SB&WRC Project

Technical Fact Sheet: Prototype 3 made from wheat straw

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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Summary

This report synthesises the experimental results obtained for Prototype 3 made from Wheat Straw within the SB&WRC project.

The aim of this research is to obtain and investigate materials with a carbon footprint that is at least 25% lower than that of conventional insulants, such as glass wool or rock wool, while also aiming to produce insulants competitive with traditional or industry standard insulating materials, in terms of energy efficiency, indoor air quality, durability, and cost-effectiveness.

The common rectangular agricultural baling process collects the straw into layers of approximately 100 mm wide across the bale, sometimes referred to as flakes. The flakes are then continuously compressed together along the length of the final shape. However, the use of traditional bales orients the straw flakes in the least efficient direction for thermal resistance, with the length of the stem folded over in oriented in the same direction as the heat flow.

In the prototype, the straw was intentionally orientated perpendicular to the heat flux through the wall. This is in order to optimise the thermal insulation properties of the material, as previous testing has shown that this orientation minimises thermal conductivity, allowing thinner walls compared to conventional straw bale walls.

The prototype is to be used as a non-load-bearing material for a wall application. The targeted density was initially set at around 110-120 kg/m^3, to provide robustness in transport, stability and fire resistance, which is close to the minimum density recommended by Jones (2002). The proposed dimensions for the prototype were initially 600 x 600 x 100 mm, but evolved into 400 x 150 x (140 or 80) mm to conform to nominal dimensions of typical timber construction.

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1. From resource to prototype

Straw bale wall construction, in which bales are dry-stacked and used for thermal insulation in both loadbearing and non-loadbearing walls, is now over hundred years old. The earliest straw bale structures developed in Nebraska, USA. In modern construction, straw bales offer a low carbon and renewable alternative to other insulation materials. However, traditional bales (Figure 1), produced as an agricultural co-product rather than for construction purposes, orient the individual straws in the least efficient direction for optimizing thermal insulation value.

This research is aimed at improving thermal efficiency and constructability of wheat straw when used as a non-load bearing insulation material by producing bales in which the straws are oriented parallel to the exposed surface and in bale sizes more suited to modern construction (Figure 2).

Figure 1. Agricultural wheat straw bales

Figure 2. Oriented re-baled straw

There have been many challenges in producing a full-scale prototype that satisfies the above criteria. First is simply orienting the straw itself when extracted from the traditional bale. As the straw has been folded and compacted previously, much of the straw is broken or in shorter sections than originally desired. As the straw is removed and loosened, a considerable amount of waste is produced. The size of the large agricultural bales are such that these smaller particles are held firmly in place and help to produce a densely packed bale. The re-baling process limits the number of smaller particles that can be contained, resulting in either an unstable bale (falling apart during handling) or extremely dense with a significant amount of straw stem sections not oriented in the intended direction.

By sifting through the loosened straw and loading into the horizontally placed chamber, a series of large straw stem layers may be interspersed with some of the smaller particles. As the oriented bale is formed, new small 'flakes' are produced encapsulating the finer pieces and producing a more stable and optimally oriented bale

Sectioning the bale and finding a pattern for loading into the prototype form was one of the first challenges to overcome. Following this it has been necessary to determine the precompression loads and slenderness limits required for producing a newly formed stable insulation bale. Following various trials these challenges have largely been overcome, and the prototype manufacturing process has been streamlined, although it still remains a lengthy process.

2. Properties of the resource

2.1 Densities

Experimental procedure

- *Bulk density* (kg.m^{-3}): the density of a material is defined as the ratio of its mass over its volume. The bulk density of the straw particle can be measured by Mercury Intrusion Porosimetry (MIP), though the bulk density of loose straw (or tapped density) is generally more useful and can be measured according to Amziane et al. (2017). The 'tapped' density is obtained in such that a container of material is 'tapped' during and after filling, marking the levelled off height and then refilling container with water to determine final volume. Lam et al. (2007) suggest the alternative of tapping a graduated cylinder 5 times and refilling, repeating until overflowing and then stricken off prior to obtaining mass and calculating density.

- *True density* (kg.m^{-3}): density of the solid part of the straw can be measured with a helium pycnometer. This is calculated from the pressure drop of a known volume of Helium that is introduced into a chamber containing a known mass of material.

- *Porosity* (%): represents the void fraction of a straw particle. It can be estimated by means of MIP, derived from bulk and true density, according to BS 1902:3 (2016). This is calculated from the pressure obtained while forcing Mercury into an evacuated chamber containing a material.

- *Moisture content* (%): is calculated from the gravimetric measure of the loss of mass after drying at 103°C (until a constant mass is reached) over the mass of the dried material. This test is done according to EN 322 (1993).

Table 1 provides a summary of the above experimentally determined values for the raw materials investigated.

Experimental results

Table 1. Summary of measured raw material densities

Wheat Straw	Bulk density		Apparent density[1]		True Density[2]		Average pore diameter		Porosity			Moisture content	
									cut (1 cm)		ground (<1mm)		
	kg.m^{-3}	CoV (%)	kg.m^{-3}	CoV (%)	kg.m^{-3}	CoV (%)	nm	CoV (%)	%	CoV (%)	%	%	CoV (%)
UK	290	4.01	2150	21.1	1430	0.62	157	9.41	85.0	3.45	79.3	10.8	3.81

[1] Apparent or particle density as determined from MIP, where the volume is determined as the solid volume of the particle including closed pores.
[2] True density calculated from true volume and mass as determined using a Helium Pycnometer and ground straw

2.2 Chemical properties

Experimental procedure

– *Thermogravimetric analysis* coupled to differential scanning calorimetry (TGA/DSC): measured according to BS EN ISO 11357-3 (2013). The heating rate is 10°C/min until 900°C, under nitrogen atmosphere.

Thermogravimetric analysis (TGA) is a method of thermal analysis in which the mass of the sample is measured over time as the material is heated or cooled. It can be used to help evaluate the thermal stability of the straw as well as the thermal degradation behaviour of the cellulose.

Experimental results

The onset temperature is the initial temperature at which mass begins to decrease. The max temperature is calculated by the first derivative of the TGA curve. The residual straw remaining at the end of the test is the Char and is reported as a percentage of the original mass. The obtained results are listed below and in Figure 3.

