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DELIVERABLE D3.4

DEVELOPMENT AND SCALING – UP OF RECYCLED WASTE PAPER AND TEXTILE FIBRE INSULATION MATS

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1. Introduction

Deliverable 3.4 of INBUILT Work Package 3 (WP3) describes the development and scaling-up of an innovative thermal insulation material by the project partner BALTICFLOC. As part of the project, this thermal insulation material, made of cellulose and recycled textile fibres, will be developed at levels TRL4–TRL8, in line with previously defined target performance indicators. During the development, the quality criteria for the raw materials will be formulated, the impact of the production process on quality and the performance of the finished product will be assessed, with testing in real-life conditions at three demonstration buildings, which is the goal of the work package (WP6). The innovative thermal insulation material is designed for insulating walls, floors, pitched roofs, and attics of buildings.

Loose cellulose thermal insulation wool made of paper is nothing new in construction, and thanks to its consistent quality and applications, has mainly found uses in the insulation of residential buildings. Its more extensive use is limited by the technical approach to its installation, which requires preparation and special equipment. This is why BALTICFLOC offers its new material in the form of mats, making it accessible to a wide range of users.

The demand for sufficient-quality paper waste that can be recycled is increasing following improvements in the paper recycling industry. This reduces the availability of such materials on the market, which in turn leads to higher waste paper prices. EU data on the quantity and recycling of paper waste also confirm this[1]. In the past decades, paper recycling technology has taken a huge step forward, and paper has become one of the most recycled types of waste. However, due to high consumption of water and the chemical processes involved, turning paper waste into new paper products is very energy-intensive and harmful to the environment. In contrast, to make cellulose thermal insulation, paper undergoes only mechanical processing, requiring only a small amount of treatment with chemicals. In recent years, textile waste has become an increasingly urgent issue, with the amount rising every year. There are various limiting factors in the recycling of textiles that make it very difficult to turn them into new textile products.

That is why the BALTICFLOC INBUILT project involves the development of an innovative cellulose-based thermal insulation material that contains recycled textile fibres, thus creating a new use for recycled textile fibres that cannot be used to make new textile products. The initial prototypes of the BALTICFLOC product show that the presence of textile fibres in the material actually improves the performance of the thermal insulation mats. The objective of the project is to develop a product that is ready for use and manufacture made out of recycled paper and textile fibres, with performance features similar to those of wood-fibre thermal insulation mats.

[1] The European Paper Recycling Council Monitoring report https://www.paperforrecycling.eu/

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2. Development work process

The goal of T3.4 work is to develop a soft mat insulation material (product #IP8) with a performance that is equal to or better than similar thermal insulation materials (e.g. wood-fibre insulation) and could serve as an alternative to rock wool insulation.

The intended product application is for thermal and sound insulation in buildings. It can be used for the following:

1. Space-filling insulation in closed cavities of external and internal walls of timber frame constructions and similar structures.
2. Insulation in closed cavities between rafters and timber beams as well as in cavities of corresponding structures.
3. Exposed insulation on horizontal areas as insulation of topmost storey ceilings like uninhabitable lofts.
4. Cavity insulation between flooring joist battens and similar substructures.

At the beginning of the project, key target hygrothermal properties were defined in terms of performance (see Table 1) and circularity indicators related to sustainability (see Table 2).

Table 1 Product performance targets

Product performance target characteristics	***Target value***
Thermal conductivity	λ – 0.036 W/(mK) for dry material
Fire performance	Reaction to fire Class D (EN 13501)
Indoor acoustic comfort	Sound absorption Class B (EN ISO 11654)

Table 2 Circularity KPI

Key circularity KPI	***Target value***
% of recycled raw material	100%
% of reusability of the products	50%
% of recyclability of the product	100%

2.1. Raw material selection

The choice of raw materials is based on Balticfloc's experience and its technological capabilities in production. Notably, the main components of the product come from local waste streams as recyclable raw materials. Textile fibre is sourced from textile waste, and cellulose fibre, from waste paper. The choice of raw materials is critical because it must enable the achievement of the finished product's performance characteristics

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(Table 1) and the project's sustainability indicators (Table 2), which were defined at the beginning of development.

