Innovation and commercialisation of Scottish homegrown wood fibre insulation

Brief: To investigate the potential for the commercialisation and innovation of Scottish wood fibre insulation in the construction industry.

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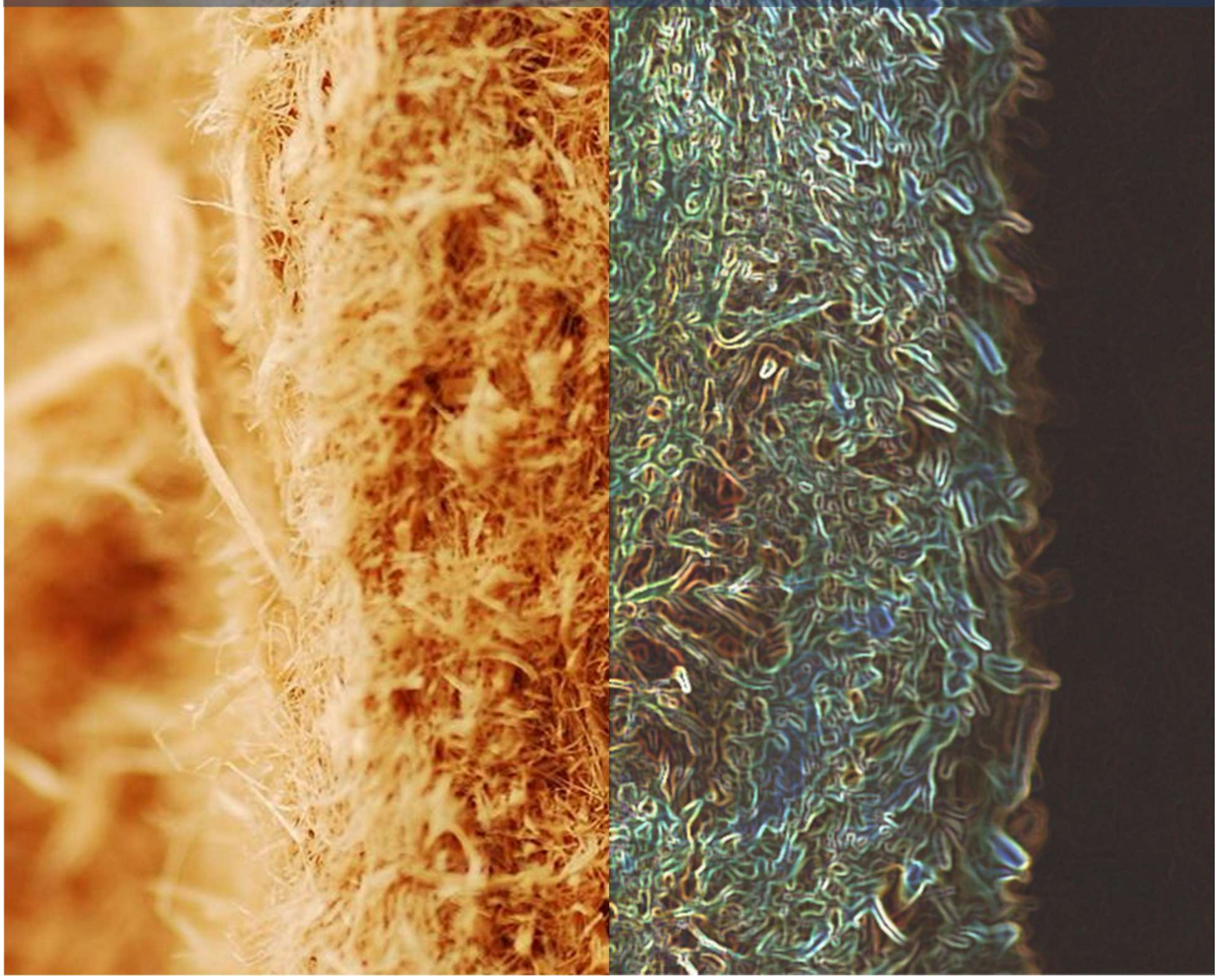

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Context

This study emerged from the strategic priorities outlined in the Roots for Further Growth strategy produced by the Scottish Forest and Timber Technologies Group [1], which aims to maximise the economic outputs of Scotland's Forests and Fibre resources through the implementation of viable technologies, and to incentivise landowners in Scotland to grow trees for wood fibre production. Additionally, the strategy seeks to increase fibre recovery from existing harvesting operations and support innovation and new technologies throughout the wood supply chain and downstream industries.

Roots for Further Growth highlights the great potential for the use and production of low embodied products in Scotland, including fibre-based materials from waste and recycling of timber. On that basis, this study seeks to investigate the full potential of homegrown wood fibre for use as insulation products.

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Executive summary

Introduction

The purpose of this study is to provide evidence to support the manufacture of wood fibre insulation using homegrown fibre. This addresses the challenges faced by the Scottish Government to reduce the embodied carbon of construction materials and meet targets for net-zero by 2040. The project was funded by Scottish Forestry and undertaken by academics at the University of Edinburgh and Edinburgh Napier University.

The project is divided into four key areas:

- an analysis of existing wood fibre insulation products that identify key material characteristics, manufacturing methods and performance levels. This included an existing literature review that explores the recent research on the performance and timber species used in wood fibre;

- a market review conducted with surveys and interviews with key stakeholders and industry professionals to consider the barriers and concerns linked to the adoption of wood fibre insulation;

- a study to understand the environmental impact of existing wood fibre insulation materials and a comparison with similar synthetic and natural fibre products;

- an analysis of best practices used in the construction industry, exploring new and retrofit methods. Included is a review of new innovative uses and emerging products in the market.

The evidence the project offers is sourced from:

- technical documentation from 10 European Union (EU) manufacturers of wood fibre insulation;

- questionnaire results from 2 EU wood fibre insulation manufacturers, 3 wood fibre UK suppliers, 7 construction professionals and interview responses from 6 construction industry representatives;

- a desktop analysis of cost and environmental data from existing wood fibre insulation products available in the UK and EU.

The primary aim of the study is to explore the potential for the commercialisation and innovation of Scottish wood fibre insulation in the construction industry. This study will be of particular interest to developers, architects and building owners aiming for net-zero and beyond whilst considering energy efficiency, healthy and low carbon living.

Findings

The main findings of this study are as follows:

1. **Benefits & barriers**

Using wood fibre insulation brings numerous benefits, particularly when correctly installed. It can contribute to thermal efficiency, acoustic performance and improve indoor air quality of building interiors by:

- buffering moisture and avoiding condensation build-up;
- lowering heat loss through conduction of heat;
- reduce sound transmission between components and rooms;
- thermal balancing by absorbing/ storing heat.

Environmentally, the use of wood fibre insulation contributes less to climate change by:

- releasing fewer carbon emissions during its production stages by having a negative global warming potential compared with most equivalent synthetic (man-made) insulation products;

- when compared with synthetic insulation, wood fibre products tend to require more energy to produce them, therefore, their embodied energy remains high. However, most manufacturers use 60% renewable energy sources for the main production stages, whilst energy to produce synthetic insulation tends to primarily use fossil fuel in their production stages;

- carbon absorbed during the trees life remains locked and sequestrated in the insulation product until disposed of and released (combusted);

- wood fibre insulation has a long end of life due to its biodegradable potential and after its intended use can be turned into other bio-based products, avoiding it being disposed of completely into landfills.

However, a number of barriers also exist:

- there aren't any manufacturers in the UK of wood fibre insulation, therefore, all products are imported from mainland Europe where several companies have a large capacity and market outreach;

- its current availability in the UK is limited as it relies on specialist suppliers, therefore, it is not available off-the-shelf unlike other insulation products;

- the cost of the imported wood fibre is higher than synthetic insulation equivalents;

- the UK construction industry does not fully comprehend the benefits that wood fibre brings to a building and mostly focuses on the like-for-like thickness and thermal conductivity (λ) values. Currently the thermal conductivity value of wood fibre products is higher than synthetic equivalents, therefore, to match the U-values of a component using wood fibre more product (thickness) is required;

- the current uptake of natural insulation products, such as wood fibre, is low, partly due to the industry being unaware of its performance and availability;

- there is also a lack of support from the government to incentivise the construction industry to use natural insulation products that contribute less to climate change and which can achieve net-zero targets faster.

2. **Present and future capacity**

- In 2018, according to the Alliance for Sustainable Building Products (ASBP), the market share for natural insulation products in the UK was worth less than 0.1% of all insulation sales compared with 6% in Germany.

- Various forums and UK distributors of natural insulation products estimate that between 2021 and 2022, the UK market will grown and is worth between £2 million to £3.5 million; less than 0.2% of the total insulation UK market.

- Wood fibre insulation is a popular product among most environmentally conscious architects, contractors, and house builders, however, in order to increase the market potential, there needs to be an increase of awareness and skills development.

- Other EU countries have a steady increase in sales of wood fibre products with one leading EU manufacturer experiencing a 30% revenue increase between 2020 and 2021.

- The results from the interviews with leading contractors, house builders and local authorities, showed support for the uptake of wood fibre insulation with a real belief on the benefits to reducing climate change and meeting their net-zero targets.

3. **Recommendations**

   - **Generate a future framework for the production of wood fibre insulation:** Forge agreements with existing supply chains and manufacturing facilities to develop a better understanding of the manufacturing needs at the scale that the homegrown market requires.

- **Produce samples of homegrown wood fibre** exploring the following variables and methods:

    - replicate the composition of existing wood fibre products imported from the EU (softwoods);
    - all fibres from available and suitable hardwood species;
    - a mixture of softwood and hardwood fibres with varying compositions and species;
    - explore varying low VOC, natural and non-petrochemical binders adhesives and fire retardants;
    - differences in fibre quality directly from virgin timber and recycling sources.

- **Test and compare the performance of the samples:** Evaluate the samples in a laboratory under similar conditions and standards used by those currently for fire, thermal, acoustic, waste, etc.

- **Evaluate the global warming potential (GWP) and embodied energy of the new variations in samples:** consider the cradle to gate methodology based on the available manufacturing alliances. These new values can be compared with EU products and the current UK made synthetic insulation products.

- **Creation of a Scottish wood fibre alliance (SWFA)**: with representatives from the supply chain members, existing manufacturers, government representatives (Scottish Forestry), wood use promoters (Confor, Timber Trade Federation, TRADA), home building federations, associations (SEDA, CarbonLite, ASBP, STBA) academics and wider industry (architects (RIBA/ RIAS), builders, Passivhaus Trust).

- **Organise awareness sessions and up-skilling** to make the use of wood fibre insulation a feasible option in the Scottish construction industry. Create group sessions composed of:

    - **Government:** Local and central government learning from other EU countries on incentives, legislation and up-take (Germany, France);
    - **Contractor groups:** Identify contractors who are keen to drive the net-zero agenda to up-skill their workers and other sub-contractors;
    - **House builders:** deliver training to private house builders and registered social landlords on the benefits and requirements;
    - **Architects:** Approach architectural practices to discuss the benefits of wood fibre, best practice use and integration to designs to change perceptions by clients and means to meet net-zero performance.

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1. Introduction

Meeting carbon targets as set out by the Scottish Government by 2045 requires the roll-out of net-zero initiatives, achievable through the collaboration of specific supply chains, private and public sectors. One such sector providing a holistic pathway to net-zero performance is the adoption of wood fibre products for the built environment. This presents a real opportunity to change how the industry considers wood fibre materials from being an expensive one-off niche product to being a more mainstream and readily available product at a competitive cost with comparable performance to synthetic equivalents.

Wood fibre insulation products already have a place in the UK and Scottish insulation markets. However, all available products are currently produced and imported by companies in mainland Europe by small scale UK distributors, mainly specialist natural product suppliers, and representatives of EU established brands.

The products themselves, offer two key benefits in meeting net-zero performance criteria. They contribute to the reduction of heat loss hence operational energy and carbon demands by increasing thermal resistance through the building envelope, a quality that most insulation materials at varying levels will have. However, wood fibre insulation is capable of much more through its increased ability to manage moisture and heat storage. Additionally, wood fibre products have a low global warming potential, and if produced locally and with renewable energy sources can potentially have a low embodied energy.

To understand how wood fibre insulation can be produced in Scotland there needs to be an open dialogue between supply chains and existing similar manufacturing setups. Scottish Forestry has commissioned this document into the current scenario and future options for the production of homegrown wood fibre insulation, exploring the performance of existing products, the market potential and its application with a view for innovation. This work is therefore a potentially significant contribution to the production of Scottish homegrown wood fibre insulation.

The main objectives of this report are:

1. To provide an understanding of the different parametres that encompass existing wood fibre products;
2. To assess and evaluate the current market of synthetic insulation products, existing imported wood fibre and future uptake;
3. To consider the required production methods and technology requirements of existing wood fibre production plants;
4. To evaluate the current best practice use of wood fibre and consider innovative products and uses.

2. Product Review

2.1. Product review and existing uses

Wood fibre insulation products can be categorised into three main typologies: loose fibre insulation, flexible batts, and rigid boards.

2.1.1. Loose fibre insulation

Loose fibre insulation products contain fibrous materials injected at high pressure. A homogeneous filling is achieved in cavity walls, roofs, and floors. Its application is suitable for new buildings but offers greater advantages for retrofitting due to its compatibility with existing materials and less invasive installation. Loose fibre is installed through high-pressure injection apparatus providing a faster installation compared with manual board/ batt insulation that requires a frame or access to the component during construction or retrofit. Required before installation, a survey of the component is undertaken to identify the cavity depth and estimate the amount of volume covered. To inject the material, 105 mm holes are bored on one side of the component, however, this might vary accordingly to the depth of the element, as the lower the depth the bigger the holes required. The density of the loose fibre insulation is suggested by the manufacturer but it depends on the depth of the cavity, and the component type, i.e., roof, wall, or floor.

2.1.2. Flexible batts

Flexible batts are ductile insulation panels suitable for compression and used between studs in walls, and rafters in roofs. The insulation application does not require high skill levels as the material can be cut with a saw, applied, and pushed between studs or rafters using a flat surface. Flexible batts are produced with the dry process, and synthetic fibres such as polyester, polyolefin, or synthetic thermoplastic polyester are used as binders. Also required is a fire retardant which the industry commonly uses ammonium polyphosphate.

2.1.3. Rigid boards

Rigid boards have multiple applications, mainly insulation for sheathing and sarking on roofs, external rendered insulation for walls, and load-bearing/water-resistant insulation for below floor screeds. Manufacturers shape the panels with tongue and groove, edges square, or shiplap edges for easy installation. A wide range of thicknesses and densities are offered on the market.

2.2. Product composition, performance and manufacture

The raw materials associated with wood fibre insulation products are composed mainly of wood fibres, binders and other additives. Softwood such as spruce and most coniferous species are typically applied as insulation fibres using a process called thermo-mechanical pulping (TMP). The TMP process uses mechanical pressures and temperatures that are regulated according to the required characteristics of the insulation products [2]. One of the key concerns during the TMP process is the high level of electrical energy required which diminishes its benefits of being naturally sourced. The use of binders will depend on the type of products, and their production process. Blown-in loose fibre (cellulose) does not require binders, meanwhile for flexible batts bi-component fibres are applied, natural material such as starch could be utilised instead.

Additives such as fire-retardants are required in blown-in loose fibre and for flexible batts. Rigid boards use hydrophobic agents such as paraffin wax solution, or latex, added during its pulping process for weatherproofing reasons. There are two main processes used to create batt or rigid board wood fibre insulation, a dry and a wet method.

2.2.1. Dry Process

The dry process is straightforward; fibres and binders are first combined and scattered forming an even mat, which is then pressed depending on the required thickness, and exposed to a mixture of air and water vapour to dry the resin, see Figure 1.

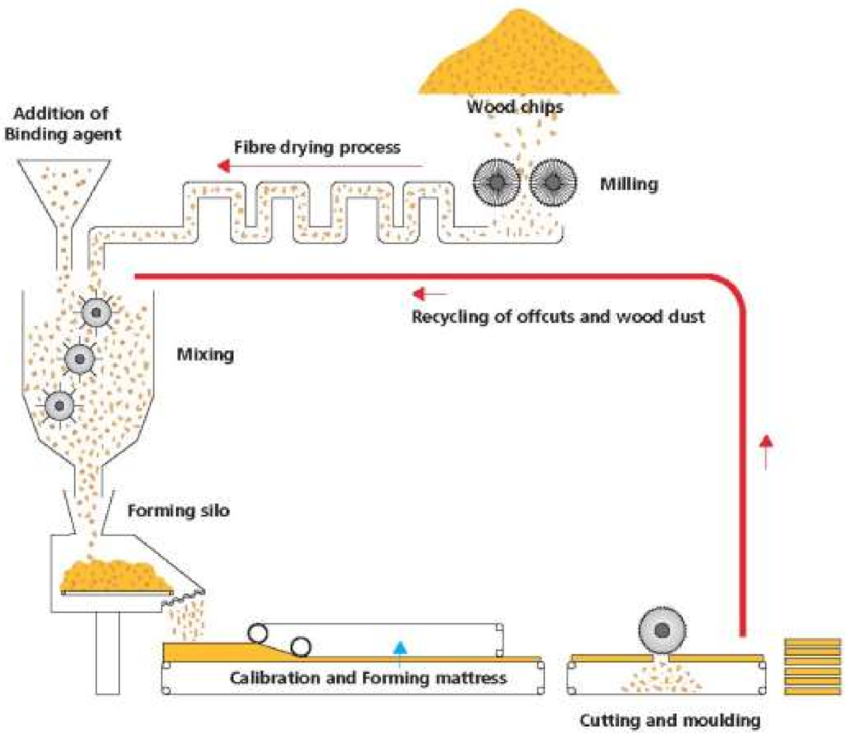

Figure 1: Dry process by Steico wood fibre producing company [3].