– T_{onset} = 310 °C
– T_{max} = 360 °C
– Char = 5.1%

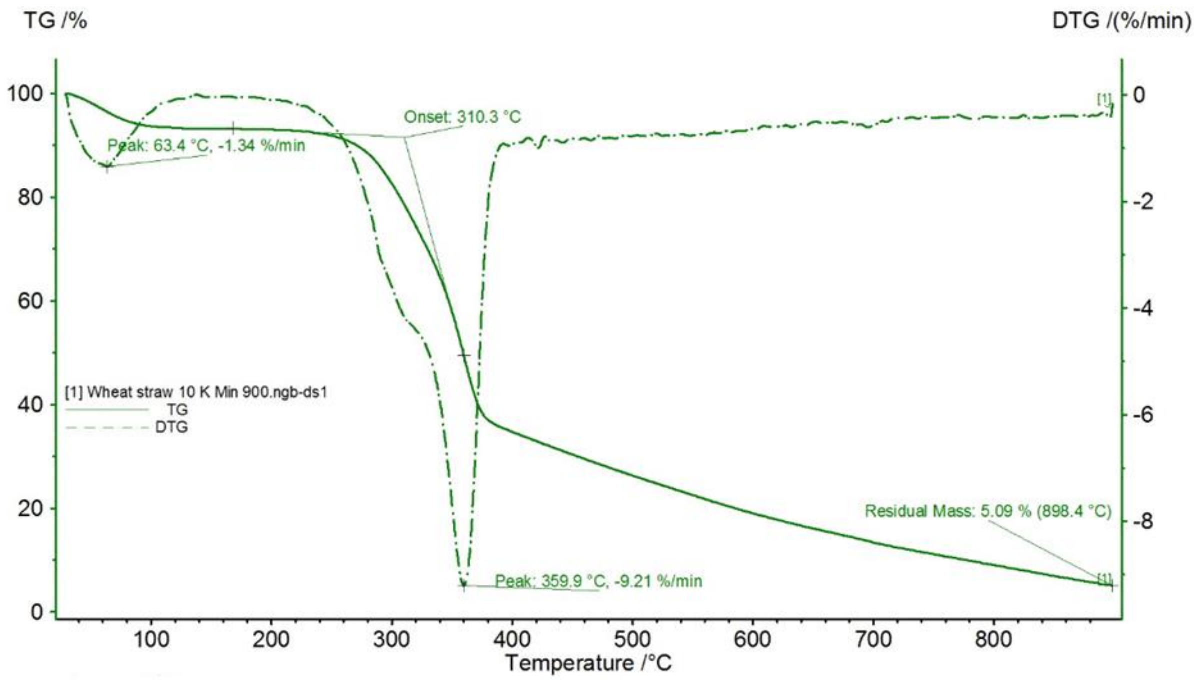


Figure 3. Graph of TGA results

2.3 Moisture and hydric properties (sorption-desorption isotherms, moisture content etc.)

Experimental procedure

- *Water absorption* (%): is the ratio of the increase in water over the dry mass of the material after a series of immersions of different times. This can be determined according to RILEM TC 236-BBM (Amziane, et al., 2017).
- *Sorption-desorption isotherms*: the gravimetric method can be used to determine the sorption capacity of a material. After drying at 50°C, the straw is placed in different relative humidity values (first increasing and then decreasing) while keeping a constant temperature. The moisture content of the material is calculated for each step. This is done with the Dynamic Vapour Sorption device (DVS), using the same procedure as Hill et al. (2010).

A summary of the water absorption results for the UK sourced straw is provided in Tables 2 and is shown in Figure 4.

Figure 5 displays the Isotherms obtained for the UK representative straw.

Experimental results

Table 2. Summary of moisture properties

Initial Rate of Absorption (IRA), (%)	56
Slope of the curve W(t) as a function of logarithmic time (K_1)	3.39
$WC_{24.hr}$ (%)	289