Four suitable raw materials must be selected for the development of the product:

1. **The recyclable waste paper**, as seen in *Figure 1* that we use is sorted newspapers, classified as Group 2 Medium grade (most common newspapers, books, office paper, and magazines) in accordance with the EN 643:2014 European standard. Sourced from local and regional waste streams.

Figure 1 Recyclable wastepaper

2. **Recycled textile fibre:** as part of looking for textile fibre, we visited Rester Oy, a partner company in Finland that converts textile waste collected in Latvia into fibres that can be used in new products. During the visit, we learned about the recycling technology, the sorting of recycling material, and the types of recycled products (fibre). Given our focus on the recycling of materials whose reuse potential is limited, Balticfloc will use the lowest-quality recycled fibre (as shown in the *Figure 2*) for the development of the new product, with a mix of cotton, polyester and other fibres.

Figure 2 Recyclable textile fibre

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3. **Fibre binding agent:** it is a finished industrial product intended for a specific application and its choice is determined by the composition and origin of the binding agent. In choosing the binding agent, it was taken into account that the final product must have the maximum possible share of environmentally harmless recycled materials and/or materials of biological origin. A typical choice is to use PE/PET fibre binder. However, for the sustainable product, the final choice of bicomponent (as seen in figure *Figure 3*) is a binding agent that contains Biobased PE fiber and recycled PET fibre.

Figure 3 Bicomponent fibre

4. **Fire-retardant additives:** ready-to-use industrial mixes common in the production of cellulose insulation, are used to provide fire-retardant and pest-repellent properties. Boric acid is for fire resistance, and borax for preventing pests and mould.

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2.2. Product formulation, optimisation and prototype production

Two prototype thermal insulation products were tested as part of the development of the product, with different textile-to-cellulose ratios of the main ingredients. The two initial prototypes were compared against each other, with thermal conductivity measurements to analyse the performance of the two composition variants in terms of the main performance parameter as stated in Table 1.

The preliminary results of the thermal conductivity measurements are very similar for the Prototype 1 and Prototype 2 samples (see Figure 4), and the difference between them is not significant. The results, as shown in Table 3 and Table 4, indicate that both prototypes differ in terms of the density's dependence on sample thickness, which is influenced by the proportion of fibres in the composition. For both prototype types, when comparing 50 mm thick samples with 100 mm thick samples cut lengthwise, the 50 mm samples were slightly heavier - denser. Meanwhile, the difference in average thermal conductivity between different samples of the same prototype with the same thickness is negligible. There is also no significant difference when comparing the thermal conductivity of prototype 1 and prototype 2.

Table 3 Preliminary thermal conductivity measurement results of Prototype 1

No	Sample	Moisture, %	Thickness, mm	Weight, g	Density, kg/m^3	λ_{10}, mW (m K)$^{-1}$
1	Prototype 1, 50 mm	4.98	47	89.4	49.77	35.958
2	Prototype 1, 50 mm	4.78	48	88.7	48.35	35.678
3	Prototype 1, 100 mm	*4.41*	*100*	*143.3*	37.69	
3.1	100mm sample nr.3 cut lengthwise	4.41	50	71.1	37.40	38.099
3.2	100mm sample nr.3 cut lengthwise	4.41	50	72.2	37.98	35.302
	Arithmetic mean Prototype 1			**80.35**	**43.37**	**36.26**

Table 4 Preliminary thermal conductivity measurement results of Prototype 2

No	Sample	Moisture %	Thickness, mm	Weight, g	Density, kg/m^3	λ_{10}, mW (m K)$^{-1}$
1	Prototype 2, 50 mm	4.97	50	92.2	47.28	36.785
2	Prototype 2, 50 mm	4.99	49	111.9	58.84	36.973
3	Prototype 2, 100 mm	4.96	100	138.6	35.54	
3.1	100mm sample nr.3 cut lengthwise	4.96	50	72.4	37.13	36.052
3.2	100mm sample n3.3 cut lengthwise	4.96	50	66.2	33.95	35.392
	Arithmetic mean Prototype 2			**85.67**	**44.30**	**36.30**

In view of these results revealing insignificant differences in thermal conductivity, it has been decided to continue the development of the product with Prototype 2. This decision was made because Prototype 2 contains more treated cellulose with fire retardants than Prototype 1, thus it could potentially improve the

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ignition test results. Currently, the cellulose fibres are treated with fire retardants during the preparation of the cellulose, while textile fibres are not treated with fire retardants at all during the process.