The main disadvantage of the dry process is that waste timber is dried and combined with petrochemical-based resins such as PMDI (polymeric methylene diphenyl diisocyanate) glue. On the other hand, there is a high level of wood components, around 95% compared to the wet process. Another advantage is the reduced amount of energy needed, around 40% less than the wet process leading to lower CO_2 emissions associated with it's production.

2.2.2. Wet Process

The wet process turns wood chips into a pulp through a steam-pressure method and water is added afterwards. This creates a wood fibres pulp that is moulded with the excess of water removed, with boards left to dry at temperatures between 160 and 220 °C, see Figure 6. This process does not usually require binders and in case they are applied, the quantities are marginal.

The insulation produced with the wet process has a higher density, offering better thermal and acoustic performances, furthermore, moisture is better controlled. However, the overall manufacturing process is more expensive and less environmentally friendly. Figures 2 to 5 show images of the wet production cycle courtesy of Gutex and Green Spec [4].

Figure 2: Wood chips and shavings mixed in water

Figure 3: Wood-water mix is delivered into a mould

Figure 4: Mix is prepared for pressing

Figure 5: Mix after pressing

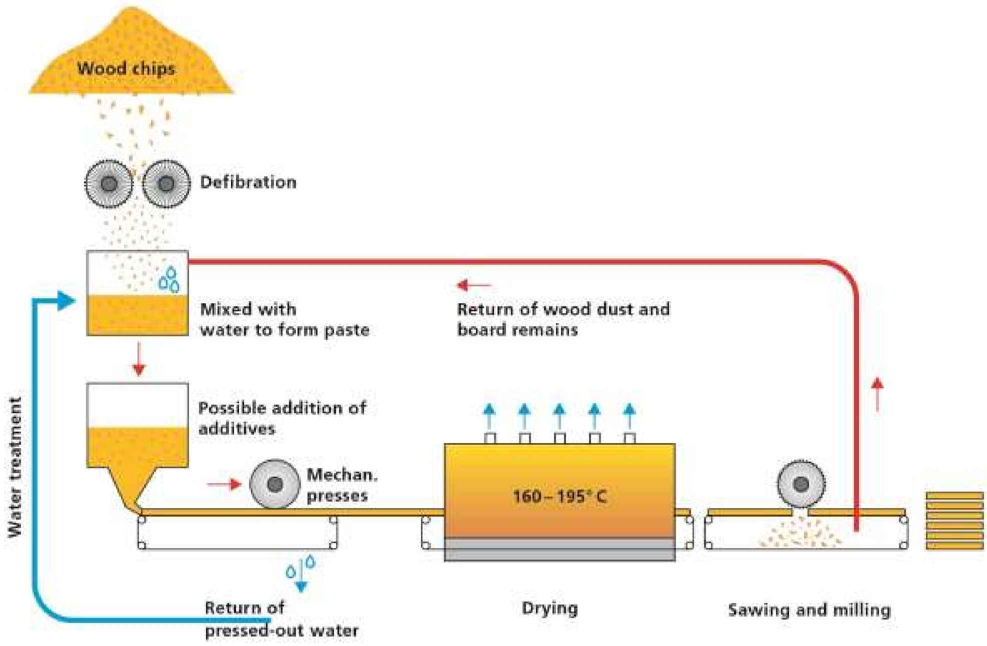

Figure 6: Wet process Steico wood fibre producing company [3].

2.3. Product characteristics

The products of nine mainland European companies were analysed. Three out of the nine companies currently dominate the wood fibre insulation market in the UK. In addition, the products of three medium-size companies and three small-size companies have been investigated. Figure 7 shows the country of origin of the nine companies.

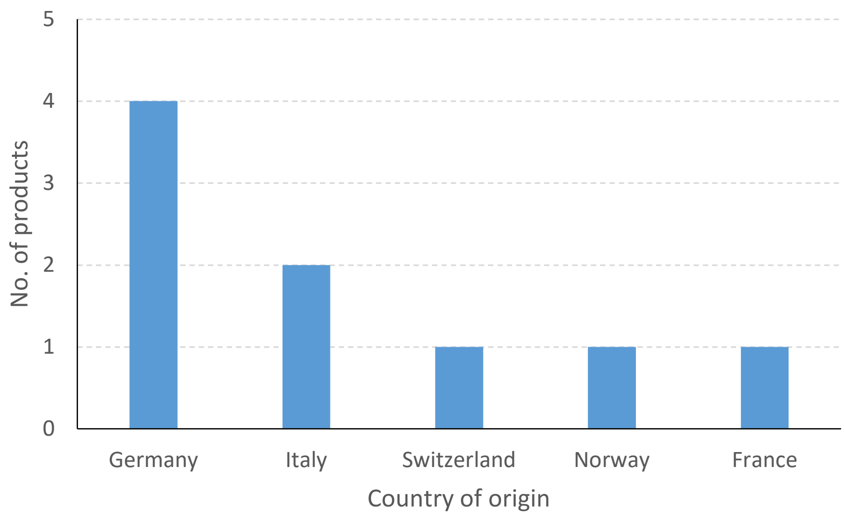

Figure 7: Number of products per country of origin.

The products by each company have been compared to understand their characteristics and performance based on three identified products commonly available in the market.

2.3.1. Hygrothermal properties

Hygrothermal characteristics include the materials density, thermal conductivity, specific heat capacity, thermal diffusivity and water vapour diffusion resistance, all of which have been evaluated.

- **Thermal conductivity** or lambda value (W/mK) represents the ability of the material to conduct heat through its mass; the lower its value the slower heat passes through it, hence more insulating by limiting heat loss.

- **Specific heat capacity** (J/KgK) is defined as the amount of heat necessary to raise the temperature of one unit (kg) of material by 1 unit of temperature (1K). This characteristic is also important for absorbing heat and limiting the rapid release of heat between elements.

- **Thermal diffusivity** (mm^2/s) combines thermal conductivity, density and specific heat capacity and is a good indicator of overall thermal performance. Thermal diffusivity for insulation products is an important value because it refers to the ability of the material to transfer and store heat but also limit heat passing through it rapidly. The lower its value the better the insulation product performs.

Wood fibre insulation products are analysed below in Table 1, loose wood fibre products, Table 2 flexible batt products and Table 3 rigid board products. Product names and producers have been anonymised, however, what's important in this analysis is the comparison and their performance.

Product	Density (kg/m^3)	Thermal Conductivity (W/mK)	Thermal Diffusivity (mm^2/s)	Specific heat capacity (J/kgK)
Wood Fibre (loose) A	30-60	0.038	-	2100
Wood Fibre (loose) B	28-38	0.041	0.70	2100
Wood Fibre (loose) C	25-50	0.038	0.36	2100
Wood Fibre (loose) D	32-45	0.038	0.48	2100
Wood Fibre (loose) E	32-45	0.038	0.48	2100

Table 1: Characteristics of loose wood fibre insulation products

Flexible batts are produced by six companies, and most of the products analysed present the same characteristics. As shown in Table 2, two types of flexible batts, produced by the same company, have lower specific heat capacity values, affecting their thermal diffusivity results.

Product	Density (kg/m^3)	Thermal Conductivity (W/mK)	Thermal Diffusivity (mm^2/s)	Specific heat capacity (J/kgK)
Flexible Batts (5 Companies)	50	0.038	0.362	2100
Flexible Batts (1 Company)	40	0.038	0.779	1220
Flexible Batt B (1 Company)	55	0.036	0.532	1230

Table 2: Characteristics of loose flexible wood fibre batt products.

Rigid boards with medium and high density are produced by all nine companies, as observed in the flexible batts two rigid board products produced by the same company, have lower specific heat capacity values, see Table 3.

Product	Density (kg/m^3)	Thermal Conductivity (W/mK)	Thermal Diffusivity (mm^2/s)	Specific heat capacity (J/kgK)
Rigid Board medium density (8 companies)	110-160	0.037-0.043	0.122-0.169	2100
Rigid Board A medium density (1 company)	110	0.041	0.296	1260
Rigid Board B medium density (1 company)	140	0.042	0.238	1260
Rigid Board high density (8 companies)	180-270	0.043-0.052	0.085-0.127	2100

Table 3: Characteristics of Rigid wood fibreboard products

In terms of the wood fibres capacity to manage liquid and vapour moisture (hygroscopicity), three characteristics should be analysed in detail. As shown in Tables 1, 2 and 3 the specific heat capacity ranges between 1200-2100 J/kgK which is the expected range in such fibres from all timber sources. However, as the density varies the amount of heat storage and its thermal conductivity will vary, shown in the thermal diffusivity as explained above. The manufacturing process provides a determining factor as those made using the wet process are denser and have a higher water vapour diffusion coefficient between 3.5 and 5 making them less vapour permeable. The dry processed boards are more vapour permeable due to their open structure and lower density. Their diffusion resistance coefficient can be 3 or lower. Flexible batts are less dense and have a lower diffusion resistance coefficient of approximately 1. However, a far more important characteristic is the varying liquid transport capability, i.e. how much liquid can be quickly absorbed and transported through its pores, dissipate and evaporate out (if allowed) avoiding moisture accumulation in the component (wall, roof or floor). Wood fibreboard manufactured using the wet-processed with a similar high density as originally grown as a tree is capable of moving moisture, therefore, is considered to have a high liquid transport. The dry processed boards with polyurethane resin coats, whilst being very vapour-permeable, are not able to transport moisture very quickly, as individual fibres are bonded together which prevents the transfer of moisture between them. Table 4 shows the vapour characteristics of wood fibre insulation types. The flexible bats have a moderate liquid transport as they are less dense and considered with loose fibres bonded close together but generally considered as not being as good at transporting moisture.

Wood fibre type	**Density (kg/m^3)**	**Specific heat capacity (J/kgK)**	**Vapour diffusion resistance coefficient**	**Liquid transport**	**Compressive strength (kN/m2)**
Wet process	140-250	2100	3.5-5	High	50-280
Dry process	100-200	2100	3	Low	50-200
Flexible batts	40-60	2100	1	Moderate	n/a

Table 4: Water vapour and liquid transport properties of wood fibre insulation manufacturing processes.

The compressive strength of the three types depends on the products intended use. Boards that are fitted in between a frame tend to be square-edged resisting about 50 kN/m^2, however, in high-density boards with tongue and groove edges they can resist between 200 and 280 kN/m^2, intended for larger loads such as those in roof sarkings.

2.3.2. Fire

All the products analysed are E classified for combustibility according to the BS EN 13501-3 Euroclass. This category means wood fibre insulation is considered a combustible material due to its flammability, thus igniting easily at ambient temperatures. However, due to the high thermal and heat capacity, the penetration takes longer though it and fire in close contact takes longer to spread and just like any wood-based element, it tends to char rather than ignite and disintegrate quickly.

Additionally, a further review of the products has shown that when wood fibre insulation is used in building elements, it could reach a fire-resistance rating of REI30 to REI90, i.e., between 30 and 90-minute fire protection until it penetrates and spreads further. However, the UK Government states that in the past five years, the most common cause of death during a building fire has been by gas or smoke inhalation, causing 25% to 30% more deaths than fatal burns [5]. Despite this, in the event of a fire, wood fibre insulation emits less toxic gases producing up to ten times less smoke than plastic-based insulants [6].

2.3.3. Waste

All the products were analysed to comply with current European Waste Codes (EWC) 030105, similar to other non-hazardous waste products and materials such as sawdust, shaving oils, cutting residues, wood and particle board. Additionally, it achieves the EWC 170201 code classified as wood. Consulted during this review were Environmental Product Declarations (EPDs) which state that wood fibre insulation products can be reused for the same application or a different one, provided that the product is not damaged or contaminated. In addition, wood fibre insulation products are biodegradable and used as biofuel as it provides a calorific value of approximately 19.3 MJ per kg, with the potential to generate heat and electrical energy.

The waste disposal and re-use of a product and its capacity to be recycled and disposed of appropriately at its end of life are becoming increasingly important. There are three main aspects that the analysed companies prioritise:

- use of waste wood as an energy source during the manufacturing process;
- products at their end-of-life can be recycled or used as an energy source;
- removal of any formaldehyde emissions from products.

Wood fibre insulation can positively contribute to a buildings circular economy as it's a product that can be re-used and recycled and once in its end of life is naturally disposed without ending in a landfill like other products. However, other insulation products such as stone wool insulations claim to be recyclable and dedicated recycling facilities are available in the UK [7]. A study comparing the types of insulation products that were recycled and disposed of appropriately found that the UK recycles 33% more EPS/XPS insulation than many EU countries [8]. The main reason EPS/XPS insulations are not recycled is due to their condition after use and demolition [8]. A study conducted by the University of Sheffield has shown that wood fibre insulation boards are 50% more resistant to compression compared with EPS boards and phenolic foam, thus resulting in less damage during its extraction at the deconstruction stages, benefiting the collection and recycling process [9].

2.3.4. Toxicity & Health Benefits

During this analysis, it was found that wood fibre content in products ranged between 80 % and 98.5 %. Synthetic materials used as additives in the products were used as binders and flame retardants. Binders constitute between 3.5%- 6.5% of the mass for rigid boards produced with the dry process, and up to 10% in flexible batts. Only one company out of the nine analysed uses natural starch as a biological binding agent for the wet process. Flame retardants applied to flexible batts constitute between 1.3% and 8% of products total mass. Rigid boards typically contain hydrophobic agents such as paraffin which constitute less than 1.5% of the products total mass.

Furthermore, four companies out of nine have the NaturePlus certification for some of their products. The requirements for the certification are as follows [10]:

- only mineral additives are allowed as flame retardants;
- waterproofing agents should not exceed 2% of the dry weight of the product;
- synthetic binding agents should be limited to ≤4% of the dry weight of the product.

Also worth considering are the benefits to occupants wider health where the use of natural materials can improve people's perception of space and provide more calm environments to work and live in. Although wood fibre products are often hidden within the building fabric, the hygrothermal benefits of moisture and heat balancing have an overarching effect and positive impact to occupants.

2.3.5. Well-being potential – Indoor air quality

Buildings are occupied by people, and the indoor environment quality is vital for their health. Biological and chemical pollutants in products in closed environments tend to have high contents of volatile organic compounds (VOC) often associated with construction materials.

For instance, there is substantial evidence to show negative effects to occupants in buildings that have been exposed to sprayed polyurethane foam (SPF) insulation with unreacted methylene diphenyl diisocyanate (MDI) [11]. Side effects include negative and increased occurrences of asthma, itching and burning eyes, headaches, dizziness, and difficulty in concentrating. Dzhordzhio et al. in a recent academic paper of 2020 [12] conducted a study on the effects of isocyanate board insulation (PUR/PIR) and spray polyurethane foam (SPF) insulation products and their impact on indoor quality. Despite the risks of exposure of VOCs and SVOCs during the installation of SPF even after one month of its application, the long term effects of such products on the building indoor air quality (IAQ) has shown that occupants concentration and productivity diminishes resulting in staff absences and long term illness.

In contrast, fewer health risks are associated with the use of wood fibre insulation, mainly due to the product's moisture balance inside the building coupled with good building detailing to reduce thermal bridging and gaps in insulation. Evidence shows that if poorly designed or applied, regardless of what insulation product is used, this can lead to mould growth and other health problems. Volfa at al. [13] analysed the accumulation of fungi spores in insulation products and found that wood fibre insulation contained less fungi spores under similar conditions to other insulation products. However, the application of such products and their attention to detail in a building component was also a leading factor to its accumulation.

2.3.6. Acoustic performance

It is essential to consider an acoustic layer to absorb sound and provide acoustic performance in buildings. Sound insulation is achieved in three ways: reduction of airborne sound or noises that move through the air (e.g. talking, music, traffic noise), impact sound caused by something striking something else (e.g. footstep, moving furniture, rain noise) through walls, floors, ceilings and roofs and flanking noises those that travel through, under or over a sound barrier. This is the case of the building's structure using steel, concrete and timber. Wrapping around with high-density insulation is essential within structural components making sure that sound is absorbed and transmitted to a lower effect. Sound waves can travel through ductwork, over or under the best soundproof wall, and through hollow core doors. Insulation materials can provide acoustic performance, however, not all can minimise flanking noise in buildings. A useful characteristic is the products density, mass and position within the construction component and layer. Less so, is the thickness of the materials in absorbing sound, hence the importance of the product's density. In the case of wood fibre insulation, products often produced using the wet system, reaching densities above 100 Kg/m3, can support effective noise protection.