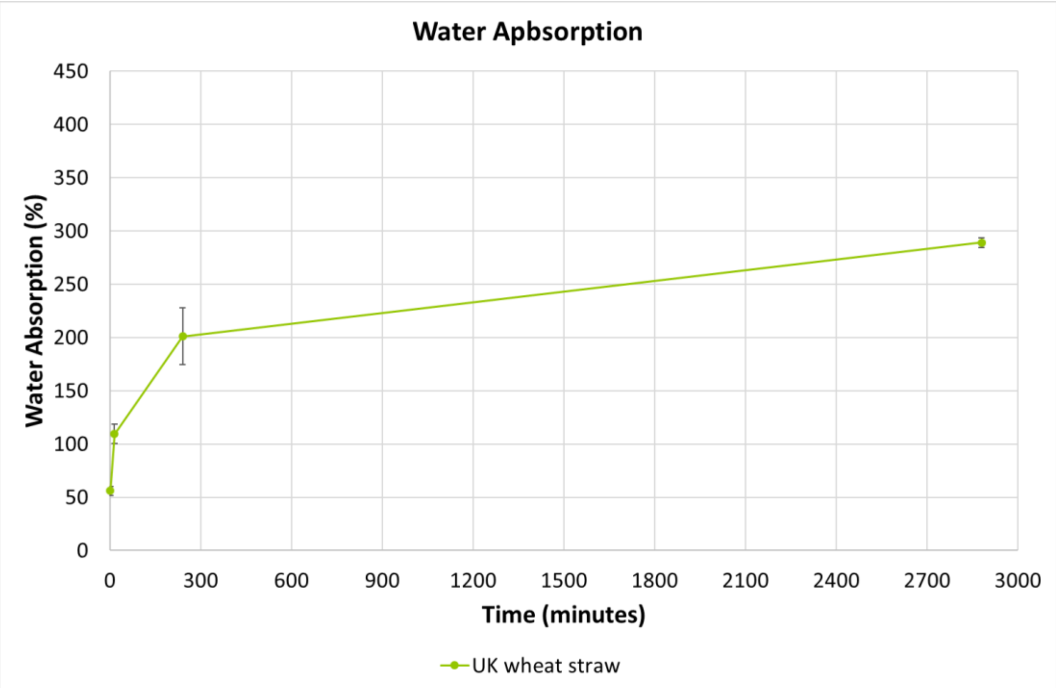


Figure 4. Water absorption for UK and FR sourced straw

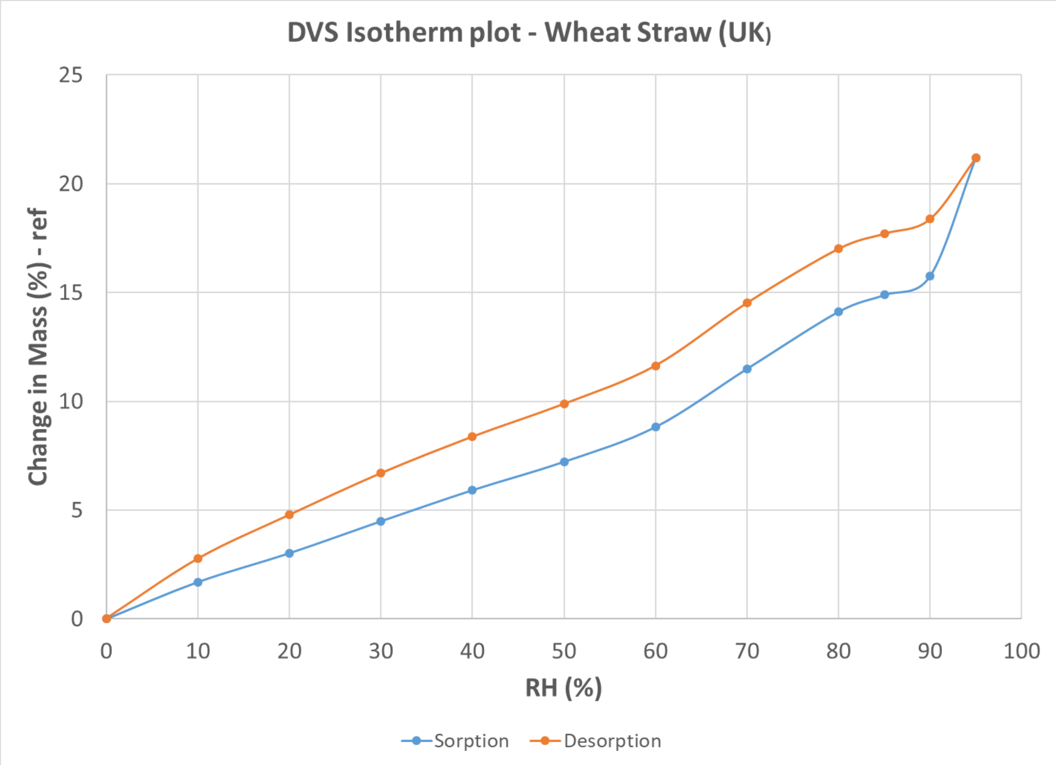


Figure 5. UK sourced wheat straw Isotherm

3. Physical properties of the prototype

3.1 Apparent density

Experimental procedure

- *Bulk density* (kg/m^3): defined as the ratio of mass over volume. Determined according to BS EN 1602 (2013).
- *Porosity* (%): is void fraction, calculated from the true density of the straw and the bulk density of the prototype.
- *Moisture content* (%): as measured by gravimetric method at the time of testing by drying random samples at 105 °C until stable mass is reached.
- *Structure*: can be assessed by CT scan (computerised tomography) which is a method combining many X-ray measurements to produce cross-sectional images.

Table 3 provides a summary of the physical characterization of the oriented straw prototype

Experimental results

Table 3. Summary of prototype 3 physical properties

Wheat Straw	Bulk density		True Density[2]		Porosity		Moisture content	
	kg/m^3	CoV (%)	kg/m^3	CoV (%)	%	CoV (%)	%	CoV (%)
UK	130	10.0	1292	0.50	89.9	0.50	30.9	10.1

[2] True density calculated from true volume and mass as determined using a Helium Pycnometer and ground straw

Computer Tomography (CT) enables a three-dimensional representation of the internal structure of a material. This was used in evaluating the finished directionality of the straw after producing the oriented straw prototype. Notice in Figure 7, that as the new bale is formed, a smaller series of 'flakes' begin to develop. Although there are still some smaller pieces of straw randomly oriented, the CT shows a highly directional bundle. This is further shown in the cross-sectional view in Figure 8 displaying the localized effect of the flake formation.