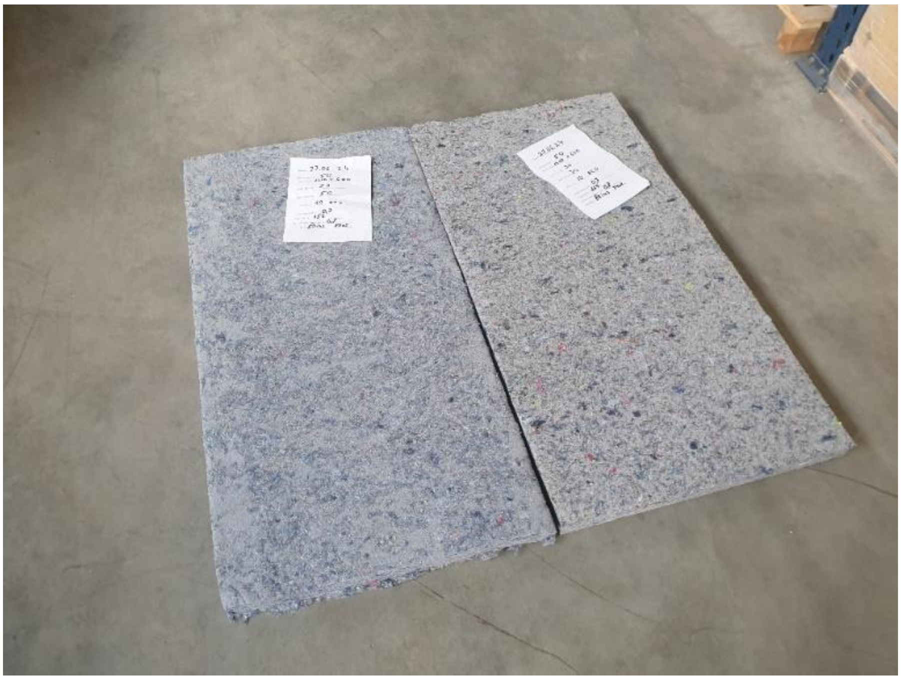

Figure 4 Prototypes of the material. Prototype 1 on the left and Prototype 2 on the right

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3. Scaling-up of recycled waste paper and textile fibre insulation mats

3.1. Optimised specimen production

Improved samples were produced as 600x1200 mm mats, and two options for thickness: 50 mm and 100 mm. A total of 27,8 m^3 of mat material was produced to assess the process of preparing the fibre material. The preparation of fibre is the most critical stage in creating a uniform fibre mix, which directly impacts the quality of the finished mat. When fibre uniformity is insufficient, it adversely affects production quality, resulting in defects in the final product because the fibre mass does not bond properly.

Figure 5 Samples produced in pilot production, 50 and 100 mm thick

A few pilot production batches were made in order to produce optimum samples (as seen in Figure 5.) Different fibre mixtures were prepared by changing the amount of fibres and mixing it to obtain a homogeneous mass of fibres. Adjustments were made in the fibre laying and thermal compaction process, which the density of the material depends on, initially set at 45–55 kg/m^3. Identifying the optimal textile to cellulose ratio improved performance with current production equipment, allowing for an optimal carpet material density of 36–48 kg/m^3.

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3.2. Specimen testing to determine the mechanical properties and performance

The test parameters to compare the performance indicators of the material with those of other thermal insulation materials were selected based on the ETA document EAD-040005-00-1201 used in the CE certification of thermal insulation mats made of natural fibres and EAD-040288-00-1201 used in the CE certification of thermal insulation mats made of polyester fibres. The use of the compliance requirements set in these documents enables a more objective comparison with the thermal insulation materials available on the market.

The target indicators were defined taking into account these EAD documents and the performance characteristics of competing products on the market. Balticfloc chose wood fibre wool mat as the product to compare against.

The product testing was done with the help of INBUILT project partners, whose task as part of the project was to provide product testing, the goal of Task 3.7 in Work Package 3 (WP3). As part of this task, University of Bath (UBATH) tested a prototype of the thermal insulation material developed by Balticfloc. University of Bath carried out laboratory measurements of thermal conductivity, heat capacity, water absorption, vapour diffusion, density, compressive strength, and dimensional stability. Details of the testing performed would be available in University of Bath Deliverable 3.7.