A product often used for sound absorption, instead of synthetic materials in ceilings are wood wool panels made from mineralised wood, making the building board breathable "vapour permeable", rot-resistant and durable. They have a good level of sound absorption especially at higher frequencies (acute tones) and are often coupled with a flexible wood fibre insulation layer. Wood fibre insulation products uniquely combine high bulk density with low thermal conductivity and thus equally support energy efficiency and noise protection.

2.3.7. Environmental impact

Most products with an EPD certificate as per the BS EN 15804: 2012 standard go through a life cycle analysis (LCA) that evaluates the product environmental impact by estimating a unit of declared material and its stages of use. These stages, also known as boundary conditions set specific criteria of the processes taken part to create a given product, each using different levels of energy and emitting carbon dioxide during it. This study purposes that as a minimum, as outlined in EN15978: 2011 and shown in Figure 8, a cradle-to-gate analysis is considered covering the product stage information A1 – A3 released during raw material extraction, processing and manufacture. However, some industry representatives and policy leaders are requesting stages C1-C4 extending to their end-of-life (EoL) and D beyond EoL and its re-use potential. In most of the EPDs consulted the biogenic carbon stored or sequestered in the product recently removed from the atmosphere, for example through photosynthesis and then stored in products manufactured from materials such as wood, straw or natural fibre. When referring to the global warming potential (GWP), products are assessed on gases released during their production process. Each atmospheric gas has a specific GWP, which allows the comparisons of associated CO2 emissions from 1 tone of a gas absorbed over a given time period also known as atmospheric residence times.

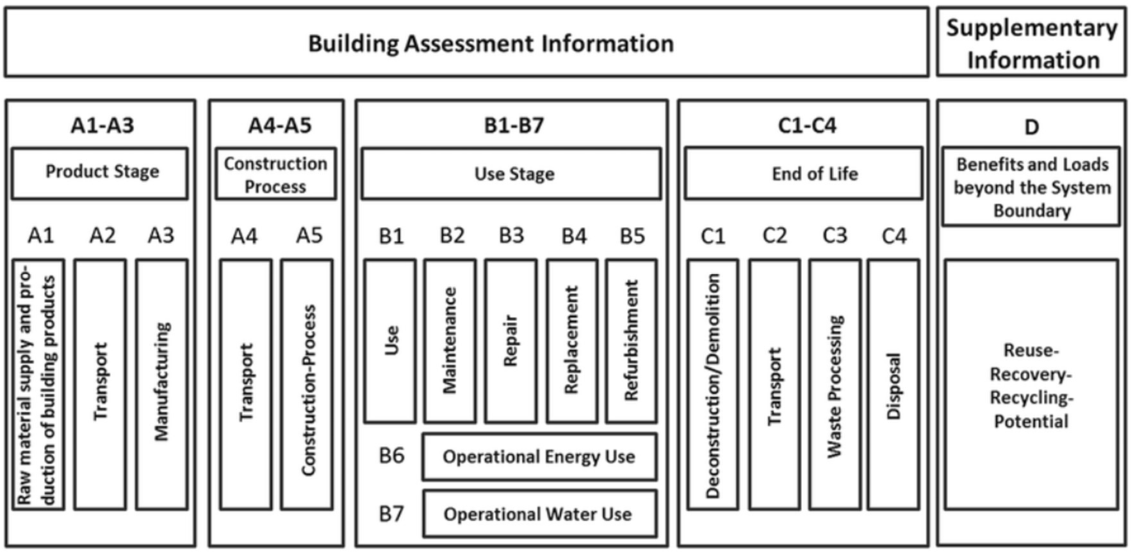

Figure 8: System boundaries according to EN 15804/EN 15978

GWP is often calculated relative to the emissions of 1 ton of carbon dioxide (CO_2) which has a very long residence time causing global warming through large concentrations over thousands of years. This is compared to methane with an average residence time of 10 years. The GWP of construction materials calculates the amount of carbon released during its lifetime. Some carbon will be released during its A1-A3 stages, however, it may balance itself with any carbon sequestrated or stored and its overall end-of-use and capacity to be re-used or go back to its original state (biodegradable or compostable) [14]. Its units of assessment are $kgCO_2e/m^3$ accounting for the carbon dioxide (kg) released for every cubic metre of material. The term embodied energy is also used in EPD certificates as a measure of the amount of energy required to produce a product or material. In most evaluations, there is a balance between the energy from fossil fuel and renewable energy consumed in each lifecycle stage of a product or activity including that used in extracting raw materials, the processing and manufacture of products, maintenance and repair and end of life disposal [15]. The unit of assessment is mega joules per metre cubed of material (MJ/m^3) and is often converted into kWh/m^3 of material and compared over the lifespan of a building, typically 60 years. Whole building evaluations are often performed alongside the building operational energy and converted into operational and embodied carbon emissions equivalent over 60 years ($kgCO_2e/yr$).

The GWP and embodied energy of wood fibre insulation products can show a contrasting result as it depends on the origin of the extracted raw material (trees), whether its sourced from recycled origins or directly from virgin wood. It also depends on the manufacturing process and the fuel source used to produce a product. Often, compared with synthetic materials, the embodied energy values can be similar and in some cases higher, however, the GWP can show some of the benefits and impact to the environment.

3. Literature review and the gap in knowledge

3.1. Wood fibre types and properties

The use of fibre products in buildings as construction materials and reinforcement has been widely explored in different forms and uses. Naturally sourced fibres such as; leaves (banana, pineapple, sisal), cereal straw (wheat, barley, oat and straw), palm tree (coir, palm fibre), bast (flax, jute, hemp) and wood fibres tend to be the most commonly used around the world [16]. Most are from agricultural waste products that often find themselves in landfills, however, they have enhanced properties through their strength, shrinkage control and formation of cracks [17]. If placed accordingly, natural fibres can have good thermal insulation properties and can enhance the regulation of temperature and humidity. Despite this, if not treated properly natural fibres tend to degrade over time making them less durable than synthetic equivalents [18]. Despite this, there have been efforts in making natural fibre products more durable by using chemical treatments such as certain coatings and substituting or blocking the hydroxyl group in the fibres by converting the organic compounds into alcohols, enhancing their solubility in water [16].

Wood fibres physical properties are important as they provide consistency for their various uses, not necessarily just for the production of insulation products but also as an aggregate in earthen construction. Wood is a ligneous plant that can be used as fibre, chips, sawdust or fine shavings for the formation of various products, including as by-products of chemical pulping processes. Their use increases the overall hygrothermal performance of a component therefore favourable as an aggregate or insulating layer. Work by A. Laborel-Préneron et al have identified both wood and cellulose properties as summarised in Table 5 below [19].

	Wood (fibre/ shavings)	**Celullose fibre (lingin fibre)**
Length:	0.3–2 cm	1.1 mm (mean)
Diametre:	0.025-0.05 mm	0.045 mm (mean)
Apparent density:	50 – 114 kg/m^3	-
Absolute density:	440 kg/m^3	-
Absorption:	240%	-
Thermal conductivity (λ):	0.035 – 0.054 W/mK	-
Specific surface area:	-	118.1 (10^{-3} m^2/g)
Specific gravity:	-	0.8-1.3
Melting temperature	-	200 °C

Table 5: Physical properties of wood fibre and cellulose fibre

Wood fibres themselves are difficult to use to form insulation products and typically binders are used to assist in the compression process of these products. Traditionally, synthetic insulation materials use polymers which consist of volatile organic compounds (VOC's) that are toxic for health and the environment often difficult to re-use and recycle. Much research has been done on using bio-based composites as binders with comparable performance to petrochemical-based products. Various examples exist to combine bio-sourced binders and natural fibres, such as wood fibres using lignin, tannins, proteins and oils, developed further by Lacoste et al [20].

Furthermore, Volf et al. [21] have investigated other properties of wood fibre insulation products such as the Thermal diffusivity at 0.39 m^2/s, heat capacity and absorption 0.12 J/m^{3}K and specific heat capacity at 240 J/KgK. Also exploring the density and thermal properties of wood fibre samples was Muthuraj et al. [22], who explored through laboratory small samples the differences between other natural products. A similar approach is taken by Pal et al. [23] who has analysed the thermal properties and composition of cellulose fibre insulation properties being comparable to other natural and recycled products such as cork, glass wool, recycled cotton and recycled glass fibre in the thermal conductivity values, however in moisture and air humidity can be used as a moisture buffer improving indoor thermal comfort and energy efficiency.

3.2. Performance in case studies

Work by Horvathova (2021) has compared various wood fibre insulation products to test the thermal and fire resistance in ventilated cladding in buildings. Fibreboard wood fibre insulation types were tested and those with bitumen content resulted in having better fire-technical properties than plain fibreboard insulation [24]. This research shows how the additives and binders used can be a determining factor in such products and something that needs more investigation inside building components.

Further research has been made on the moisture conditions of wood fibre insulation in timber frame walls, a typical combination used in dwellings across the UK. Results presented by Bunkholt et al. [25] highlight the moisture capacity of wood fibre insulation with the effect of forced convection of moist air. Various other insulation types are compared in a lab-based test showing the moisture conditions and their distribution and behaviour within the timber panel. The results show that wood fibre insulation presents the same risks as synthetic insulation, however, wood fibre absorbs condensation and can distribute it over a large volume minimising mould growth while others don't provide that quality.

To ensure the durability of traditional construction, natural fibres are preferable as they can let air and moisture vapour flow through it, minimising condensation build-up [26]. Retrofit studies have shown that they can also absorb moisture and release it again when the air is drier providing a hygroscopic performance. Indeed, the use of wood fibres is the preferred material for insulation in many studies, particularly in the retrofit of floors and roofs where 17% and 21% of studies focused on this material but only 4% of studies used it in walls [27].

In terms of the usability of wood fibre, case studies suggest that they are heavier to handle than similar comparable insulation, e.g., rigid wood fibreboards compared with rigid mineral wool or rockwool. That said, studies claim that when it is being installed it is easier to shave off or plane to fit into small spaces compared with polystyrene insulation that disintegrates and lose it ability to shape into size. Some interlocking tongue and groove systems offer a better installation assurance minimising gaps between panels. Installation was also regarded as easier and healthier to use, e.g., there are minimal toxic gases released, fewer synthetic petrochemical smells and more pleasant to the touch when handling compared with other synthetic insulation types [28].

Bianco et al. [29] compared wood fibre insulation with extruded polystyrene insulation (XPS) in a retrofit case study. The work showed that the wood fibre insulation once applied on a larger surface of a roof better controlled indoor air temperature fluctuation, influenced by the good thermal inertia properties of the material. It also states that the embodied energy of wood fibre insulation products is approximately 4,942 MJ/m^3 compared with XPS insulation which is 3,236 MJ/m^3 and for polyurethane insulation 3,045 MJ/m^3. Despite wood fibre resulting in a higher value, not considered are the sequestrated (absorbed and locked) carbon in the material which shows its negative global warming potential (GWP), compared with equivalent synthetic materials with a positive GWP.

In case study work produced by Historic Environment Scotland [30,31], the reduction of thermal transmittance is evident in walls, shown in a trial with 100 mm of internally lined wood fibreboards. The in-situ U-value tests showed an 80% reduction where 1.7 W/m^2K was measured between a pre and post-intervention set of tests. Similarly in a coom with 50mm wood fibreboard with a 50% improvement in measured U-values and in a flat ceiling that achieved an 80% U-value improvement using 100 mm of wood fibreboard. These results show the thermal benefits, however, it's was pointed out that a more local supply chain of insulation products is needed, but it was accepted that the scale of the demand needs to be greater for this to happen [32].

3.3. Wellbeing, health and sustainability

The health benefits of wood fibre products are particularly evident as they help to improve interior environments. Work by Korjenic et al. [17] shows that natural fibres, including wood fibres, have a positive influence on healthy living by retaining fine dust particles, reducing the level of noise and protecting the structure from weather effects. Wood fibre is vapour open therefore it allows moisture to pass through the building fabric without vapour barriers. It tends to regulate indoor climate conditions acting as a temperature and moisture buffer but importantly keeping buildings warm in the winter and cool in the summer. These benefits are important to maintain good indoor air quality benefiting occupant thermal comfort and reducing allergens and other respiratory health issues.

Compared with synthetic insulation, wood fibre products don't expel volatile organic compounds (VOCs) during their manufacture or after installation in the form of off-gassing. VOC's can be particularly damaging to occupants over a prolonged period causing the nose eyes and throat to lightly irritate, or cause nausea, headaches and dizziness. However, more concerning problems can be caused by synthetic petrochemical products causing allergic and non-allergic rhinitis, some respiratory cancers, liver or kidney damage and central nervous system damage [33].

Many of the toxic gases in insulation products come in the form of the binders, adhesives and fire retardants used. In wood fibre products some of these are either not used or substituted with organic equivalents, however, some flame retardants are still included but most products will substitute high VOC compounds for less harmful ones, for example substituting the normally used Boron retardants with Ammonium Sulphate retardants. Adhesives such as cellulose glues rather than other toxic glues has also been used against rot and fire. Others use boric acid as a flame retardant and Ammonium Sulphate as a hydrating agent [33].

3.4. Manufacturing and production

Although the manufacturing and production of wood fibre insulation often depends on the technology available in any factory setup, it has been suggested by Imken et al. [34] that it is the availability of the raw material that causes problems. In mainland Europe the timber industry has a shortage of coniferous (softwood) due to its rapid decline, therefore alternatives using hardwoods need to be considered. This investigation showed that the mechanical strength of hardwood fibres was significantly lower than for softwood fibres while water absorption was the opposite. This was also the case for the thermal conductivity of hardwood fibres that were higher than those for softwood fibres. However, hardwood fibre mixed with at least 20% of softwood fibres showed comparable results made from pure softwood fibres.

Wood fibre production and the life cycle of the whole process is also something that requires further thought due to the energy requirements and the processes required to produce insulation products. A study by Skinner et al. [35] showed that when monitoring the energy demand of a factory during the production process it was shown that 88% of greenhouse gases (GHG) emissions were directly associated with fibre production.

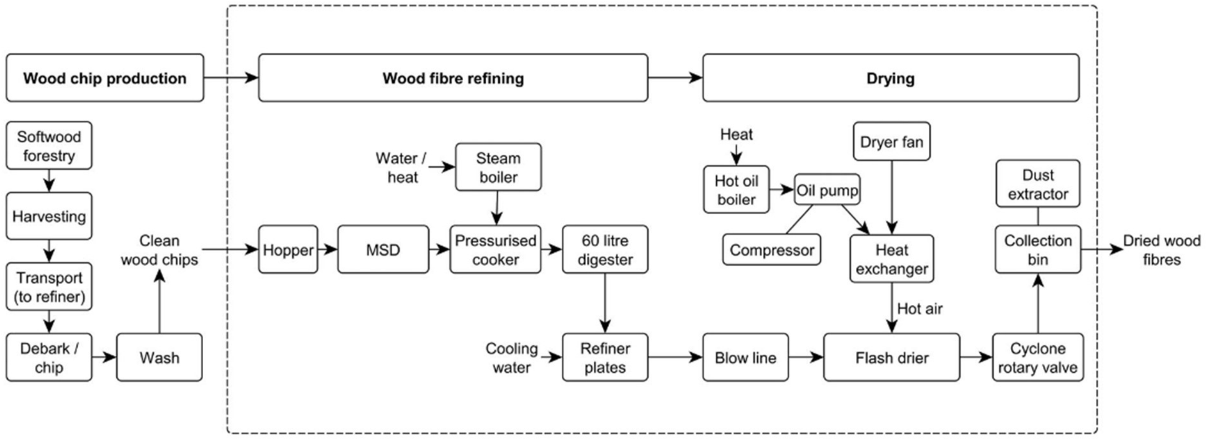

Figure 9: System boundary of a wood fibre production process by Skinner et al. (2016).

This research further shows the different energy uses per production stage exploring the variation in the fibre refining pressures providing potential savings. The research further explores the stages of production as shown in Figure 9 above, split between the wood chip production, wood fibre refining and the drying process.

The two processes, wet and dry as described in section 2.1 have been documented in many of the environmental product declaration's (EPD's) issued for certification and embodied energy and carbon emissions [36,37]. However, the distinctions between the two highlight the varying levels of energy consumption in the processing and also the additional materials/ additives required to create the final product. Predominantly, most products consist of 89.0 to 98.0 % of softwood, mainly Douglas fir or Spruce, with additional adhesives, binders and flame retardants that help form the products. In the wet process, layers are generally formed in 25mm sections and adhesives such as PVA glue are used to reach different thicknesses for the construction industry. Binders such as the use of paraffin and latex are mixed with water to form such layers, albeit in small percentages as shown in Table 6. Wet-processed boards tend to be better at transporting liquid moisture (capillarity) and generally have a higher density due to the wet slurry compression that is needed to create the boards. Increased density generally leads to higher thermal inertia which helps to balance temperature fluctuations that can lead to overheating. There is also research that suggests that this higher density improves sound absorption.