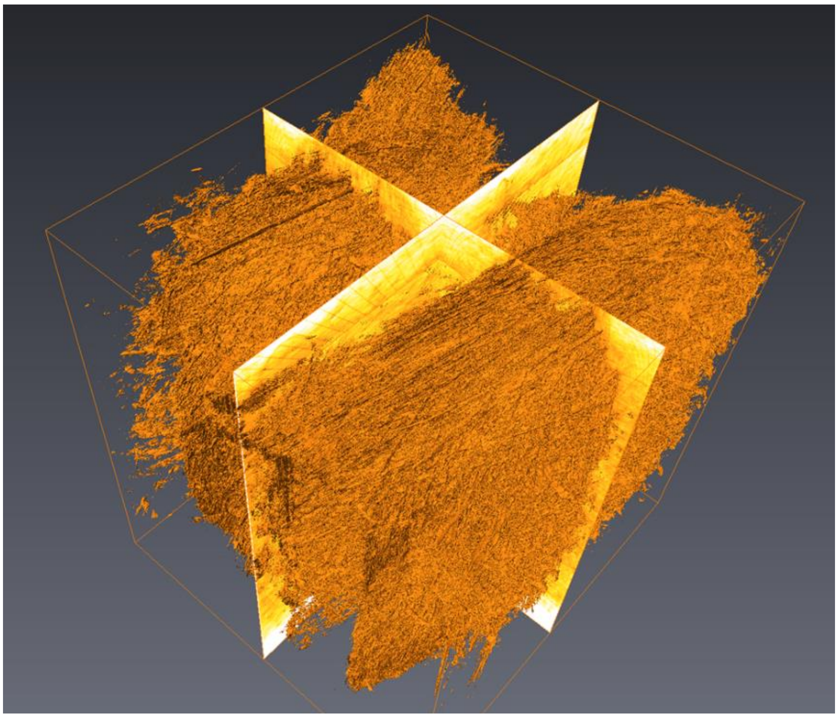


Figure 7. Three-dimensional representation of prototype 3

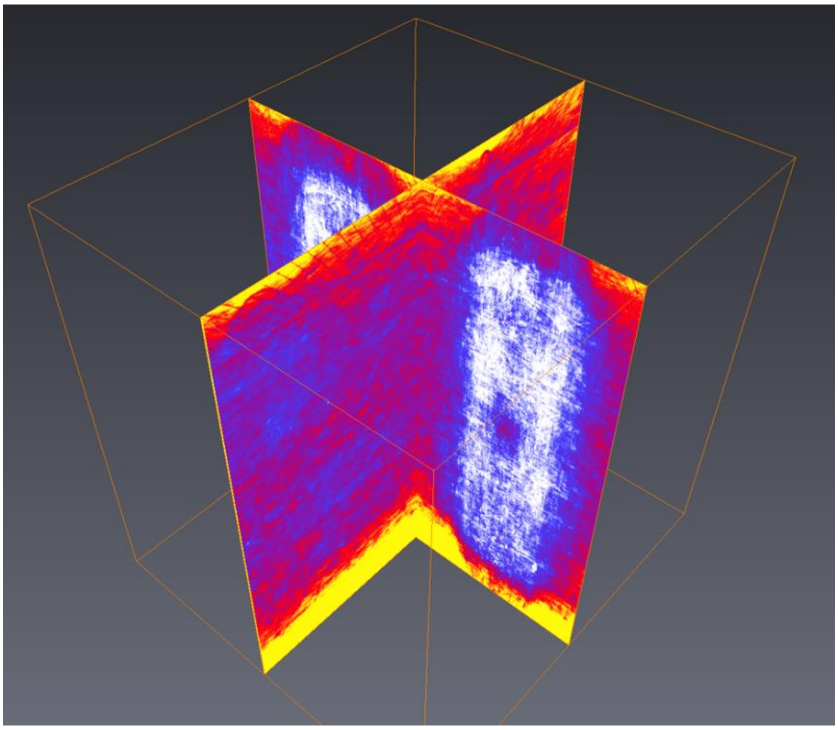


Figure 8. Cross section of prototype 3

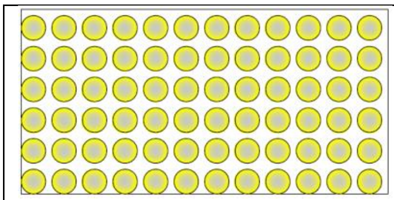
3.2 Mechanical properties

Experimental procedure

– *Compression resistance* (kPa): a force is applied at a given rate of displacement and the maximum stress supported by the specimen calculated. If no failure is observed before 10% strain, the compressive stress at 10% strain is calculated and reported. This is measured according to BS EN 826 (2013) – *Determination of Compression Behaviour*

The BS EN 826 methodology is applicable to thermal insulating products and can be used to determine the compressive stress for applications in which insulation products are only exposed to short-term loads. This procedure is generally reserved as an A- B type comparison test, that is, it is not recommended for design but rather for quality control purposes and material performance comparison.

As the oriented straw prototype is formed, the straw is deformed as the airspace around the stems is reduced. This process produces an anisotropic bale relative to the formation load. Figure 9 provides a graphic reference of this process. To capture this property, the compressive resistance was tested both parallel and perpendicular to the production load.

	Straw is loaded into chamber

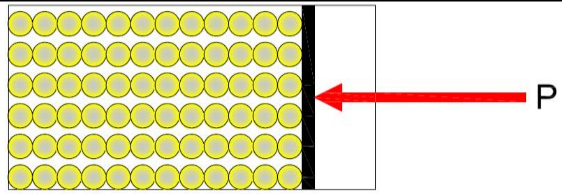
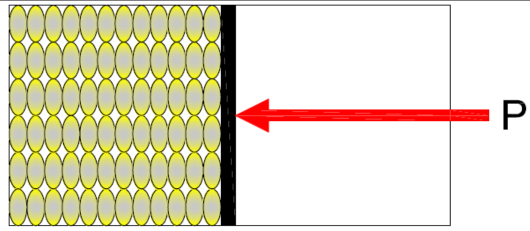
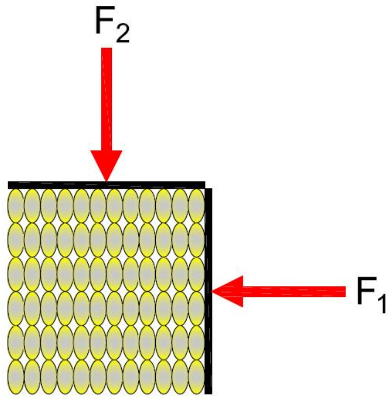
	Straw is compressed inside of chamber
	Straw begins to deform under high compressive production load (P)
	Compression resistance testing was completed for two separate series of randomly selected prototypes. The first series was tested with loading (F_1) parallel with the production load (P). The second series was tested with loading (F_2) perpendicular with the production load (P)

Figure 9. Production and testing load directions

Table 4 provides a summary of the compressive resistance of the oriented straw prototype and Figure 10 displays the load-deformation curve from each series tested.

Experimental results

Table 4. Summary of compressive behaviour for prototype 3

Direction of compression relative to bale formation loading	$\varepsilon_{10\%}$		$\varepsilon_{20\%}$		$\sigma_{10\%}$		$\sigma_{20\%}$		$E_{apparent}$	
	%	CoV (%)	%	CoV (%)	kPa	CoV (%)	kPa	CoV (%)	kPa	CoV (%)
Parallel	9.99	0.043	20.0	0.022	13.3	5.32	28.9	13.5	78.9	19.9
Perpendicular	9.99	0.038	20.0	0.019	16.1	11.7	32.9	16.6	118	23.1