For the rest of the performance indicators, laboratories outside the project consortium were used that had the technical expertise to carry out the testing. Riga Technical University (RTU) tested biological resistance to mould, Forest and Wood Products Research and Development Institute (MEKA) determined the fire reaction of the product, and Technical and Testing Institute for Construction Prague, s.p., (TZUS) carried out sound absorption testing. The Table 5 shows the original target indicators for the product and the results of the testing. Detailed results and procedure of the testing will be listed in Deliverable 3.7 (WP3).

Table 5 Comparison of test results and target indicators

Product characteristics to be tested	*Testing laboratory*	*Target values*	*Test results for 50mm thick*	*Test results for 100mm thick*
Thermal conductivity	UBATH	Not higher than λ - 0.036 W/(mK) dry	0.0375 ±0.0001 W/mK (T_mean = 10°C, RH=50%)	0.0386 ±0.0003 (T_mean = 10°C, RH=50%)
Water vapour diffusion resistance	UBATH	Not specified	2.5 (dry cup), 1.5 (wet cup)	1.7 (dry cup), 1.4 (wet cup)
Water absorption coefficient	UBATH	Not specified	0.25 ±0.02 $kg/m^2s^{0.5}$	-
Density	UBATH	45-55 kg/m^3	48 kg/m^3	36 kg/m^3
Specific heat capacity	UBATH	Not specified	1183 ± 198 J/(kgK)	1286 ± 221 J/(kgK)
Reaction to fire	MEKA	Class D	Class E	Class E

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Compressive Strength	UBATH	Not specified	Compressive Strength at 10% strain 1.09 kPa Elasticity 10.9 kPa	Compressive Strength at 10% strain 0.42 kPa Elasticity 1.87 kPa
Dimensional stability	UBATH	Not specified	Stable (0% change in 45 hours at 90%RH and 50°C)	Stable (0% change in 45 hours at 90%RH and 50°C)
Sound absorption	TZUS	Class B	Class A, α_w-0,9	-
Biological resistance	RTU	Not specified	Growth rate: 0 dry @23°C, RH 0, 0 wet @23°C, RH50	-

Below is a brief overview of the testing process for tests conducted outside the project consortium, which are not included in the University of Bath deliverable D3.7.

Single flame source test

In order to evaluate the reaction of materials to fire, each sample has been exposed to a flame source to assess the response of the material to fire during specific time under the guidelines of standard EN ISO 11925. The flame application time is 15 or 30 seconds, depending on the target classification for which the tests are performed. The flame is applied to the side surface and the bottom edge. Each sample has been then assessed according to the following parameters: ignition time, flame reach, damage by flame, ignition of filter paper and flame out time, flaming droplets and smoke production.

To determine if the samples comply with class D requirements, they were exposed to a surface flame for 30 seconds. Within 60 seconds of applying the flame, the vertical spread of the flame must not exceed 150 mm from the point of application.

Considering that the flames reached the 150 mm mark on the samples within 60 seconds, the requirements of class D are not met. However, when observing the flame exposure during the tests, it was observed that the flame did not reach the 150 mm mark within 30 seconds, which corresponds to the criteria of class E.

Biological resistance test

The evaluation of the fungal activity has been carried out by exposing the samples to wood decay fungi, by means of using soft and brown rot fungi. The test samples were exposed to two different climatic conditions for four weeks: a set temperature of 23°C with 0% relative humidity, and a temperature of 23°C with 50% relative humidity. After aging, ten representative samples were taken from each test sample for microscopic evaluation of the presence of fungi. After ageing, ten representative samples were extracted from the test sample for evaluation of the presence of fungi under microscopy. Testing of samples for biological effects has been carried out in accordance with the EN ISO 846 standard.

The test results show no presence of mould fungi in any of the samples, neither at 0% humidity nor at 50% humidity at 23°C in the climate chamber.