During the dry method and particularly for high-density products (200-240 Kg/m^3), paraffin wax is used together with a polyurethane resin, PMDI glue (isocyanate) and latex as binders as described in Table 7. The pDMI glue is also used in OSB and MDF boards regarded to be very stable and inert without off-gassing during application and throughout its use. Often used for roof and timber-framed wall applications, the dry method is generally less dense with varying thicknesses obtained in a single layer. The flexible and less dense products, (circa 50 Kg/m^3) fibre binding additives such as polyamide are used as well as flame retardants such as ammonium phosphate. Further research is needed to meet current certification and regulation requirements and substitute toxic and petrochemical additives with natural and less harmful equivalents. One such research was developed by Kirsch et al. [38] into the manufacturing of wood fibre insulation boards using the dry process with an innovative curing method combining hot air and steam methods with the use of the Laccase-Mediator-System (LMS) with an enzynatic binder instead of other additives conventionally used. It was found that by using these heating methods with LMS instead of pMDI's a better lignin repolymerization was obtained meaning fibres bonded adequately without the use of harmful additives. Further work by Bouajila et al. [39] shows this relationship between water and temperature concerning the thickness and the location of pressure on the wood fibreboard which enhances the plasticisation of lignins in the fibres.

Name	Value	Unit
Softwood	89.0-98.0	% abs.dry
Paraffin	0.5-1.5	% abs.dry
White glue PVAc	1.5-2.5	% abs.dry
Aluminium sulphate	0.5-1.0	% abs.dry
Starch	0.5-2.0	% abs.dry
Flocculant	0.02-0.04	% abs.dry
Latex	1.5-4.5	% abs.dry
Soda max.	0.35	% abs.dry

Name	Value	Unit
Softwood	95.2	% abs.dry
Polyurea	4	% abs.dry
Paraffin	0.7	% abs.dry
Aqueous polymer concentrate	0.14	% abs.dry

Table 6: (left) Typical wet process material composition – 200 to 240 kg/m^3 density

Table 7: (right) Typical dry process material composition – 210 kg/m^3 density

Advances in reducing the softwood content in wood fibre insulation have been explored by Imken et al. [34] with the use of hardwoods, however, alternatives such as the use of bark, often difficult to process and re-use in other industries, were developed by Kain et al. [40]. This method researched the alternatives in the use of larch bark as insulation boards by testing the mechanical properties and hygrothermal performance. The results showed that the barks particle orientation and density influenced performance, those placed in a vertical direction were superior in the mechanical testing. However, in terms of thermal conductance, the two-particle directions had similar values, with horizontal directions being moderately better.

3.5. Market analysis

Prices for wood fibre insulation vary from project to project, and are subject to quantities and type used. While it may not be the cheapest insulation product on the market, the overall cost is competitive when the full performance benefits are taken into account [28].

The Roots for Growth report identified how the construction and housebuilding industries can benefit from the use of trees in low carbon building products [1]. This creates a market and pushes for better management of trees grown in Scotland by implementing technology and innovation to process and manufacture wood fibre for a variety of end uses [1]. The report advises on an improved understanding of forest ownership in Scotland as well as identifying new markets and supply chains creating new wood fibre products into the market. It also calls for more investment in new machinery and processes for market development by the individual companies.

Through different market reports, the UK insulation market was worth an estimated £1.5 billion in 2013 [40], with an expected 16% fall in market values produced by COVID-19 in 2020 [42]. Despite this, the insulation market has survived economic downturns, such as experienced in 2008-2010 in which it still grew by 25%. It is expected to recover in 2021 by a 6% increase and 9% in 2022 from pre-pandemic levels [42]. However, a split between synthetic and natural insulation products is not available. The market improves and is transformed further by government measures of energy efficiency and retrofit, for example, the 2012 CERT and CESP measures, the Green Deal and others. If a similar scheme is introduced, further changes and increased demand would be experienced.

Various forums and UK distributors of natural insulation products have estimated that between 2021 and 2022, the UK market has grown and is worth between £2 million and £3.5 million or less than 0.20% of the total insulation UK market. By contrast, as stated by the Alliance for Sustainable Building Products (ASBP) natural insulation materials in the EU represent between 5-10% market penetration. In France, for example, all public buildings require the use of at least 50% of total materials from natural sources by 2022 which creates an important driver for the uptake of natural insulation products. Past statistical analysis has shown that the UK represents a fifth of the total EU insulation sales. It is estimated that EU sales of natural insulation range between €250 and €300 million meaning the UK market can be worth approximately €55 million or just over £45 million, indicating room for growth on the uptake of natural insulation products.

Natural insulation imports from continental Europe have not yet been directly impacted from the trade changes introduced by Brexit. Discussions with UK distributors have highlighted that a slight delay in getting products has been due to increased paperwork when arriving on UK soil causing more bureaucracy in the approval and customs arrival. Changes in legislation, certification and product criteria and performance have yet to be experienced as a reform in UK standards different to the ones set up by the EU are yet to be fully imposed, however, it is expected to align with these given the product's type and origin. More of a concern is the delivery delays and shipping of such imported products into the UK. Due to shortages in delivery drivers, continued delays have created deficiencies in certain products including insulation products. It is difficult to speculate how the natural fibre industry has and will be affected by these changes, let alone how it’s impacted the whole insulation industry.

Addressing the production and manufacturing of wood fibre products requires an analysis of existing waste and supply chains in the UK. According to the latest forestry statistics [43] published in 2021 the following informs the capacity of timber in Scotland:

- In Scotland, combined softwood removals (FLS and private sector) were nearly 6.4 million green tonnes, of which just over 3 million green tonnes was consumed by Scottish sawmills, 50% of total UK sawmill deliveries;

- There were 47 sawmills in Scotland, of which 14 were classified as ‘large’ (production of 25,000m^3 /year or higher);

- In Scotland, 37% of large sawmills output went to the construction market, 33% to fencing and 22% to packaging & pallets;

- UK panel mills (manufacturing OSB, chipboard & MDF) consumed 3.8 million green tonnes of material, including 1.2 M tonnes of virgin wood fibre, 1.5M of sawmill co-products & 1M tonnes of recycled wood fibre.

Wood-based panels share similar processing methods to high-density wood fibre insulation boards. Currently, West Fraser has a production line for MDF and particleboard in Cowie near Sterling and a plant with a continuous press line at a higher density producing Norbord OSB in Inverness. Other sources of wood fibre supply could come from panel and paper mills, however, these may be considered more as consumers rather than suppliers. This creates an opportunity of shared production and machinery setup where cellulose and high density wood fibreboards could be produced in-situ and contribute to its use in Scotland.

If Scotland was to meet the expected £2 million UK market of natural fibre insulation demand (2021-22) with wood fibre insulation using homegrown timber, assuming this is met by high density boards:

- a 1m^2 rigid wood fibreboard with a 100mm thickness weighs approximately 10kg. On average 95% of the board is virgin wood fibre, i.e., 9.5 kg;

- using a proxy of an average of £30/m2, around 67,000 wood fibre boards would need to be produced. (£2M/£30 ~ 67,000);

- This leads approximately to 640 tonnes (67,000 boards @ 9.5 kg/board) of virgin wood fibre would be required to meet current demand. Suggesting that, in the context of the overall domestic softwood market there is sufficient capacity to source current required wood fibre inputs.

3.6. Gap in knowledge

There are clear gaps in research and industry approaches that need to be explored further. This document will try and explore these and create some dialogue around the needs and ways forward in the creation of a homegrown insulation product using wood fibres.

In terms of performance, there needs to be a further investigation into how a homegrown product will perform against the existing EU products. Tests need to be made using fibres from Scottish grown soft and hardwoods with different additives and binders, procuring a natural and environmental equivalent. A focus on the processes will help to plan on the type of products made for trials and performance checks based on the available infrastructure and partnerships in Scotland.

4. Market analysis & use of wood fibre insulation

This section of the report will be expanding on the analysis made of the current market and uptake of wood fibre insulation in Scotland. An explanation of the synthetic insulation competitors and their products as well as a description of the current market leaders in wood fibreboard and their UK distributors.

The following is a description of the current market drivers for insulation and specifically natural insulation products with a focus on wood fibre. This section will provide a demand-side analysis based on opportunities offered by government funding with a focus on the built environment.

An industry perspective is described through the results obtained from several surveys and interviews deployed to distributors, EU manufacturers and representatives from the housing and construction industry in Scotland. This is followed by parametric analysis of existing products linked to the matrix in Appendix A.

4.1. Current scenario

Insulation materials can increase the thermal resistance of building components by limiting the flow of heat through them, a quality that is dependent on the product thermal conductance value and the thickness installed. There are many different types of insulation in the market ranging from synthetic, natural and recycled types. A distinction that sets them apart is their composition and performance based on the laboratory tested thermal conductance value and the vapour permeability values – amongst other characteristics, that determine the rate of heat flow and how it manages (absorbs and release) vapour and humidity through it. Generally, products that are vapour open with typically a low vapour permeability value are regarded as open-cell insulation whilst closed-cell insulation can have higher vapour permeability values limiting the flow of vapour and humidity.

A good example of open-cell material is glass wool insulation as it has many air pockets around its glass fibre layers, however, this air remains encapsulated inside it limiting heat transfer by convection. A closed-cell or high vapour permeable product example would be extruded polystyrene insulation that traps bubbles of gas with a very low thermal conductivity added during its production. With these two distinctions, there can be variances and degrees of the cell size and hygrothermal behaviour, distinguishing the products apart. Other important factors are their ease of installation, shrinkage, compaction and settlement as well as their thermal inertia or capacitance.

4.1.1. Synthetic insulation – leading competitors

Synthetic materials can be divided into five categories; 1) Quilt or blanket batts, 2) Foams (sprayed or as rigid panels), 3) Radiant film insulation, 4) Blown-in, 5) High performance. These can be summarised in Table 8. The key advantage of synthetic materials is that they are readily available and as a result have a lower cost per board and m^2. However, they have many disadvantages such as their petrochemical origin, levels of toxicity during production and some after being installed as off-gassing of chemicals. Some products are considered as being more environmentally friendly than others, with some originating from recycled sources or bi-products of other manufacturing processes. The UK is a leading country in the manufacture of such products and although the environmental credentials are poor, the manufacturing process itself is considered low energy as many industries are introducing the use of renewable technology and low carbon transportation schemes to suppliers.

	Product description	**Product availability**	**Thermal conductance value (λ, lambda value)**	**Vapour type & behaviour**	**Typical use**	**Product examples**
	Glass Mineral wool – origin, recycled molten glass.	Batts and rolls	Circa 0.035 W/mK	Open-cell	Open/ closed timber panels, roofs and floor cassettes.	Knauf earthwool, Isover, Superglass, etc.
	Rock mineral wool – origin: rock (stone), furnace molten rock.	Boards, batts & rolls.	0.032 – 0.044 W/mK	Open-cell	Open/ closed timber panels, roofs and floor cassettes.	Rockwool, Knauf Rocksilk, etc.
	Icynene foam	Wet spray foam, poured	Circa 0.039 W/mK	Closed-cell	Sprayed on roof rafters and joists, floor joists and open panels, cavities.	Icynene

	Penolic foam, resole resin.	Rigid boards,	Circa 0.018 - 0.023 W/mK	Closed-cell	Roof external or between rafters/ joists. Cavities in walls, perimetres floor.	Kingspan Kooltherm, Celotex,
	Polyisocyanurate/ Polyurethane foam (PIR/PUR), organic compound polymer	Rigid boards (foil backed), foam (sprayed)	0.023 – 0.026 W/mK	Closed-cell	Roofs and walls.	Celotex, Kingspan.
	Expanded polystyrene (EPS), an aromatic polymer made from the monomer styrene	Boards and loose-fill (injected)	0.034 – 0.038 W/mK	Closed/ open cell	Roofs, walls, cavities, floors.	Jablite, Kingspan.
	Extruded polystyrene (XPS)	Rigid boards	0.033 – 0.035 W/mK	Closed-cell	Roofs, walls, cavities, floors.	Jablite, Kingspan, Stylite
	Aerogel, porous ultralight material derived from a Silica gel.	10mm quilts	0.014 W/mK	Closed-cell	Walls, internal insulation.	Proctor, Spacetherm, Thermoblok.

Table 8: Synthetic insulation types

4.1.2. Natural insulation manufacturers & UK distributors

Sales of natural building products in the UK are mostly through leading distributors who have a direct supply of products from mainland Europe. They are often representatives of the manufacturer only offering their specific products or they are a natural products wholesale company that distributes many products, including fibre insulation products and other natural materials. In Scotland, the leading materials general builder's merchants (B&Q, Wickes, Travis Perkins, Jewsons) do not supply natural insulation products. However, there are smaller retail merchants that state on their websites that they can stock certain natural fibre insulation products, but often can't supply small quantities. An identified challenge in the natural insulation distribution is that natural insulation has a low value to volume ratio, making it an expensive item to stock [41]. Table 9 below outlines the leading companies in the EU.

	Country of origin	Company	UK office or distributor	Scottish Supply Partner
	Germany	Best Wood Schneider	Tŷ-Mawr Lime Ltd, Powys.	-
	Switzerland	Pavatex	Natural Building Technologies (Soprema)	-
	Germany	Steico UK Ltd	Head Office, Caddington.	Ultimate Insulation Supplies, Stirling
	Germany	Gutex	Ecological Building Systems UK Ltd.	-
	Germany	Unger-Diffutherm (UdiDAEMMSYSTEME)	Back to earth Ltd, Exeter.	-
	Italy	Beton Wood	Not available in the UK	-
	Norway	Hunton	Not yet available, looking for retailers	-
	France	Isonat (Buitex)	Not available in the UK	-
	Germany	Sonae Arauco's	Not available in the UK	-
	Italy	Natural BAU	Not available in the UK	-

Table 9: Natural wood fibre producers and UK distributors

4.2. Market opportunities & demand analysis

4.2.1. Policy and standards (Net-Zero)

A good evaluation of any insulation uptake depends on the current market needs driven by local and national policy changes and opportunities. In Scotland, a consultation on the Scottish Building Regulations and the proposed changes to Energy Standards took place between July 2021 and November 2021. Results are due in early 2022 with an ambition to apply changes later in the year. These changes will certainly require the improvement to the building envelope by setting new thermal transmission values (U-values) in new buildings. However, it is still unsure what guidelines for retrofit (if any) will come into place. For now, in Scotland, much of the guidance on the appropriate retrofit of buildings comes from technical documents, trials and best practices produced by Historic Environment Scotland. However, there is a gap between the guidance available and retrofit uptake, particularly in large developments owned by RSL's and local authorities and indeed by the private rented and owner-occupied properties both for the domestic and non-domestic sector. Incentives, grants or low-interest loans are available that drive the uptake of insulation, and if following best practices, by using vapour open insulation in pre-1919 solid wall thermal interventions, these should generate a healthy market, particularly in the net-zero performance requirements of existing buildings in Scotland [44].

A mass retrofit programme as proposed by Smith (2021) as part of the ZEST Task Group - Technical Working Group will deliver net-zero technical solutions for Scotland existing homes by supporting working groups to deliver energy efficiency at a large scale [45]. Proposals such as these would increase the demand for natural fibre insulation. In new buildings, and particularly the domestic sector, builders, local authorities and private house builders recognise the need to transition into low embodied energy materials, including natural fibre insulation. However, many are in that transition to trial out the way it is used in their homes or are sceptical in the uptake given the lack of suppliers and the increased cost.

4.2.2. New build sector

In a recent Programme of Government in September 2021, The Scottish Government committed to investing £3.5 billion in the current parliamentary term to build 110,000 affordable homes across Scotland by 2032. Within that amount, £1.8bn is allocated to make homes and buildings energy efficient and ready to achieve net-zero performance. This commitment requires local authorities and registered social landlords (RSL's) to increase capacity and provide a procurement route to deliver sites where homes can be built. A real challenge relevant to this document is to make the use of natural wood fibre insulation a mainstream option in the construction of these homes, competing against the existing insulation leaders and providing confidence to house builders of the technical and cost benefits.

Additional to a government buy-in, there needs to be a clear driver from minimal energy requirements that achieve at best operational net-zero performance to a whole net-zero approach that considers embodied energy of materials. This shift in the industry will increase demand for such products placing wood fibre insulation as a leading example of such carbon savings coupled with good energy performance.

4.2.3. Retrofit

At present any incentives or grants and low-interest loans are aimed at homeowners in existing properties who require energy efficiency interventions to increase the properties energy performance certificate (EPC) score and overall compliance environmental impact. However, it's important to highlight that many of the approaches are predicated on compliance calculations and prescribed performance, focusing on thermal transmission (U-value) improvement and not the wider benefits such as health, indoor air quality, thermal capacity (mas and inertia). The retrofit industry relies on the available synthetic insulation products and methods, certified and recommended by government groups who provide the funding and grants.