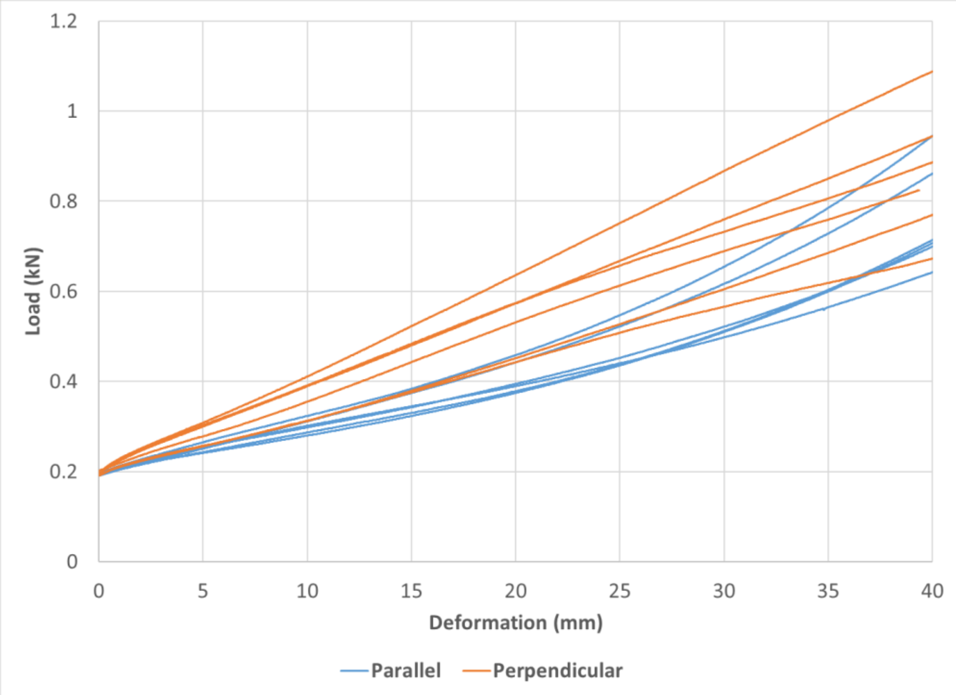


Figure 10. Load-Deformation graph for straw prototype in two direction

The Load deformation curves shown in Figure 10 show a clear trend in the compressive resistance performance of the oriented bale. This translates to the prototypes function in the field and indicates that directionality of the installed prototype is important.

4. Hygrothermal properties of the prototype

4.1 Thermal conductivity and heat capacity

Experimental procedure

– *Specific heat capacity* (J/kg·K): thermal storage property corresponds to the amount of energy needed to change the temperature of 1 kg of the substance by 1°C, measured according to ASTM C1784 (2013) and Ruuska et al. (2017).

– *Thermal conductivity* (W/m·K): density of heat flow rate is measured for a given temperature difference by means of a heat flow meter, according to ISO 8301 and EN 12664. The test will be done at the dried state but also might be done depending on the moisture.

Small bale sections with lengths of 40 and 80 mm were taken from 100 mm square prototypes and dried at 105°C until stable mass was reached. These were then placed in a conditioning chamber at 23°C and 50 %RH for a minimum of 24 hours. Within the chamber, the samples were tested using the TPS 3500 Hot Disk Thermal Constants Analyser to determine thermal conductivity and specific heat (Figure 11). Table 5 provides a summary of these results.

Figure 11. Hot Disk setup for straw thermal conductivity parallel to the heat flow

Experimental results

Table 5. Summary of thermal conductivity of straw oriented parallel and perpendicular to the heat flux

Property		Direction of straw relative to the heat flow	
		Parallel	Perpendicular
Thermal Conductivity – λ	$W/_{m \cdot K}$	0.086	0.075
Specific heat capacity - c	$J/_{kg \cdot K}$	0.238	0.157

The results presented from the Hot Disk clearly indicate a benefit to the directionality of the straw orientation. The values obtained in this test are slightly higher than expected and likely due to the smaller samples sizes and in this case are more representative of the raw material rather than the prototype. The limiting size of the sensor also restricts the area of tested material.

4.2 Thermal transmittance/Resistance

Experimental procedure

– *Thermal conductivity* (W/m.K): density of heat flow rate is measured for a given temperature difference by means of a heat flow meter, according to ISO 8301 (1991) and EN 12664 (2001).

Prototype oriented straw bales were produced at 100 x 100 x 400 mm. The bales were then reloaded into the press and re-compressed with the same formation load of 4-tonne. This was done to permit the bundling on four bales to produce a 'package' type bale representative of potential preconfigured distribution product. Additional 'packages' for testing purposes were built by cutting the oriented straw bales down to 100 mm lengths, producing 100 x 100 x 100 mm bale sections. The two end lengths of 50 mm were discarded leaving three sections 100 mm in length from each of the originally produced oriented straw prototypes. These bale sections were loaded into the press rotating their direction by 90 degrees so that the straw was oriented parallel to the intended heat flow and again re-compressed a 4-tonne load before being tied off (Figures 12 and 13). Each of these bale packages was dried at 105°C until stable mass was reached and then then tested using the Fox Instruments Heat flow meter for a minimum of three consecutive tests. After equilibrium was reached and a thermal conductivity calculated with an acceptable percentage of error (<3%), the bale packages were conditioned at 23°C and 50 %RH before repeating the tests. At each stage the bundles were wrapped in thin plastic wrap to help maintain conditioning during the tests (Figure 14). Table 6 provides a summary of the tests conducted for two straw samples in both the parallel and perpendicular directions with respect to the heat low.

Figure 12. Bundled sections – parallel to the heat flow

Figure 13. Bundled sections – perpendicular to the heat flow

Figure 14. Bundled prototypes (oriented perpendicular to the heat flow) in the heat flow meter

Experimental results

Table 6. Summary of heat flow meter tests for straw oriented parallel and perpendicular to the heat flux

Property		Direction of straw relative to the heat flow			
		Parallel		Perpendicular	
		1	2	1	2
Thickness	mm	102	102	99.4	99.0
Thermal Conductivity – λ	$W/_{m \cdot K}$	0.078	0.078	0.054	0.053
Deviation in 10 runs after >100 runs	%	3.22	2.66	1.05	0.29

The tests here provide supporting evidence of the directionality of the raw material as previously discussed as well as the translation of that property in the prototype. The increased performance of the larger scale prototype captures the overall performance in an isolated environment.

4.3 Water absorption coefficient

Experimental procedure

– *Water absorption coefficient* ($m^2.s^{-1}$): corresponds to the change in mass of the specimen of which the bottom surface is in contact with water, according to EN ISO 15148.

Sections of the oriented bale prototypes were placed in a pan with an internal rack providing an immersion depth of 5 mm (Figure 15). This level is maintained by adding water as required throughout the experiment. At the prescribed lengths of time, each sample is removed and blotted dry before measuring its mass. This test is modified from EN ISO 15148, in that due to the irregularities of the straw bales, the sides were not sealed.

Figure 15. Samples on rack for water absorption test

Experimental results

Table 7 provides a summary of the water absorption coefficients (Aw) for straw oriented parallel and perpendicular to the water surface. The graph in Figure 16 shows the variation in the performance of the samples.