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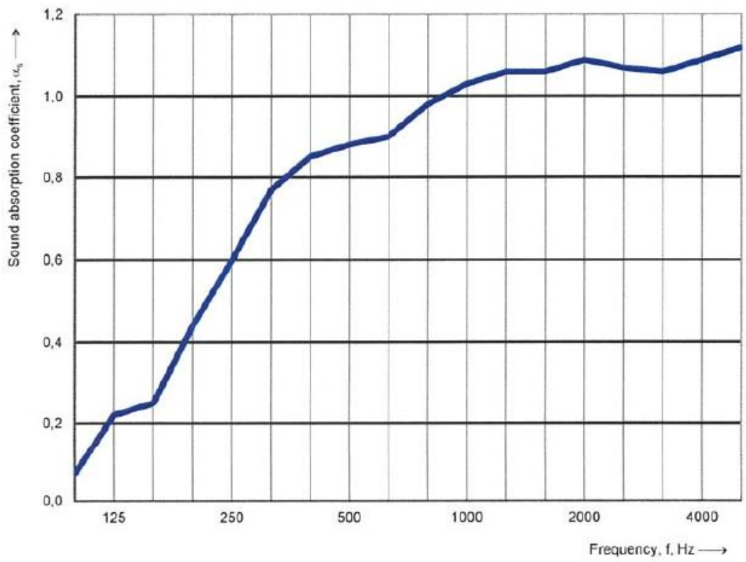
Sound absorption test

The sound absorption test, according to EN ISO 354 is a standardised laboratory procedure used to measure the sound absorption coefficient of materials. To determine how much sound energy is absorbed (vs. reflected) by a test specimen, a reverberation room method is used. The results are used for rating materials in architectural acoustics. The measurement is done by the omnidirectional impact of the sound wave on the sample and is based on the measurement of the reverberation time of the empty chamber and the chamber containing the tested sample. The difference in measurements is used to specify the equivalent absorption area of the sample and the sound absorption coefficient. The results of the test as shown in Figure 6 are the values of the sound absorption coefficient α_s in one third octave bands from 100 to 5000Hz. The main result of testing that is objectively related to the tested structure is the single-digit variable of the weighted sound absorption α_W, which is obtained as 0,9 according to the standard EN ISO 11654, which is used to rate sound absorption.

Frequency f [Hz]	α_s
100	0,07
125	0,22
160	0,25
200	0,44
250	0,60
315	0,77
400	0,85
500	0,88
630	0,90
800	0,98
1000	1,03
1250	1,06
1600	1,06
2000	1,09
2500	1,07
3150	1,06
4000	1,09
5000	1,12



Weighted sound absorption coefficient according to ISO 11654
α_w = 0,90

Figure 6 Measurements of sound absorption coefficient

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3.3. Product testing in DEMO buildings

In WP6, the developed insulation will be tested in real-world conditions in several demonstration buildings. Considering the intended application of the developed material, it will be installed in three different buildings, with different locations and climatic conditions. The demonstration buildings will be:

1. Demo site 1 – residential building with flats and offices, located in France.
2. Demo site 2 – recovered timber frame Tiny house building, located in Nice, France.
3. Demo site 3 – reconstructed old factory into a public space, located in Birmingham, UK.

The developed #IP8 insulation is to be installed in demonstration buildings respectively equipped with monitoring systems to monitor thermal insulation of construction, as well as indoor climate. The overall monitoring time will be 12 months to cover all seasons.

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4. #IP8 performance comparison

The tests confirmed the performance characteristics of the new BFlex Textile thermal insulation material in key parameters (see Table 5): thermal conductivity, breathability of the material, moisture and sound absorption, fire reaction, and other important parameters. The development of new textile-cellulose mat insulation has produced good results, leading to the conclusion that the material is capable of performing the thermal insulation and sound insulation functions.