A good driver for the uptake of retrofit methods and materials has been the introduction of appropriate standards and interventions with certified designers, project managers, and coordinators such as the government's PAS 2035 scheme. It prioritises the holistic ‘fabric first’ approach where the building fabric is improved through insulation and a large emphasis on ecological and natural solutions forms part of this standard. Schemes and guidance of this type with adequate site supervision and coordination will increase the demand for such products, particularly if a focus on wider benefits is promoted.

Despite government legislation and certification of retrofit best practices, there have been many failed attempts to help homeowners in the retrofit challenge the UK faces. To name a few, the Green Deal and more recently the Green Homes Grants in England & Wales failed for many reasons out with the complexity of retrofitting homes and more around financial agreements, skills gaps, coordination and uptake. However, more successful schemes linked to case study approaches and trials such as Retrofit for the Future and Scaling Up Retrofit helped to show the benefits of insulation and the use of existing building methods compatibility.

Current support includes the energy company obligation scheme (ECO), which provides energy efficiency improvements including insulation and some heating options in low income and vulnerable households. Many Local Authorities and RSL’s take advantage of these to improve their current stock, however, these are delivered and installed by contractors with limited knowledge of the benefits brought by natural insulation such as wood fibre and instead choose synthetic products available by many suppliers at reduced costs and large quantities. In a recent survey of existing homes in Scotland under the ECO programme, only 59% of walls have insulation with the large majority (73%) through cavity wall insulation methods where wood fibre would not be an option. The remaining 18% of these insulated properties have solid walls where wood fibre can be applied by implementing internal and external solutions. The potential to apply insulation to solid walls is quite considerable as data suggests that 75% of private homes and 35% of the social sector homes built before 1919 remain uninsulated.

For private owners, there are 5 to 10-year low-interest loans provided by the Energy Saving Trust that cover most building envelope interventions, however, there isn't a best practice approach and most homeowners and contractors will not be aware of natural wood fibre insulation products on the market as currently, they are available as specialist products at a premium.

4.2.4. Alternative energy standards - Passivhaus

A building standard that is widely applied to buildings, particularly in mainland EU, is Passivhaus for new buildings and EnerPhit for the retrofit of existing buildings. It has remained since its conception a more operational energy demand reduction standard with very low levels of carbon emissions. Less so has been the focus of the origin, carbon content and environmental footprint of the employed materials despite most of their accredited and best practice construction details suggesting the use of wood fibre insulation. There are current case studies that explore the balance between the operational savings and embodied content of materials as considered by Crawford & Stephan [46]. Results have shown that a Passivhaus home emits more embodied energy than standard homes, mainly due to the additional materials used and the origin of these, with most sourced from petrochemical processes. However, Passivhaus predicates high thermal performance and currently, wood fibre insulation can be at a disadvantage meaning larger thicknesses would be required and additional material, compared to conventional (synthetic) high thermal resistance insulation products. Despite this, the Passivhaus Institute recognises the need to select low embodied energy products and components to guarantee a low carbon lifetime for the building.

4.3. Industry perspective

To obtain an industry perspective on the uptake of wood fibre insulation in Scotland and the opportunity to have it produced locally, a series of industry-focused surveys were deployed using a questionnaire to three sectors:

1. Built Environment professionals – Architects and Ecological designers
2. Wood fibre suppliers – Ecological building suppliers and representatives
3. Manufacturers in mainland EU - main company representatives

A fourth survey was performed as an interview with influential industry representatives of the delivery, construction and design of homes across Scotland. These represent the following companies and government groupings:

1. City of Glasgow Council, Housing Strategy and Investment
2. Link Housing Association, Registered Social Landlord
3. Places for People Group, Property Services
4. Stewart Milne Group, timber insulated panel systems manufacturer
5. Cala Homes, private housebuilders
6. Robertson Homes, Contractors of timber insulated homes

4.3.1. Adopted methodology

The methodology adopted in this research was an industry-focused cross-sectional survey, administered only one time as opposed to a longitudinal survey over extended periods using various surveys. Cross-sectional surveys provide researchers with a fixed snapshot in time and offer responses at a specific period, influenced by the current policy and industry circumstances.

For the questionnaires deployed to the three key sectors, scenario setting and specific statement questions were used to understand the respondent's attitudes and perceptions. These were divided into particular thematic sections to obtain a whole view of the adoption, market perception and challenges the wood fibre industry is facing in the EU, Scotland and the UK. For EU Manufacturers questions, it was critical to capture their current manufacturing and production as well as the complications and competition in the UK.

The following thematic questions were used:

1. Manufacturing of wood fibre insulation, raw material sourcing
2. The proportion of product range being wood fibre
3. Type of insulation products manufactured
4. Accreditation of wood
5. Cost appraisal
6. Thermal performance
7. Applicability to future building standards & Environmental impact
8. Growth in the uptake of wood fibre, export and UK demand
9. Impact and complications of Brexit

The thematic questions directed to the current UK suppliers of wood fibre insulation were asked to comment on the products they sell, the market dominance of wood fibre and how the UK market is shaped around natural insulation products. The following thematic questions were used:

1. Products sold and their properties (raw materials, environment)
2. Source of products – location
3. Expectation on cost
4. Impact of Brexit and the availability of products
5. Manufacturing capacity in the UK

The opposite end of the market was also provided with questions. It was important to obtain the thoughts and perceptions of Scottish professionals in the built environment industry. The following thematic questions were used:

1. Thermal and environmental performance/ credentials
2. Cost and added value
3. Recycling potential, longevity
4. Comparison with standard (synthetic) products
5. Availability in the market
6. Awareness of its benefits
7. Demand and UK manufacturing

The surveys were created in an online format and shared as a link in a personalised email. EU manufacturers were contacted via their marketing and public outreach teams whilst UK suppliers were identified through industry trade online databases contacting via email the company's main office and representative. Scottish design and construction professionals were contacted via chartered associations such as the Royal Incorporation of Architects Scotland (RIAS) and the Scottish Environmental Design Association (SEDA) members list. The interviews with key industry members were selected based on their sector, however, three strands were chosen: 1) Local Authority and registered landlords, 2) Private house builders, and 3) Off-site manufacturing companies/ contractors. Their survey was done via a 20 minute MS Teams video call interview which was recorded covering a wider discussion about the uptake of wood fibre insulation in their business. The responses were shown in a written interpretation with key bullet points providing a summary of the interviewee's point of view.

4.3.1.1. Results

The response rate of the questionnaire sent to EU wood fibre insulation manufacturers was 20% with only 2 responses from the 10 companies approached. For the UK suppliers, 6 out of 3 companies provided responses representing a 50% response rate. A similar result was obtained from the Scottish professionals but with a larger number of respondents. From the 20 professionals contacted, 7 were able to return a complete set of answers to the questionnaire with some very interesting outcomes and comments. The focused interview was well received with 6 industry representatives taking place out of the 10 approached, providing a 60% uptake. A summary of the general comments and some conclusions is available below.

4.3.1.2. EU manufacturers

The two companies who responded commented that they manufacture wood fibre insulation using the wet and dry methods from 95% wood sources. One of the companies mentioned that they had other product ranges other than wood fibre insulation. However, despite all wood originating from sustainable sources, their origin was different; one from EU forests and the other from non-EU forests. When asked about the cost of manufacturing wood fibre products there was a general agreement that they are more expensive than other types, despite remaining neutral in their performance against other products and agreeing it's a good material type for lowering the environmental impacts from buildings. A positive response came when asked about how wood fibre insulation products will help to achieve EU building standards with both agreeing that they can. Both respondents strongly agreed that the demand for wood fibre products is growing, this is despite agreeing that there is sufficient raw material (wood) but an insufficient manufacturing capacity to meet the demand. There was little agreement or disagreement in the effects on the production of wood fibre despite the fluctuating prices of timber in the EU. In terms of product exports to the UK, one company supplies directly and another both directly and indirectly to UK suppliers, however over the last 5 years, only 10% of their products are exported to the UK despite agreeing that UK demand is growing and that Brexit has resulted in paying higher import costs. Interestingly, they both strongly disagree that the UK has sufficient manufacturing capacity to produce wood fibre products which provides them with an assurance of the EU as a market leader. There was a negative response to the regulations and added measures brought by Brexit, demonstrating that it hasn’t affected these companies enough to comment on it.

In terms of volume sold in the UK, one respondent commented that it's between 45,000 m3 and 47,000 m3 per year and that a great deal of it is used for DIY applications under laminate and engineered floors. Generally, the impact of regulations from the EU after Brexit will result in CE marking changing to UKCA markings which will add costs, but most agree that Brexit is not the driver to producing homegrown wood fibre insulation as Brexit has not stopped sales in the UK and it continues to grow despite added layers of paperwork and legislation changes.

4.3.1.3. UK Suppliers

Three UK suppliers of wood fibre insulation were able to respond to the issued questionnaire. All three stated that their products originate from the EU, however, there was a split answer between the cost increase of wood fibre insulation against other types with one agreeing they were more expensive, another saying they were neither higher nor lower and another saying they disagreed that they are more expensive. In terms of thermal performance and lower environmental impact, all agreed such products have a higher performance and are less harmful compared with other equivalent products.

In terms of the uptake and demand of the products all three agreed that there has been substantial growth over the years, however, there is a feeling that Brexit is impacting the costs of these products with two respondents agreeing and one being neutral to higher prices being experienced due to importation constraints which clearly will impact customers who may be unwilling to pay such surges and go back to other synthetic products made in the UK. The three respondents were certain that the UK doesn’t have sufficient manufacturing capacity at present to meet the domestic demand for insulation products and that for wood fibre to be a leading product this would have to be stepped up with funding and partnerships with supply chains. Alluding to this last response, the three respondents are not convinced that in the UK there is enough raw material or materials are readily available to produce wood fibre products, which demonstrates that a clearer supply chain of fibre from timber supply chains is needed.

4.3.1.4. Professionals

The questions provided by the professionals were answered with an additional commentary which enriched the understanding of their use within the built environment profession. Concerning the thermal performance of wood fibre insulation, three respondents agreed it is better than other insulation products, with two others being neutral and the remaining two disagreeing. This causes a clear split in opinion, as some respondents may refer to the wider thermal performance and others only its ability to stop the flow of heat, which other products can achieve easier and with a reduced thickness. There is a recognition that wood fibre products are also better performing in the moisture balance and thermal mass, particularly in retrofit interventions of existing buildings. The respondents also agreed that the environmental benefits and their ability to be recycled and not go directly to landfills surpass those from synthetic equivalents, however, there are concerns about recycled cellulose fibres in its impact at processing stages.

Concerning the cost of wood fibre insulation, there is again a split opinion with some strongly agreeing that they are more expensive to buy and others disagreeing that they are more costly. The comments go on to say that although when comparing product-by-product the cost will be higher, there can be savings in other materials in the build-up of a component such as vapour control layers and other membranes to control humidity which would be normally used in synthetic materials. However, a reason for the increased cost was its lack of availability, and most respondents disagreed that wood fibre insulation was effectively marketed in the UK. However, despite most respondents agreeing that the demand for wood fibre is growing, the awareness of such products needs more attention as most think that there wasn't enough done to inform contractors and installers on its benefits and wide use in construction. This turns to the question about compatibility with standard construction details, and responses agreed mostly that they were compatible, however, adjustments would need to be made to accommodate the increased thickness to reach required U-values. This impacted the performance degradation and how long-lasting they are compared with synthetic products. Most respondents agreed on these characteristics but it depended on how well they were used and installed, which applies to many products in the construction industry.

4.3.1.5. Housing industry interviews

Appendix B shows the list of questions asked at the interviews with housing professionals in Scotland. The interviews turned out to be an interesting conversation focusing on the company's plans and perceptions of the adoption of wood fibre insulation in their house components and designs.

Question one: *Has your company/ LO considered changing to low embodied carbon (CO_2) materials such as natural, homegrown insulation (Wood fibre)?*

The first question asked whether the company is willing to adopt low embodied carbon materials such as wood fibre insulation in their designs, construction systems or procurement process achieving low carbon performance. A timber panel manufacturer mentioned that although they recognised the benefits and importance of the product, they were not prepared to adopt to such a product, mainly because of all the investment already made on their current designs and manufacturing process. A private house builder confirmed that they have been seriously thinking of changing and adapting it, however, they were concerned about the certification of their design and the problems the industry faces around fire regulations. There were concerns over the time needed to get systems approved and certified and a change of material would impact the company nationally across all their delivery of homes. A Scottish house-building contractor and timber panel producer told us that they had looked at the cost of changing some five years ago and have re-visited it recently as they considered it being critical in the whole life carbon of homes and the companies view to achieving a service that considers the circular economy of the built environment. When asking a local authority about their switch to adopting wood fibre in their homes, there was a positive answer particularly in adopting more low embodied carbon materials not just in new homes but also for retrofit purposes of existing buildings. The two registered social landlords (RSL) interviewed were very positive on the use of such materials and one mentioned that it was now part of their sustainability strategy moving forward to achieving net-zero compliance.

Question two: *What timeline have you set to change from synthetic materials/ insulation products to more natural or recycled materials such as wood fibre insulation?*

This question asked what timeline was set for the adoption of wood fibre or similar insulation. The timber manufacturer mentioned that they don’t have a timeline yet as they are a volume house builder and they would require large quantities to meet their needs at a cost and availability that was as reliable and accessible as with their current suppliers of insulation. The private house builder mentioned that they would conduct trials in the next 2-3 years seeking certification and assurance in performance. Hence, adopting it fully nationally within 5 to 10 years allows time for a whole business shift and that transition between existing and future sites. The other timber panel manufacturer and volume house builder mentioned that after previous consideration, they were planning to make the switch in their production and delivery factories in a 5 to 10-year timeline but were driven by the costs and driven by government legislation. The local authority was confident to include it in their procurement and specification request within the next 2 to 5 years, however, this was dependent on availability and cost as it would impact directly on the delivery of homes and the government funding towards this. After some trials using the material in retrofit projects, the interviewee was convinced this would be adopted thereafter in all projects. Similarly, one RSL mentioned that they are looking to do the shift to more natural insulation materials in the next 2 to 5 years as they were very concerned about meeting net-zero targets and embodied energy was going to be the next priority in their design and delivery of homes. The other RSL was cautious as there were still many barriers and estimated that this would take longer, and required a 10-year adaptation period.

Question three: *What principal barriers do you foresee in switching over from synthetic insulation products to wood fibre or other natural insulation types?*

For this question, a wider discussion on the different barriers was obtained which covered relevant options up to question eight of the interview and is summarised as follows:

The timber panel manufacturer and volume house builder identified that the industry as a whole has a gap in knowledge around the benefits and origins of wood fibre insulation, most house builders would simply don't consider it as a solution. However, there were concerns about meeting the volumes required for their use as a volume house builder and considered that the supply chain is still not there for it to be used in a production line. The cost was also a concern, as currently, the materials are more expensive, linked to demand and sourcing of the material, yet to be established, particularly considering the like-for-like difference in thermal performance to meet current U-values, requiring more material (thickness) and more cost per house. They were also concerned about understanding the benefits of thermal and humidity control of the products, which were not widely known by others in the industry, as well as slumping and fire certification. Their agreements with current suppliers were not fixed, but currently, they met their supply and cost which made them competitive as a volume house builder.

The private house builder mentioned that in the technical department there was a good knowledge of the products and their potential concerning performance and lower carbon emissions in their production compared with synthetic equivalents. However, they still thought it was in its early stages and considered an "infant technology". They thought there was a lack of skills in the contractor stage of the product but considered that upskilling would come and be rolled out quickly. Despite this, there was less of the knowledge and impact the switch would have in completed homes, particularly large quantities and the benefits it gave their clients. Which would hopefully be captured in a desktop study to begin with and a smaller development to learn from the experience rather than roll-out in all the sites. Concerning cost, there was still a hesitation to make the switch completely, so again a study would be done followed by a small project that could be observed and calculated in detail. They certainly thought that cost was a current concern, but volume and demand would hopefully lower this as the material was incorporated and its availability in the UK was assured. Most of the current agreements with material suppliers were fixed for certain developments lasting 2-3 years, but as a whole, there weren't any in place.

The other timber panel and house builder considered that switching to something new always required new knowledge and adaptation and new training, however, they did not see it as a difficult task as training can be in place and it is something they have been investigating since first considering it five years ago. Adaptation of standard house designs is something that has been investigated, as currently most details are focused on synthetic insulation products, particularly in the depth required to meet the same U-values. Some adaptation and training would need to be issued to understand these changes on-site, but once again this has been contemplated and is in the process. For example in the humidity and use of vapour control layers, when to use them, hence requiring fewer materials and complexity in the stages of build making it a “smarter build”. There were concerns over accreditation and knowledge of the house type approvals and national house building certification from NHBC and similar. Approval from these groups would need to be fast-tracked as there are worries this shift would delay guarantees for a project, thus prior discussions and work would need to be made beforehand. At the contractor level, they are confident that the knowledge can be acquired swiftly and without problems, given they have done it before not being considered a barrier to their adaptation as most prefer using it compared to mineral wool and it is a more healthy product. The cost aspect was a concern, particularly as the products were imported and security of supply was an issue. However, they have been in touch with current UK suppliers and were waiting for cost plans and possibly an agreement. In terms of prior agreements with existing suppliers, this house builder mentioned that there wasn’t a long-term commitment to a product or company, making it easy to switch as required in each project.