Table 7. Summary of water absorption coefficient

Specimen (straw orientation)		Δm_{tf} kg.m^{-2}	A_w $kg/(m^2 \cdot s^{0.5})$
Parallel	A	15300	52.1
	B	20000	68.0
	C	17413	59.0
Perpendicular	A	8488	28.9
	B	15867	54.0
	C	14063	47.8

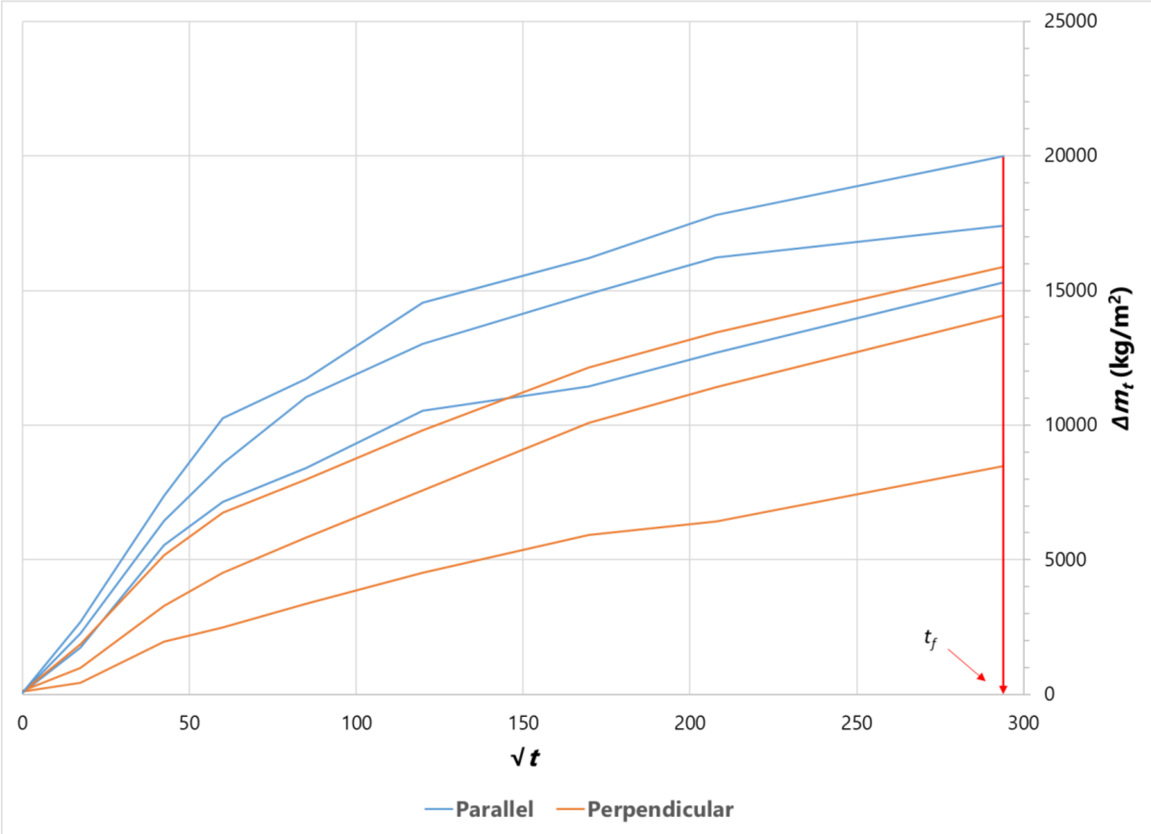


Figure 16. Type B graph (EN ISO 15148) of change in mass with respect to time

4.4 Adsorption-desorption (Moisture Buffer value)

Experimental procedure

– *Moisture Buffer Value* (MBV) (g.m^{-2}.%RH^{-1}): one surface of the material is exposed to a cyclic relative humidity which allows to assess a regular moisture adsorption-desorption content per unit of surface, according to ISO 24353 (2008).

Sections of the oriented straw bale prototypes were placed inside of 150 mm 5 sided clear Perspex cubes as shown in Figure 17 after conditioning at 23°C and 50%RH until stable mass was recorded. The prepared cubes were returned to the conditioned space to minimize any affects from handling during specimen preparation.

The mass of the cubes was recorded and then placed within the small environmental chamber for further conditioning for 12 hrs before a 12-hour cyclic program was initiated under the conditions stated in Table 8.

Parallel *Perpendicular*

Figure 17. Samples of straw in two directions for MBV

Table 8. Chamber settings as per ISO 24363:2008

Humidity conditions at 23 °C	Relative humidity (%)		
	Preconditioning	Moisture adsorption	Moisture desorption
		Step 1	Step 2
	63	75	50

The samples were placed in the climatic chamber for a period of 12 hours at 63% RH for a period of 12 hours prior to cycling through periods of 75 and 50% RH for a total of four cycles.

Experimental results

The four-cycle adsorption and desorption performance is displayed in Figure 18 for straw oriented parallel and perpendicular to the exposed surface. Table 9 shows the change in mass for the fourth cycle. The adsorption/ desorption content and Moisture Buffering Value (MBV) is provided in Table 10. Only one sample for each orientation was run for this test.

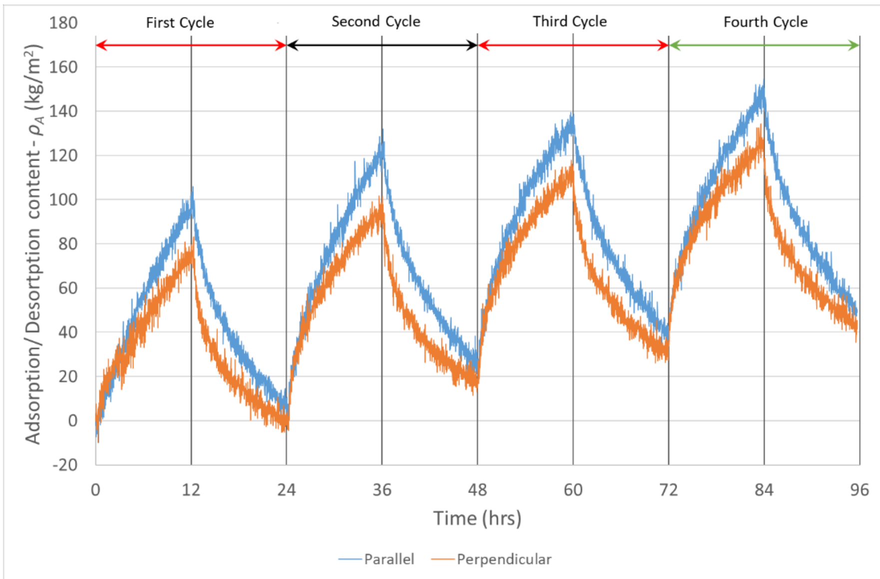


Figure 18. Moisture adsorption/ desorption over time for oriented straw bales

Table 9. Fourth cycle change in mass

	m_0	m_a	m_d
Parallel (g)	674	678	675
Perpendicular (g)	614	617	615

Table 10. Summary of cyclic results (after 4 cycles)