Table 6 Comparison of developed #IP8 indicators with other products

Product Type	Cellulose/textile slabs	Wood fibre	Cotton insulation	Sheep wool	Sheep wool	Cellulose matt
Product name	***#IP8 BFlex Textile***	Steico Flex 036	COTTON 3D	Alchimea lana Dämmvlies	ISOLENA	CelluBOR SW
Thickness mm	***50-100***	30-240	45-120	40-120	30-100	40-100
Density kg/m^3	***36-48***	50	24	25	30	45
Thermal conductivity ***W/(mK)***	***0.0375***	0.036	0.039	0.039	0.036	0.039
Reaction to fire	***Class E***	Class E	Class F	Class E	Class E	Class E
Biological resistance	***Class 0***	-	Class 0	Class 0	Class 0	Class 0
Air Flow Resistivity AFr kPa.s/m^2	-	5 kPa.s/m^2	16 kPa.s/m^2	3 kPa.s/m^2	10.2 kPa.s/m^2	> 5 kPa.s/m^2 at 30kg/m^3
Sound absorption (α_w)	***α_W 0.9 Class A***	-	A (α_W =0.95)	-	B (α_W =0.85)	-
Water vapour transmission	***2.5 (dry) 1.5 (wet)***	2	4	-	1	1.5
Water absorption	-	-	less than 7 kg/m^2	1.8 kg/m^2	2.45 kg/m^2	-
Compressive strength kPa	***1.09***	-	-	-	-	-
Tensile strength kPa	-	≥ 1 kPa	10 kPa	-	-	-
Dimensional stability	**Stable (0% change in 45 hours at 90%RH and 50°C)**	-	-	-	-	-

In the Table 6, other biologically-based insulation materials are compared to the BFlex Textile product. Evaluating the performance indicators developed for the #IP8 product shows that they are comparable and competitive. While the thermal conductivity indicator of BFlex Textile is considered good, its thermal

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conductivity is average compared to other products. Better indicators are observed in sheep wool insulation and wood fibre insulation, while cotton and cellulose insulation have a higher thermal conductivity indicator. Fire reaction and biological resistance indicators are the same across all products that have been assessed under this criterion. Differences are noted in product density, which for BFlex material ranges from 36–48 kg/m^3, while for comparable products it is a constant value. This variation is linked to the technological process of BFlex Textile.

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5. Conclusion

During T3.4, a new material has been developed from the recyclable waste paper and textile waste and as part of the task, a performance evaluation of the developed product was carried out. Although the initially defined certain performance indicators (as defined in Table 1) have not been achieved, overall the Balticfloc development team considers the results as recognizable when compared to other biologically based products already available on the market (see comparison on Table 6). In our view, this indicates the product's potential, and Balticfloc has already identified areas for improvement to achieve the initially defined indicators. During the project's course, it was found that improving the fire reaction indicator is hindered by the current technological process, which cannot be quickly modified at this time.

The BFlex Textile mats developed during the project have good performance characteristics (see Table 5) that are sufficient to replace materials made from fossil raw materials, thus expanding consumer choice. If used at scale, it would reduce an important volume of these waste, whose reuse potential is otherwise limited. At the same time, its manufacturing process does not require water use or high-temperature processes. The only additives used are to ensure fire retardancy and pest prevention.

In order to assess the positive environmental impact of BFlex Textile, its sustainability and environmental impact will be assessed in the further course of the project by conducting a Life Cycle Assessment (LCA) as part of Task 4.3, and its results will be included in Deliverable 4.3.

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6. Main facts / results

The innovation of the #IP8 thermal insulation material developed as part of the project is based on the waste streams of paper and textiles. The binding agent used also consists of a biodegradable polyethylene (PE) and recycled waste polyethylene terephthalate (PET). Flame-retardant and pest-repellent additives are used: boric acid for pest and mould prevention, borax for fire resistance; both of these are salts of natural origin.

The key characteristic of the developed the thermal insulation material (#IP8 product samples shown in Figure 7):

- Very good thermal insulation characteristics, 0.0375 W/(mK)
- Good fire resistance, Class E according Euro classification
- Excellent sound absorption, α_W 0.9, Class A
- High share of recycled raw materials in the product: 94% by weight

Characteristics to be assessed within Work package 4, task 4.3:

- Ability to direct reuse as thermal insulation without recycling: up to 50% (target)
- Ability to recycle the product into new thermal insulation material: 100% (as targeted)

Figure 7 Finished #IP8 product – thermal insulation BFlex Textile

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References

EN 13501-1 Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests

EN 643 Paper and board - European list of standard grades of paper and board for recycling

EN ISO 846 Plastics - Evaluation of the action of microorganisms

EN ISO 354 Acoustics - Measurement of sound absorption in a reverberation room

EN ISO 11654 Acoustics - Sound absorbers for use in buildings - Rating of sound absorption

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