The local authority related to some of the barriers, but others were not a concern as it was more a problem faced by house builders and contractors. What they were prepared to do was to stipulate certain materials for certain projects, however, this added costs to a project often passed on to the occupiers to pay, particularly in retrofit projects. A barrier and concern were quantities needed and whether there would be a reliable supply at a reasonable price. The knowledge part of the adoption of wood fibre was not considered a barrier as it would be up to the contractor to upskill as demand increased for such products. What they were concerned about was that this up-skilling was done properly and it translated to the proper use at the end product and delivery stage. The cost aspect would affect directly the capital cost of projects and not necessarily a clear return of investment over a short time. For the retrofit of homes, it came down to the government subsidies and whether wood fibre insulation would fall under these options particularly if the cost was higher for them. All of which ends up impacting the tenants and contractors.

One of the RSL’s saw a switch to this material as a great way to shift people’s minds and increase the knowledge of meeting net-zero performance in homes beyond the operational carbon reductions done in a project. There was a lack of understanding and there are plans to inform staff better and prepare for such a change in the timeline agreed. However, the trades and contractors would adopt this change quickly in the short term. There are concerns over knowledge of the thermal and humidity benefits of such products and although some general knowledge was in place, the differences between existing synthetic equivalents were not clear, particularly on the impacts on health and the building performance. Also recognised were the changes needed technically which required a detailed brief to contractors and designers, however, this should be embraced well by the existing and future companies they work with. They recognised the cost barrier and sourcing as a concern, with set costs for house delivery which turned on to the number of homes finalised with the existing funding provided by the Scottish Government. The interviewee mentioned, if SG wanted homes to be net-zero, they needed to recognise that this will be an added cost using current supply and commercialisation setups reliant on imported materials. Therefore investment in these sorts of materials is required at the lower end and top end of the housing delivery.

Another RSL was concerned about all the barriers set out in the interview. There was a concern over the cost as this would make homes more expensive and to all the performance uncertainties linked to the skills aspect as many unintended consequences could surface if upskilling of trades was not delivered directly to on-site knowledge. There were also concerns over the warranties and clarity around its performance once installed, and how knowledge could be transferrable quickly enough. They do anticipate a higher cost given the origin of the existing products. Despite being from natural sources their concern is not so much cost, but that it delivers as stated on performance and overall embodied carbon emissions.

Question Nine: *Based on the UK and Scottish targets imposed to reach net-zero performance and the pressure for our homes to be more environmentally conscious, please answer the following:*

Do you consider this a driver for you to specify and switch to natural and wood fibre-based insulation?

This last question was answered similarly across all the interviewees. Most saw the adoption of wood fibre and others as a clear answer to meeting wider net-zero requirements, however with the consideration of all the barriers mentioned. The private house builder mentioned that the pressure from the government has been mainly around operational carbon emissions, however, the targets were becoming more specific and that other sources of carbon needed to be tackled, such as embodied carbon with the use of natural products. For the retrofit of homes, a real concern for local authorities, this goes beyond being a driver as there is a concern also for the longevity of solutions that are sympathetic to existing forms and materials, therefore different drivers are required.

4.4. Cost review comparison

Most wood fibre products are commercially priced as packets or pallets classified by their density; rigid board, flexible batt pack or loose-fill pack. Most suppliers will only sell the insulation in larger quantities for large projects or renovations by the pallet to facilitate transport. This makes it harder for smaller projects or even small DIY jobs to purchase individual or smaller amounts of insulation, compared with many synthetic equivalents available off-the-shelf by most building material merchants or large DIY stores (B&Q or Wickes).

The analysis of cost in Pound Sterling (£) between products considered four leading manufacturers that shared or displayed their costs as a price list on their website sold by UK distributors. The costs analysed of products was made randomly based on the availability of data, however, a common product type and thickness was prioritised to make a fair comparison between products and manufacturers. The analysis was based on the cost per board including tax but omitting transportation and delivery to site as this is based on the larger allowable packs or pallets ordered. Costs were normalised to provide comparable values, cost per thickness and the cost per square metre (m^2) of the product. To make a fair comparison all costs include basic products with plain edges and without rendered sides. The following Figures explain the differences including synthetic or other natural equivalents.

Rigid board insulation is often of a higher density using the wet process. The four products analysed by leading EU manufacturers have a mean cost per millimetre of insulation, considering a 100mm product, of £0.20/mm (Figure 10). In terms of the cost per metre squared of insulation, Figure 11 shows a mean value of £24.64/m2 between the products.

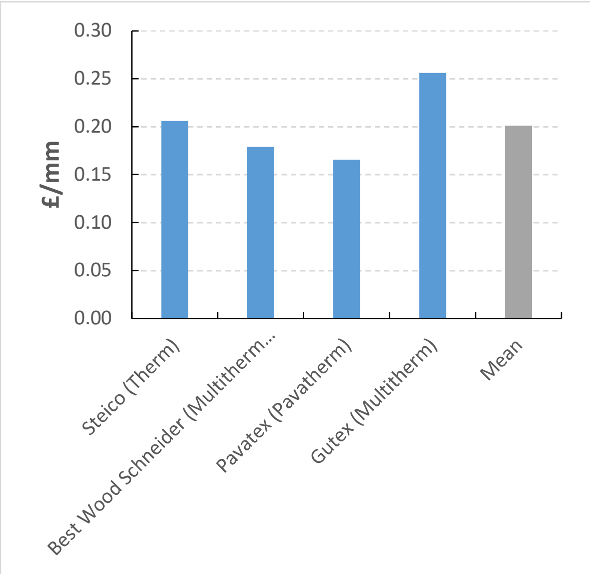

Figure 10: Rigid woof fibreboards by £/mm

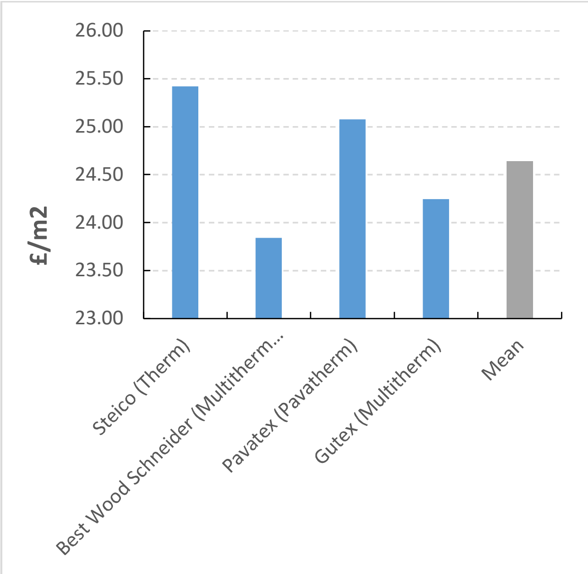

Figure 11: Rigid wood fibreboards by £/m2

A similar analysis is made of flexible batts of wood fibre insulation supplied to the UK by the four EU manufacturers. Figure 12 shows the costs per thickness difference between products with a mean value of £0.09/mm. Figure 13 shows the difference between the products and the cost per square metre coverage with a mean value of £14.40/m2.

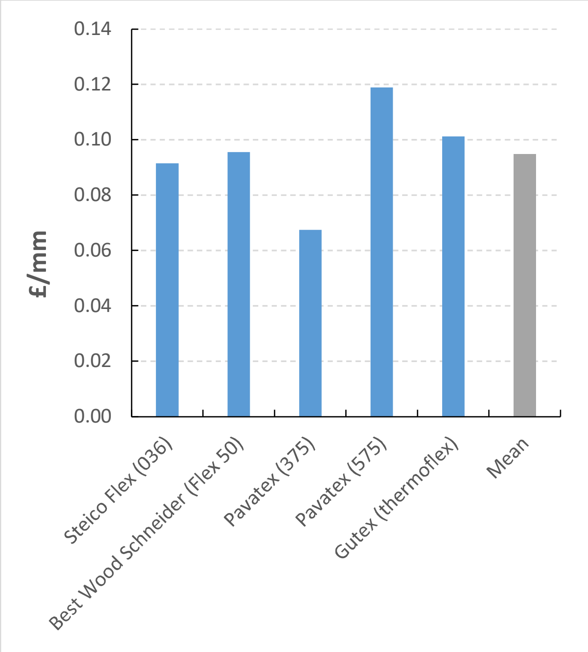

Figure 12: Flexible batts of wood fibre by £/mm

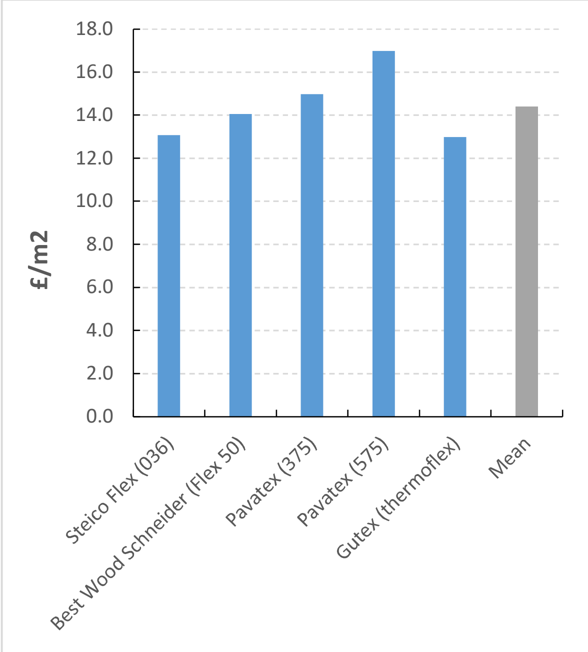

Figure 13: Flexible batts of wood fibre by £/m2

As a point of reference, a similar analysis is conducted with equivalent representative synthetic and other natural (hemp & cork) insulation products. Figure 14 shows the comparison between these products with a mean cost per thickness value of £0.18/mm. An analysing of the cost per m^2 coverage shows the mean value between the products is £18/mm. The value that outstrips the wood fibre products is that of PIR insulation which is three times more in cost per board but with a lower thermal conductivity value of 0.022 W/mK compared with all other products. Hemp fibre insulation remains competitive between synthetic and wood fibre insulation products, however, the granulated cork boards are double the cost, albeit with a lower thermal conductance value than most of the equivalent products. Figure 15 shows the cost per metre squared coverage showing that PIR insulation can compete with the other products, however, the granulated cork remains a higher cost per squared metre coverage. Low-density mineral and stone wool remains the cheaper option compared with all products.

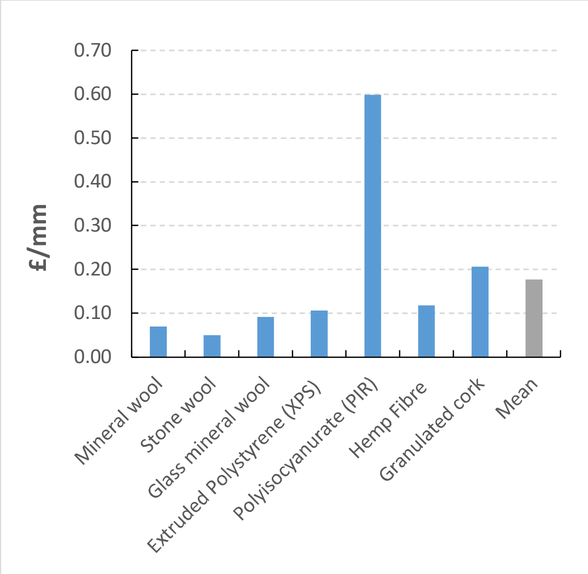

Figure 14: Equivalent £/ mm of synthetic and other insulation

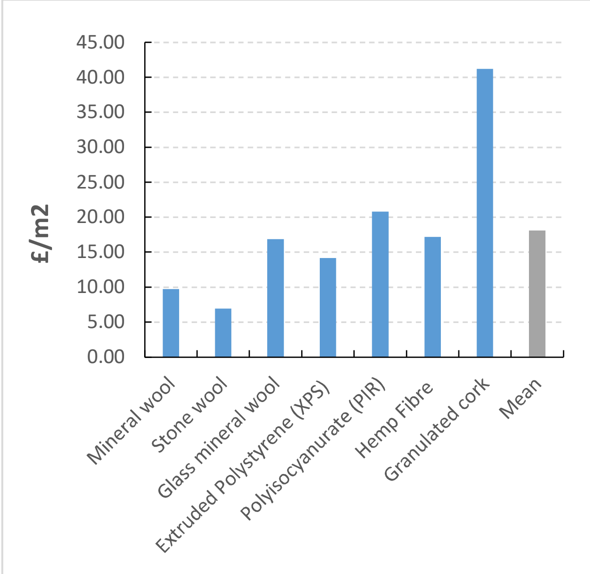

Figure 15: Equivalent £/ m2 of synthetic and other insulation

Loose-fill recycled paper and wood fibre were also analysed, however, these are compared separately as they depend on the areas covered, density packed into the gaps or cavities. The costs per bag covering 3m^2 remained similar at £6.10/m^2 and £6/m^2 at a density between 30-50 Kg/m^3.

5. Global Warming Potential (GWP) and Embodied Energy

Existing products manufactured in mainland Europe were analysed in line with the boundary conditions (cradle-to-gate) to understand the potential and also levels of environmental impact to aspire to in homegrown insulation in the UK and Scotland. Omitted from the evaluation are A4 – Transport and the subsequent boundary conditions leading to cradle-to-grave analysis which would require more accurate data of UK manufacture and specific uses. The following analysis compares products on their GWP and embodied energy but does not consider embodied carbon as specific fuel use is not specified in the product manufacture.

5.1.1. Loose wood fibre products

The data extracted for three (A, B & C) loose fibre insulation products shows that the manufacturing stage can add to the amount of carbon released into the atmosphere. Data shown in Figures 9 and 10 show that product (A) has an A1 stage of raw material extraction and production of -54 kgCO_2e/m3, however, its A2 stage for transport to the manufacturing plant is +61 kgCO_2e/m^3 and A3 for the actual manufacturing process +378 kgCO_2e/m^3 amounting to a total GWP of 385 kgCO_2e/m^3. Another product (B) shows a similar value for the A1 stage but much lower A2 of +0.25 kgCO_2e/m^3 and +14 kgCO_2e/m^3 for A2 resulting in a total GWP of -40 kgCO_2e/m^3. These two products show that the transportation to the manufacturing stage is negligible in product B meaning it is close to the location of the extraction of raw material compared to product A which can be several miles away. Similarly, in stage A3 of the manufacturing process, the carbon (CO_2) released by product A is much higher than product B meaning the latter is more efficient and uses cleaner fuels with renewable technology. Product (C) is wood fibre cellulose insulation composed of recycled newspaper. It presents very low GWP values and a total of just 4.8 $kgCO_2e/m^3$. This shows how the recycling origin and manufacturing process can make a difference, see Figure 16. In contrast, the embodied energy for products A, B & C is similar, 1385 MJ/m^3, 1000 MJ/m^3 & 915 MJ/m^3 respectively, with at least 48% of the energy required coming from renewable resources, see Figure 17.

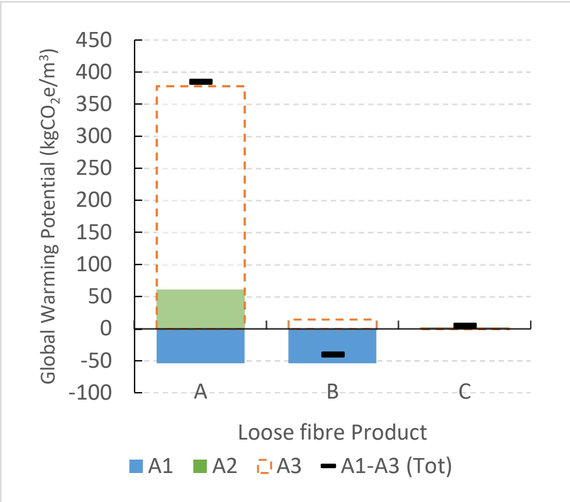

Figure 16: GWP of three loose fibre products

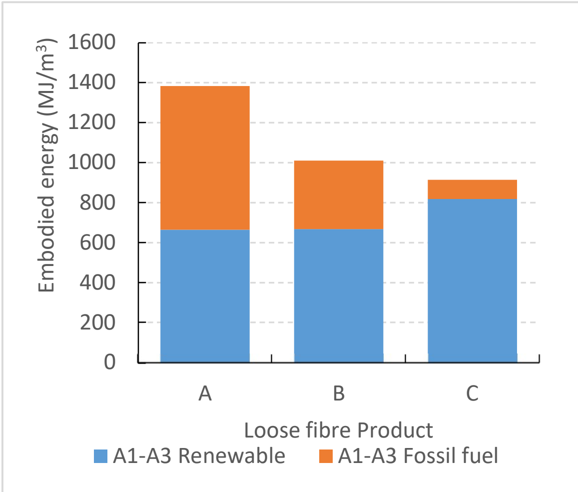

Figure 17: Embodied energy of three loose fibre products

5.1.2. Flexible wood fibre batt products

An analysis of six flexible low-density batts was performed using available data in their EPDs. Only two manufacturers provided a breakdown of the A1 to A3 stages for the GWP and embodied energy of their products. Figure 18 shows the total GWP for the wood fibre analysed products compared against equivalent synthetic products. Wood fibre products A to D show zero to negative A1 to A3 GWP totals, whilst wood fibre products E and F present a positive GWP value similar to the three synthetic equivalents. Details of these two products (E & F) are unknown but often the distance (A2) between raw material extraction and manufacture is long resulting in a high GWP impacting the total value.