	Parallel		Perpendicular	
	Adsorption/ Desorption Content (g.m^{-2})	MBV (g/m^2·Δ%RH)	Adsorption/ Desorption Content (g.m^{-2})	MBV (g/m^2·Δ%RH)
$\rho_{A,ac}$	*115*	4.59	82.2	3.29
$\rho_{A,dc}$	100	4.00	71.1	2.84
$\rho_{A,sc}$	14.7	0.587	11.1	0.444

Where:

$\rho_{A,ac}$ - moisture adsorption content at the time of completion of moisture adsorption process of the fourth adsorption/desorption cycle.

$\rho_{A,dc}$ - moisture desorption content at the time of completion of moisture desorption process of the fourth adsorption/desorption cycle.

$\rho_{A,sc}$ - Difference between moisture adsorption/desorption content at the time of completion of the fourth adsorption/desorption cycle.

The Moisture Buffering Value can be subsequently calculated as 0.59 g/m2·Δ%RH and 0.44 g/m2·Δ%RH for the parallel and perpendicular straw respectively.

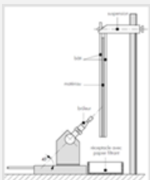
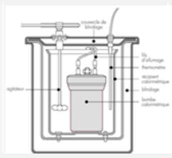
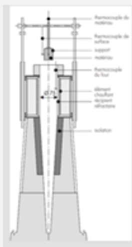
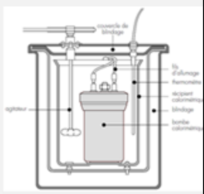
5. Fire test of prototype 3

A fire is an uncontrolled burning which, by spreading rapidly and uncontrollably, causes significant damage. Most fires are created by the combination of three elements: a fuel, an oxidizer and a source of energy also known as the «fire triangle».

To limit the damage caused by fires, the regulations on the fire safety of buildings have a number of requirements, particularly in terms of choice of materials. The role of building materials during a fire assessed through the following measures: *(i)* **the fire reaction of the material**, *i.e.* its behavior of materials during the first phases of the fire, the ease of ignition & *(ii)* **fire resistance**.

Since 2002[1], construction products for which a classification is mandatory, have to undergo a series of tests that simulate the first three phases of the development of a fire to obtain their reaction to fire classification. Existing tests corresponding to the three development phases are illustrated and are summarized in Table 11:

Table 11 : Simulation of fire phases and associated tests

	Tests realized		Principle	classification categories
Starting of test	Method for testing of ignitability		Punctual attack at the small flame on a sample of material being arranged vertically	B, C, D, E and F
Starting of Fire	Test single Burning Item (SBI)		attack with inflamed object with measurement of temperature and oxygen and carbon dioxide concentration	A2, B, C and D
Complete inflammation	ISO oven test		Flammability test on a sample exposed vertically in oven at 750°C during 60 minutes	A1 or A2
	calorimetric test		Measurement of the higher calorific value	A1 or A2

[1] EN 13501-1 : Classement au feu des produits et éléments de construction - Partie 1 : Classement à partir des données d'essais de réaction au feu. AFNOR (2018).

When all these tests are carried out, a classification letter is attributed to the material according to the following European classification (Table 12):

Table 12 : European fire reaction classification

A1	No contribution to fire
A2	Very low contribution to fire
B	Low fire contribution
C	Significant contribution to fire
D	High contribution to fire
E	Significant contribution to fire
F	Very important contribution to fire
NPD	No behavior in response to determined fire

Experimental protocol

According to the NF EN ISO 11925-2[2] standard, the small flame ignitability method corresponding to the first phase for development of fire (described in standard EN 13501-1). It consists in placing a sample of the prototype in a chamber test (Figure 19), and apply a 2cm propane flame for 15 seconds on the lower surface of a sample of material. This test give us some information about the capacity of a material to ignite more or less quickly in contact with a flame. After removal of the burner, a visual observation can determine if there is inflammation and the time during which the persistent flame has exceeded the height set by the standard to 15 cm. The presence of any inflamed droplets should be noted.

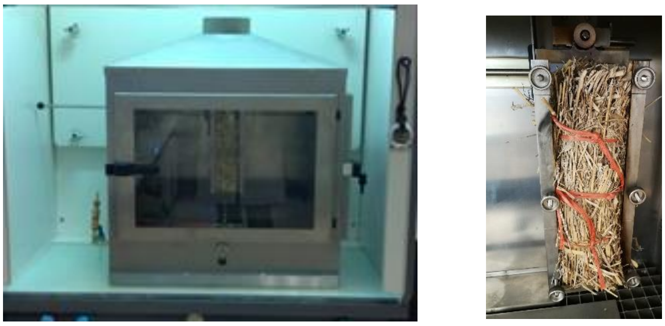


Figure 19: Fire test chamber (left) sample before test (right)

According to the NF EN ISO 11925-2 standard, materials having a degradation zone inferior than 15cm and not producing inflamed droplets, have good resistance to ignitability.

[2] NF EN ISO 11925-2 : Réaction au feu – Allumabilité des produits de bâtiment soumis à l'incidence directe de la flamme – Partie 2 : Essai à l'aide d'une source à flamme unique. AFNOR (2013).

Experimental results

The small flame ignitability method for prototype 3 and for a commercial polystyrene reference was carried out at UniLaSalle. The results of this test are summarized in the following Table 13:

Table 13: Fire test result

Material	Prototype 3	commercial polystyrene reference
Sample before testing		
Sample after 15 seconds in contact with small flame		
Height of damage area	Superior to 15 cm	Superior to 15 cm
Total destruction time of the sample	80 minutes	15 seconds
Droplet production	No	Yes

The observations made during these first tests show that after removal of the burner, the damaged area is greater than the 15 cm recommended by the standard for both materials. In addition, particles remain incandescent and progressively consume the sample of prototype 3 until complete destruction after 80 minutes. On the other hand, no inflammation or droplet production is observed.

