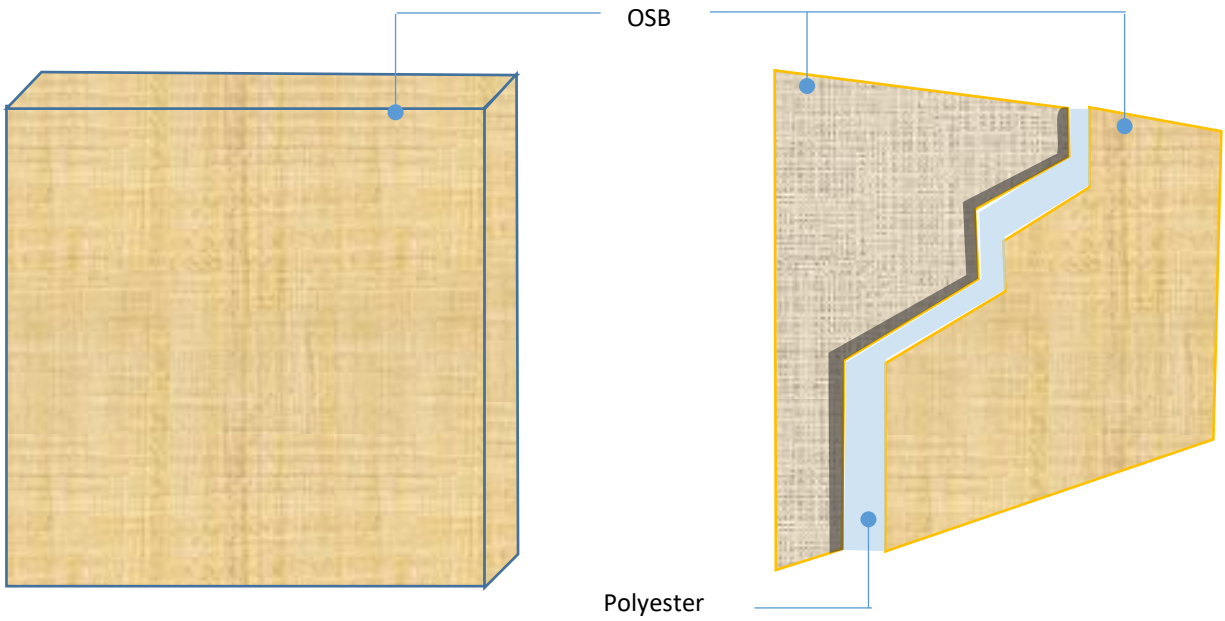

Figure 2: OSB timber box

6. Prototype characterisation

6.1 Thermal properties

In this project, the thermal performance of the prototype 2 (polyester + OSB) will be studied. To determine the thermal properties of this prototype on a real scale, a Hot Box apparatus will be used. With this apparatus, a wall to be tested is positioned between two ambiences, one hot and the other cold. Once the steady-state is reached, measurement of the heat dissipated to keep a constant temperature gradient through the specimen wall is performed. Thanks to these data, dissipated power and temperature difference between the two atmospheres, thermal performance of the wall can be calculated. So, the prototype thermal resistance can be determined by using the following relationship:

$$R = \frac{A.(T_h - T_c)}{Q}$$

where:

- R: prototype overall thermal resistance, m^2.K/W.
- A: metering box opening area, m^2.
- T_h: environmental temperature at the hot side (metering chamber), °C.
- T_c: environmental temperature at the cold side (climatic chamber), °C.
- Q: rate of heat flow throw the prototype to be tested, W.

Once the prototype thermal resistance is known, an effective thermal conductivity can be calculated using the following relationship:

$$\lambda = \frac{L}{R}$$

- λ: prototype effective thermal conductivity, W/(m.K).
- L: prototype thickness, m.

In this work, a measuring system is developed by following the ASTM C1363-11 and NF EN ISO 8990 norms. In Figure 3, a typical scheme of a Hot Box apparatus is shown.

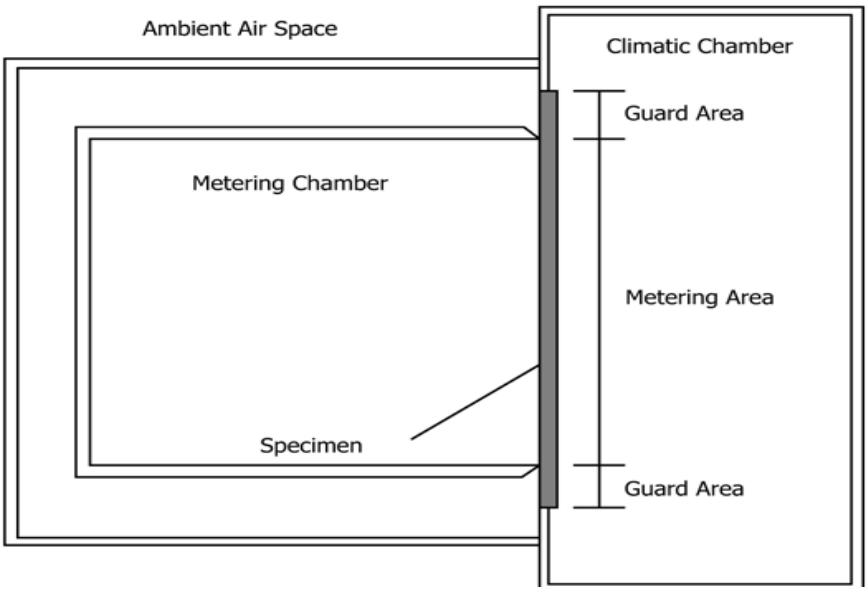

Figure 4: Typical Hot Box apparatus schematic [ASTM C1363]

Our measuring system consists of two climatic chambers separated by a polyurethane wall. The separating wall contain a 2 m x 2 m opening where the sample to characterize should be placed. A metering chamber having an opening of 1.27 m x 1.46 m was built. A heating system was placed inside this metering chamber and powered by a DC power supply. Temperatures in both sides of the wall are measured by T type thermocouples which are linked to a data acquisition system. A LabVIEW program was created in a computer in order to perform temperature regulation, data acquisition and signal processing. An overview of the experimental setup is represented in Figure 4.

Figure 3: Overview of the experimental device used for thermal characterization of the prototype 2

7. Annex: materials specification

Produced by Local Works Studio for University of Brighton

- Feathers: Sourced from waste duvets
- Polyester: Sourced from waste duvets
- OSB timber board: Orientated Strand Board – common construction board material
- Tyvek: Water-proof, breathable membrane used in construction.
- Jesmonite: Acrylic modified gypsum composite used as a binder for external and internal architectural castings. Water based, solvent and VOC free, fire-resistant, lighter weight than concrete and stone.
- Marseille Soap: Traditional hard soap made from vegetable oils. Used in construction to seal, waterproof and clean traditional polished lime plaster finishes.
- Waste Aggregate: taken from demolition work at University of Brighton. Mix of crushed bricks and concrete. Sieved to 5mm to dust.
- Lime: Binder for render made from calcined oyster shells.

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).