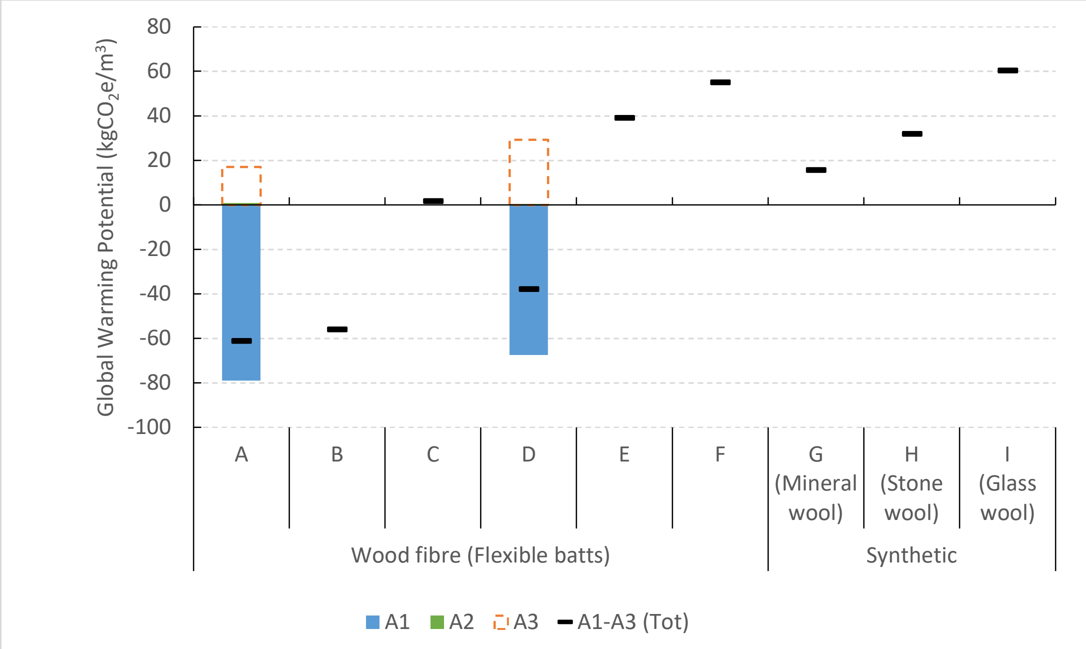

Figure 18: GWP for flexible wood fibre batts compared with synthetic equivalents.

Figure 19 shows total embodied energy including the six wood fibre flexible batt products and three synthetic equivalents. All six wood fibre products have a mean value of 1,950 MJ/m3 with all accounting for 50-60% of total energy provided by low carbon renewable energy. Synthetic equivalents average embodied energy is 970 ML/m3 and products are substantially lower than wood fibre products, however, most manufacture and material sourcing is at the same production plant and factory reducing transport energy. Most energy sources rely on fossil fuels with a small percentage from renewable sources of energy.

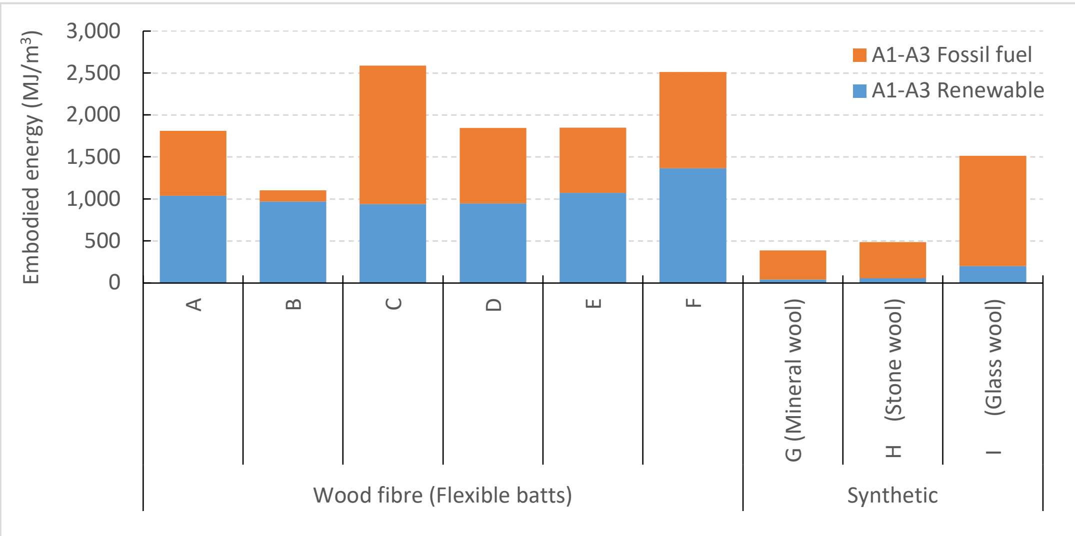

Figure 19: Embodied energy for flexible wood fibre batts and synthetic equivalents.

5.1.3. Medium-density rigid board products

Figure 20 shows the GWP for wood fibre medium-density boards (MDBs) against similar density board synthetic products. Another important distinction is the method of production, from a wet and dry process. MDB's products A to E using the dry process have a negative GWP with an average total value (A1 – A3 total) of -180 $kgCO^2e/m^3$, however, for unknown reasons, there are two products (F and G) that stand out as having a positive set of values which show their process is not as environmentally friendly. Two products using the wet process have a similar negative GWP value of -140 $kgCO^2e/m^3$. Product H shows a high GWP during its manufacturing process (A3) however the raw material extraction process and the negligible transport values maintain an overall negative total value. Against synthetic equivalent products, both MDB rock wool products have a positive GWP, 196 $kgCO^2e/m^3$ and 155 $kgCO^2e/m^3$ respectively. A comparative natural fibre product is included in the analysis, Hemp fibreboard with a total A1-A3 value of -22 $kgCO^2e/m^3$. This additional natural product shows that despite it being of a similar origin, wood fibre is more environmentally friendly with much lower GWP.

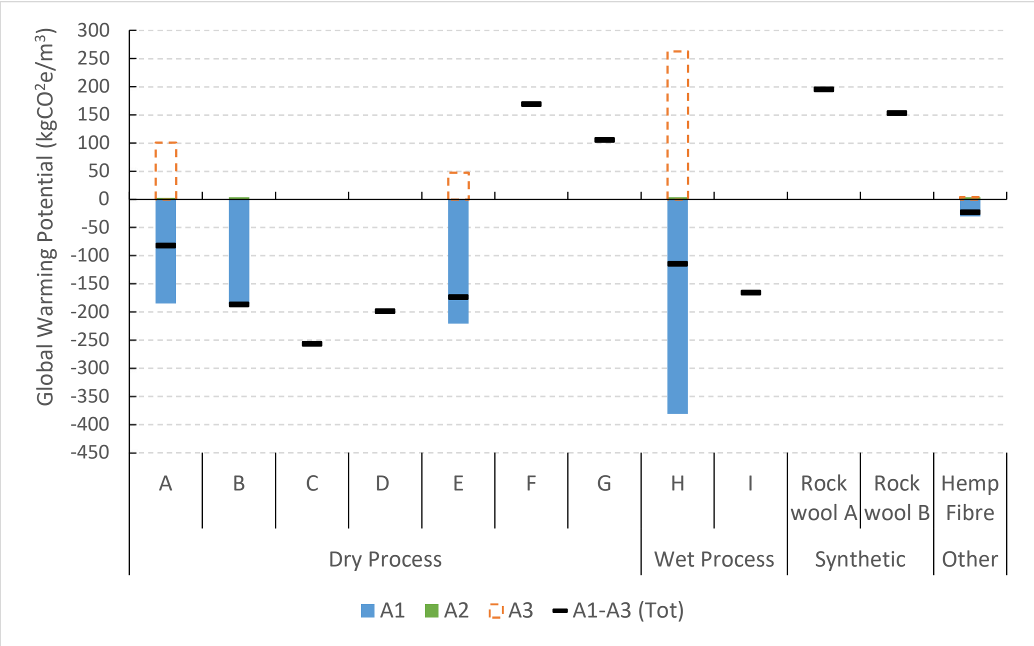

Figure 20: GWP for medium-density wood fibreboards compared with synthetic equivalents.

The data obtained for the embodied energy of MDB's in Figure 21 shows that wood fibre products have a high energy consumption, despite large amounts produced from renewable sources. The highest value obtained from a dry process product (F) of 9,800 MJ/m^3 is followed by a wet process product (H) of 8,800 MJ/m3. The data shows that the use of renewable energy is not typically employed in the production of synthetic insulation products despite requiring lower amounts of energy to produce them. Hemp insulation has shown that its process from A1 to A3 requires the least amount of energy, with a good share of renewable energy lowering the resultant embodied carbon.

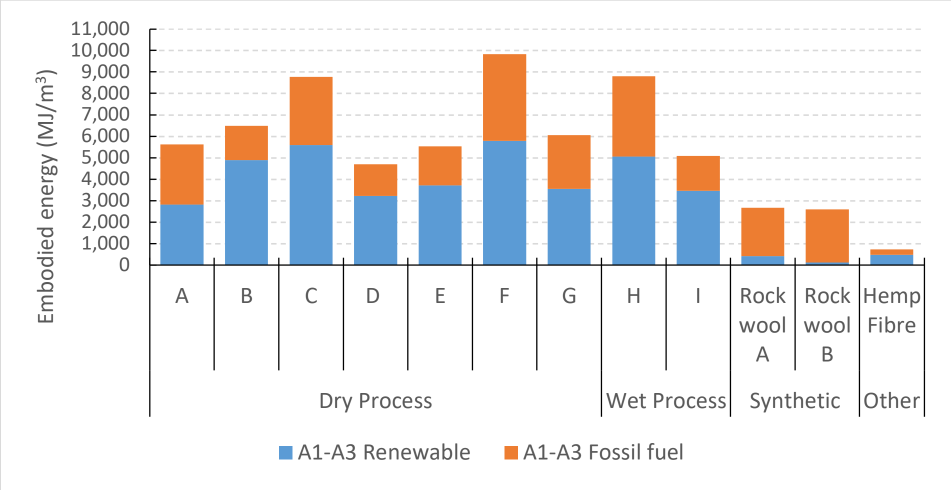

Figure 21: Embodied energy for wood fibre medium density rigid boards

5.1.4. Rigid high-density wood fibreboard products

Rigid wood fibre insulation used for roofs and external wall insulation of a high density, between 180 and 250 kg/m^3 are shown in Figure 22. Board A and B have similar properties to the MDB analysis in Figure 13, however, rigid boards C, D and E in the dry process show a contrasting set of results from different manufacturing companies. Product C has a -200 $kgCO^2e/m^3$ compared with product D with +140 $kgCO^2e/m^3$, details of which are unknown but the distance between A1 and A3 will influence as well as the A3 process. Product E using the dry process has a substantially low GWP -425 $kgCO^2e/m^3$ which shows the differences in manufacturing between processes with an influence on forest availability and distance within the factory setting.

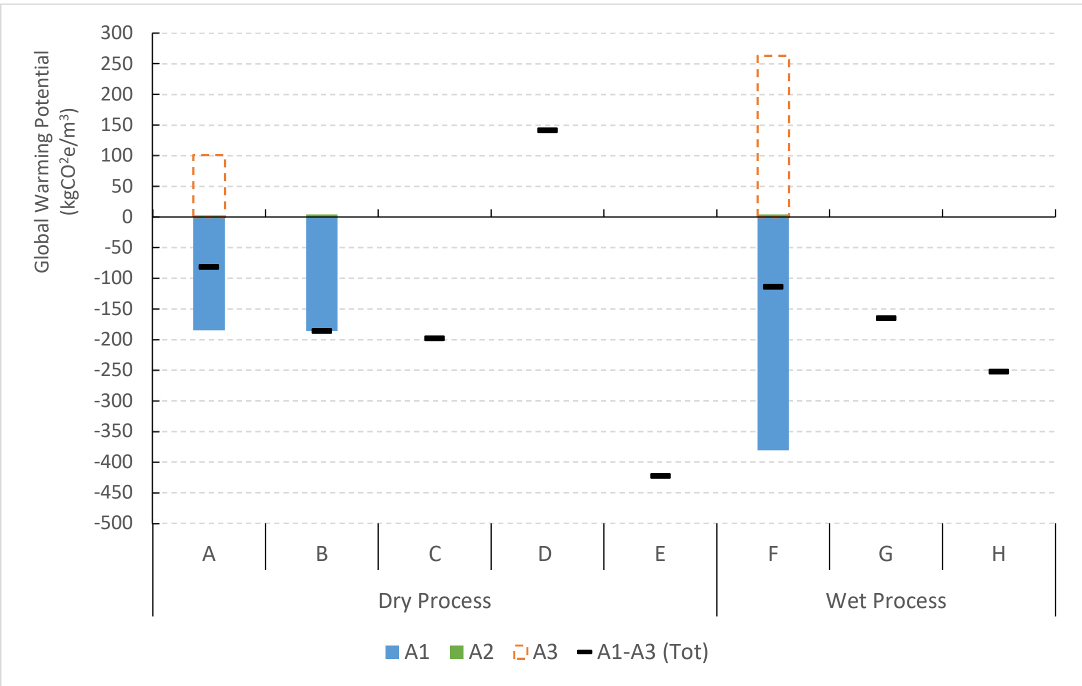

Figure 22: GWP for high-density wood fibreboards, wet and dry process.

Wet process products F, G and H present a final negative GWP value, however, product F shows a high manufacturing GWP compared with data on the dry process. Figure 23 shows the embodied energy required for processes A1 to A3 using renewable and fossil fuel energy. Comparing data obtained for GWP in Figure 15 and embodied energy in Figure 16 shows that products such as D and E present interesting results. Product D has a high GWP but shows a low embodied energy all of which is delivered by renewable energy sources. Product E is the opposite, its GWP is very low but the energy required to produce it is very high, despite 60% of it being delivered by renewable energy sources. Overall, the products produced using the wet process had a mean value of 7,000 MJ/m^3 consuming more energy than the dry process with a mean value of 7,500 MJ/m^3, despite Product E having a high energy content.

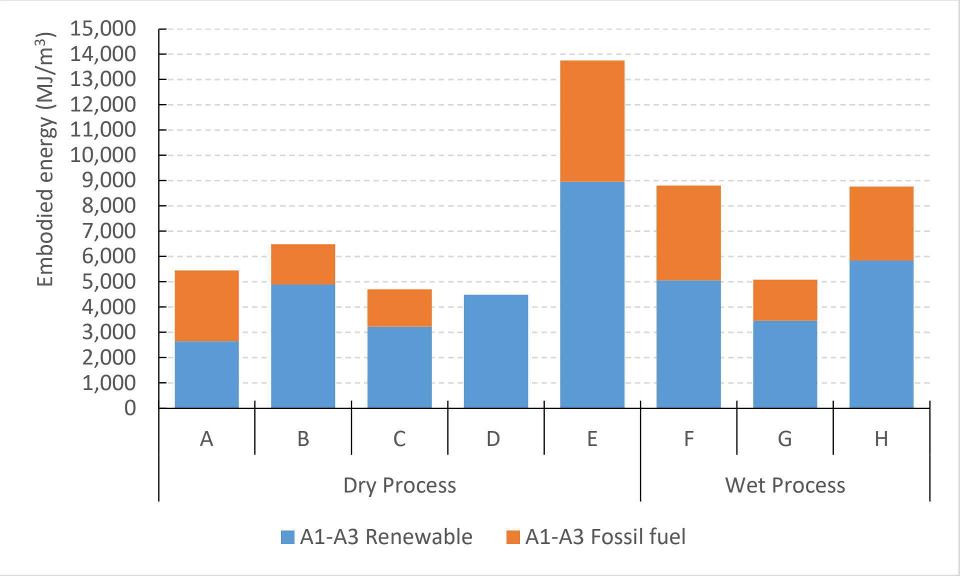

Figure 23: Embodied energy for wood fibre high-density rigid boards.