The tests for the commercial reference of polystyrene demonstrate an immediate inflammation of the sample with droplet production. The sample is totally destroyed in 15 seconds.

At the end of this first test, the prototype 3 as well as the polystyrene commercial reference are classified E. According to NF EN ISO 11925-2 standard, they contribute significantly to fire. However, this test also highlights the interest of the use of crop byproducts material in insulating materials because the resistance of this materials before total combustion is significantly higher than that of the polystyrene board. As weather is a crucial parameter during a fire, this saving of time is therefore a major asset for particles boards.

6. Biodegradability of prototype 3

The end of life of biobased materials is still poorly known, due to the recent nature of the deployment of this type of material in buildings. However, a study carried out by ADEME[3] estimates the arrival of the first bio-based insulation materials in the end-of-life sectors as early as 2020. In the context of material recovery processes, manufacturers are looking for simple, pragmatic and practical solutions and economically viable.

Composting method is a process on an industrial scale that represents a solution for the sustainable management of agricultural byproducts. It is one of the fastest ways of transforming biowaste into a kind of humus, a stable material that can return to the soil as an organic amendment, thus completing the cycle of organic matter and to bring a beneficial effect taken into account in the context of a LCA, related to the ecosystem service (biodegradation) rendered by microorganisms degrading materials.

The compostability of a material is defined by a standard ISO 14855[4] and realized in laboratory (Figure 20), which measures the amount of CO_2 produced (mineralization phase) by microorganisms during the compost biodegradation process.

Figure 20: Biodegradation system

[3] Rapport ADEME 2014, Identification des gisements et valorisation des matériaux biosourcés en fin de vie en France.

[4] ISO 14855, Évaluation de la biodégradabilité aérobie ultime des matériaux plastiques dans des conditions contrôlées de compostage -- Méthode par analyse du dioxyde de carbone libéré.

Many research studies is being done on the behavior of different crop byproducts[5], such as those studied in the SB&WRC project (wheat straw, rapeseed and maize straws), and highlight their compostability and agronomic value.

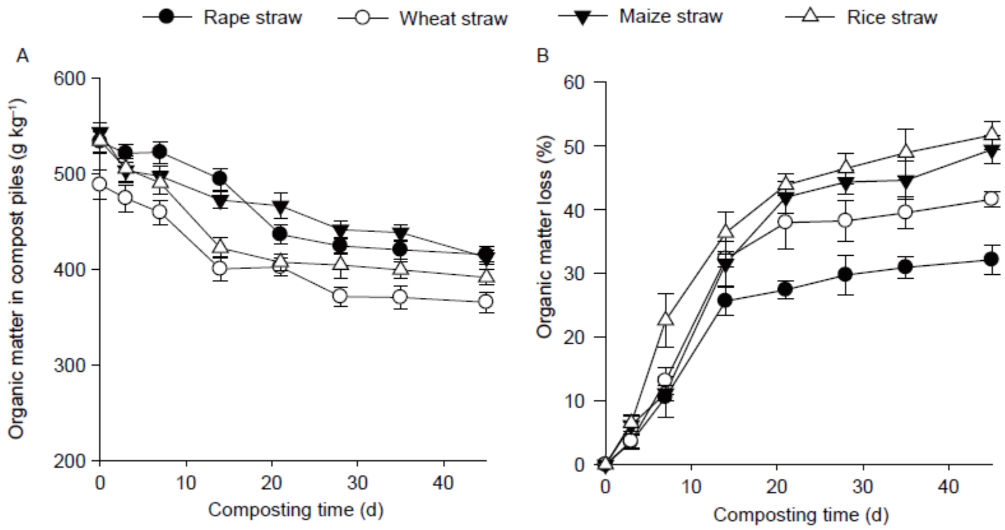


Figure 21: Study of Agricultural residues composting (Xiu-Lang et al., 2016)

Regarding the prototype 3, we can rely on these bibliographic elements to confirm their compostability and the interest of continuing studies on the development of a composting industry for the end of life of these materials. However, it is important also to verify that the conditions and process of formulation chosen for the material has no effect on its biodegradation. Recent research conducted at UniLaSalle shows that the thermocompression process in a context of direct return to the soil does not impact the biodegradation of the material obtained[6]. This thesis project entitled "Decomposition on soils of crop residues and biosourced materials: impact on microbial communities of agricultural soils and associated functions" defended by Fida Mrad in 20th December 2018.

In this thesis work, the wheat straw was tested according to the XPU 44-163 standard of 2009 relating to the decomposition of vegetable matter in soil (and a material elaborated from straw and then ground for a biodegradability study can be assimilated to simply straw) and it turns out that the plateau phase of mineralization is reached after 83 days. Given that biodegradation in a compost conditions is faster than in soil and that wheat straw is decomposed on the ground in less than 6 months, it can be said that the wheat straw material is biodegradable (in soil) and that it is inevitably compostable.

This type of approach can be gives for the material the possibility to close the carbon cycle, in a logic of circular economy, by the degradation of the carbon sources contained in agro-resources or agricultural by-products. Including a deconstruction and sorting adapted, this approach, already common for some products such as packaging labelled OK compost[7] and it is still experimental in the building sector but could open new perspectives.

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[5] Xiu-Lang et al., Journal of Integrative Agriculture 2016, 15(1): 232–240.
[6] Thèse Fida Mrad 2018, décomposition au sol de résidus de culture et de matériaux biosourcés : impact sur les communautés microbiennes des sols agricoles et les fonctions associées.
[7] EN 13432, Emballage - Exigences relatives aux emballages valorisables par compostage et biodégradation - Programme d'essai et critères d'évaluation de l'acceptation finale des emballages.

7. Summary and conclusions

In summary, the performance of wheat straw oriented perpendicular to the heat flow and therefore to the elements in general was greater than wheat straw oriented parallel as seen in traditional agricultural straw bales.

The thermal conductivity of the oriented straw prototype was higher than traditional mineral wool values ($\lambda \approx 0.035$ to 0.040) but much improved compared to traditional agricultural bales.

As traditional mineral wool insulation does not absorb moisture, the straw prototype offers further benefits through hygroscopic performance and indoor air quality through buffering internal relative humidity levels.

8. References

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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).