5.1.5. Conclusions

The global warming potential and embodied energy of different products, processes and densities have been analysed in detail compared with synthetic equivalents and some natural fibre (non-wood fibre) products. From the analysis made of GWP the higher the density, the lower the impact to the environment. This is also true for embodied energy, as for loose and flexible batts energy consumption can be substantially lower than high-density boards. In higher density boards, embodied energy is high, even between processes such as the dry and wet methods. A small distinction between these can be observed and on average these are similar.

An interesting observation on embodied energy sources of energy can be made where most products use between 60 and 70% of renewable energy during stages A1, A2 and A3. This embodied energy although now part of the history of the product can be deducted from the total, as its equivalent carbon emissions can be offset. This calculation has not taken place as it is unclear what fossil fuel and renewable energy technology is employed to apply appropriate carbon equivalent factors.

Not part of this evaluation are the subsequent stages in the life time of such products, such as the transport to site, use stage and end of life. Large carbon content can be accounted for in the transportation of the products to the construction site where they will be used, known as stage A4 of Figure 8. EU products despite having low GWP in their production stage, will increase significantly in the embodied energy and carbon to the retail store location and eventually to the construction site where they will be used. In the case of the UK and Scotland, this involves transportation from the production location as indicated in Figure 7 to their distributors and some building material suppliers. Production in Scotland would maintain that low GWP and make this product much more environmentally significant.

6. Innovation in the application, new products and processes

6.1. Best practice use in the new-build sector

Loose fibre insulation can be applied inside cavities on roofs, external walls and floors, often used in prefabricated components. Particular attention is needed during the installation process as the performance of the insulation can decrease due to transportation to the site, primarily due to the product sagging creating pockets that are un-insulated. Companies such as Steico suggest increasing the material quantity by 7 kg/m³ in closed panels with inspections on site required to verify the components' standards.

Flexible medium and high-density boards are suitable for timber frame and timber panel constructions. They can be used in roofs and suspended ceilings between rafters, internal and insulation in walls with appropriate framing systems. Figure 24 shows the application of flexible wood fibre between rafters and a high-density board acting as a sarking board to carry battens and roof tiles [4].

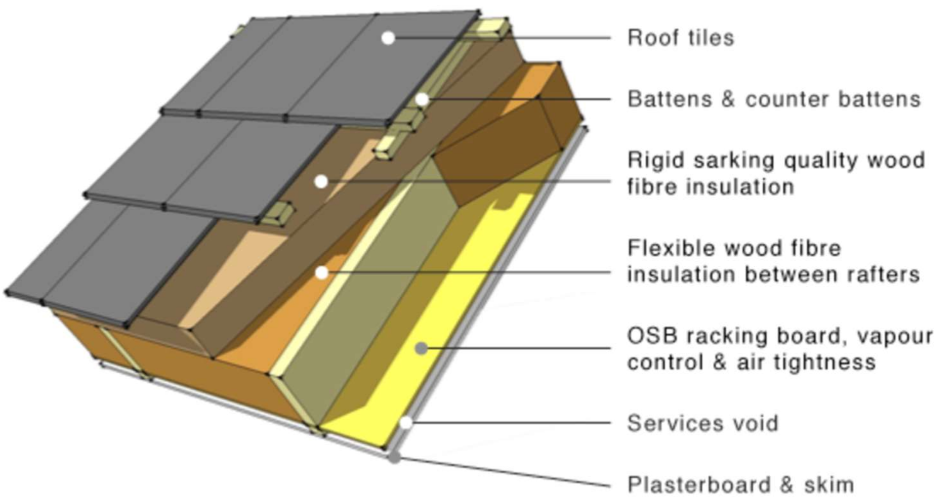

Figure 24: Flexible batts in new buildings roof. Source: Green Spec.

The U-value of the above roof structure can be between 0.13-0.18 W/m²K with a time delay for heat being stored also known as the decrement delay of approximately 12 hours, compared with standard build-ups of between 8 and 10 hours.

Wood fibre insulation is also used in timber panel walls with flexible batts or medium-density boards (MDB) between structural members, as shown in Figure 25. Rigid insulation boards can be used without a frame to minimise thermal bridging and to act as a sheathing board. As a result of the wood fibres low vapour permeability vapour control layer (VCL) are omitted and instead, an OSB panel is sealed around all its edges.

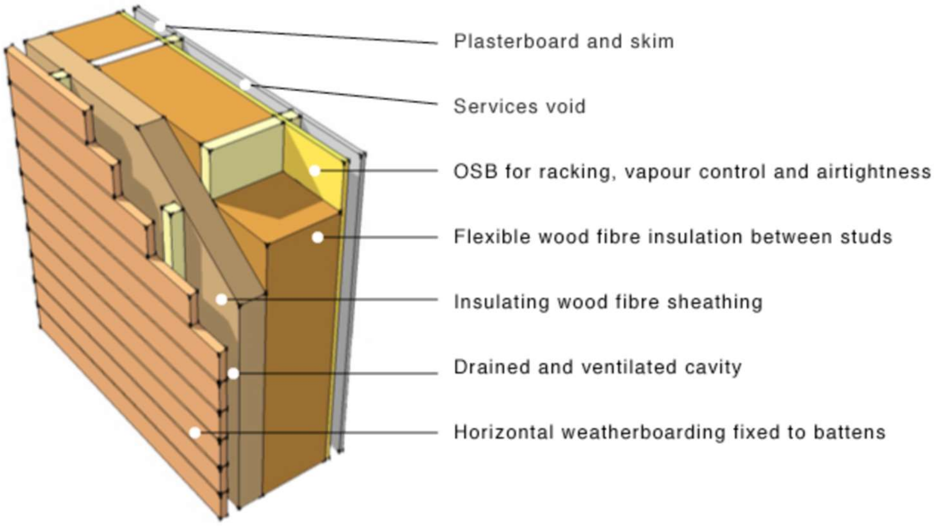

Figure 25: Wood fibre insulation between timber studs in a closed panel wall. Source: Green Spec.

Another example of good practice is with cross-laminated timber (CLT) using medium-density boards (MDB's) and flexible wood fibre insulation both internally and externally with appropriate framing systems or mechanically fixed with long timber screws. A second wood fibre insulation high-density board without any framing is required for thermal bridging purposes. Figure 26 shows a wall system with I/joists and CLT that can achieve a low U-value between 0.12 and 0.15 W/m^{2}K.

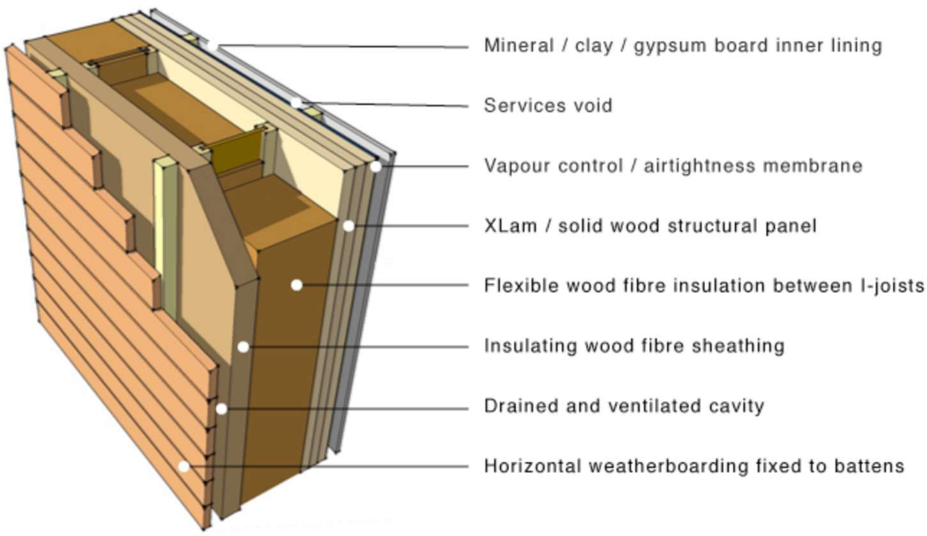

Figure 26: CLT wall with flexible and MDB of wood fibre insulation. Source: Green Spec.

Masonry walls are still a popular way of building in the UK and wood fibreboards can be installed to provide vapour and thermal improvements. A combination of internal and external layers with and without a framing system is used, however, external solutions with a rigid high-density board can be used mechanically fixed with long masonry screws, as shown in Figure 27. If solid masonry is used, a large thickness (200mm) of insulation is required to achieve U-values below 0.18 W/m2K. However, in combination with blown-in loose fibre in a cavity masonry wall and external or internal wood fibreboards can also achieve desirable U-values. Timber insulated panels can be installed in the outside of the masonry wall as shown in Figure 28, with flexible or MDB wood fibre between studs and a high-density board as a thermal bridging barrier.

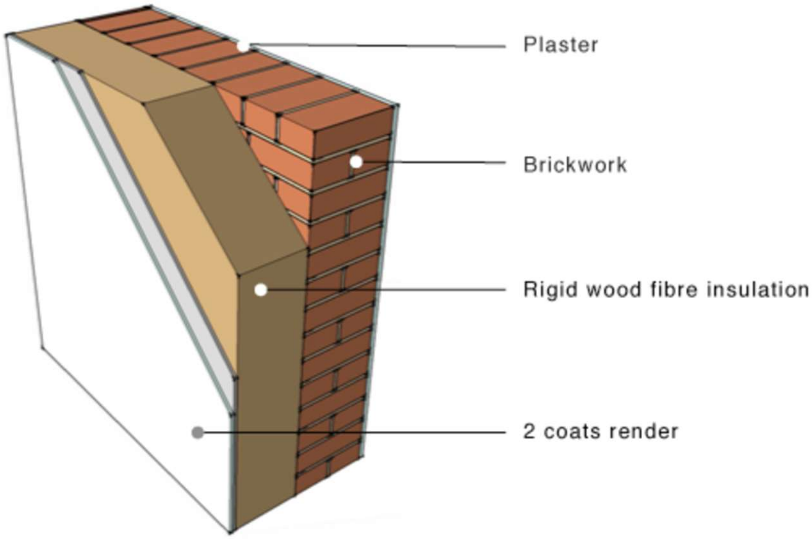

Figure 27: Rigid high-density wood fibreboard installed externally in a masonry wall. Source: Green Spec.

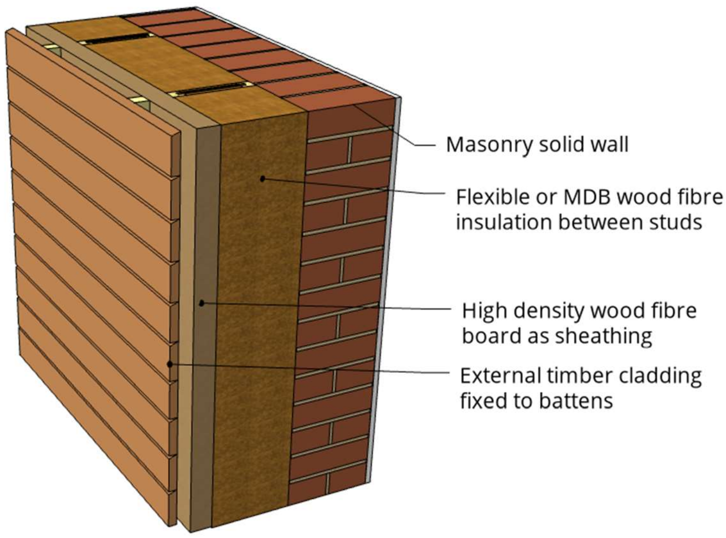

Figure 28: Timber panel installed externally to cover the masonry wall. Source: Green Spec.

6.2. Best practice use in the retrofit sector

The primary aim in existing properties is to apply retrofit interventions that can limit heat loss without disturbing the behaviour and composition of existing materials and components. Such solutions will maintain the original composition and create comfortable spaces for users with a reduction in energy demand. Buildings also become healthy spaces for occupants limiting the accumulation of humidity, mould growth and toxins. Wood fibre insulation plays a vital role in achieving this aim.

Loose fibre insulation products are suitable for insulation of lofts, cooms and in some situations below floors if the conditions and depth are permitted. Loose fibres are injected in cavities that are under pressure until filled avoiding any gaps and untreated areas. In some deep retrofit projects, new framing systems are placed onto existing masonry walls with blown wet cellulose applied between frames and once dry is covered and finished. Figures 29 and 30 show some examples courtesy of Historic Environment Scotland [47].

Figure 29: Cellulose sprayed over the existing brick wall existing dry lining.

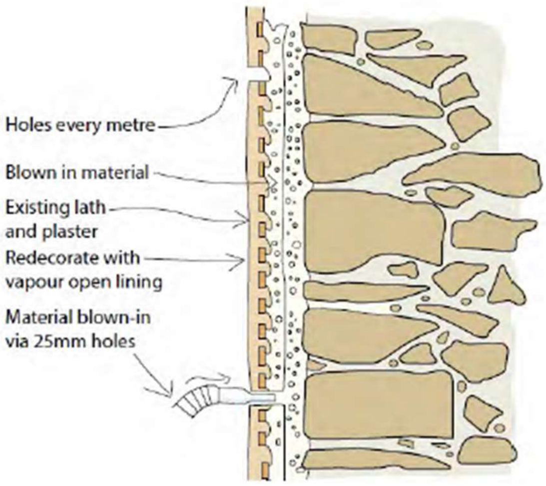

Figure 30: Injected loose insulation behind the

Wood fibre insulation can reduce U-values from 1.9 to 0.4 W/m^{2}K achieving an 80% reduction in existing roofs. In cold roof solutions, as shown in Figure 31, flexible or MDB wood fibre is placed between and over ceiling joists making sure all gaps are filled and there is a tight fit [44]. In the Leighton Library, Dunblane, Scotland this solution was adopted using two layers of 100 mm wood fibre rigid boards. The roof U-value improved from 1.3 to 0.2 W/m^{2}K [48]. Similarly, wood fibreboards can be placed in between floor joists leaving small ventilation gaps between the floorboards, as shown in Figure 32. To support the insulation, small timber runners are used to hold the weight and to maintain a close fit without gaps.

Figure 31: Wood fibre insulation between ceiling joists

Figure 32: Wood fibre insulation between floor joists

As shown in Figure 33, to achieve a warm roof space in roof voids; useful if warmer attic space is required, wood fibre is installed between rafters and the thickness of the flexible batts will depend on the depth of the rafters, to increase thermal efficiency additional boards over rafters are added to reduce thermal bridging. Table 10 shows resultant U-values against insulation thickness and the storage and release time of heat (decrement delay) showing the thermal mass properties of the insulation [49].

Rafters size (mm)	Wood fibre board thickness (mm)	U-value (W/m²K)	Decrement Delay (h)
150	60	0.19	8.3
	80	0.17	9.7
	100	0.16	11.1
	120	0.15	12.5
175	60	0.17	9.3
	80	0.16	10.7
	100	0.15	12.1
	120	0.14	13.5
219	60	0.15	10.9
	80	0.14	12.3
	100	0.13	13.7
	120	0.12	15.1

Table 10: Variations of U-values between retrofitted warm roofs using varying thickness [49].

Figure 33: Wood fibreboards between rafters. [50].

Flexible batts and rigid boards offer great opportunities for upgrading the thermal performance of existing masonry walls as they can be installed internally or externally with additional timber framing or directly onto the substrate if the density allows and mechanical fixing is used. Table 11 shows the required thickness of wood fibreboards to achieve different U-values for external application with the associated decrement delay and thermal mass characteristics.

Wall type	Wood fibreboard thickness (mm)	U-value (W/m²K)	Decrement Delay (h)
215 mm brick work	160	0.22	16.6
	180	0.20	18.0
	200	0.18	19.3
215 mm concrete block	160	0.22	18.2
	180	0.20	19.5
	200	0.18	20.9

Table 11: Variations of U-values of masonry wall retrofitted with external wood fibreboards [51].

Insulation on external walls is generally applied internally to avoid changing the external elevation in many cases listed or in a conservation area. The U-values of a wall with wood fibre insulation will depend on the thickness of the insulation applied, at least 80mm is suggested. However, the use of internal insulation will be influenced by the building characteristics and decoration. If there are cornices that need to be preserved, the insulation might have to stop short of these to preserve the internal feature. If applied, a wood fibreboard of 80mm of wood fibreboards can reduce a U-value from 1.1 W/m²K to 0.19 W/m²K [52].

Piccardo C. et al. conducted a life-cycle analysis (LCA) study of the building materials study in the refurbishment of concrete walls in buildings located in Sweden built-in 1974. To achieve high standards of energy efficiency such as the Passivhaus standard different insulation materials and systems for the openings were investigated. The analysis concluded that wood fibre insulation with brick cladding and wood-framed windows had the lowest CO_2 emissions and primary energy (PE) consumption, compared with glass wool insulation and aluminium window frame and external cladding system. Figure 34 shows the different retrofit interventions and their energy and carbon results.

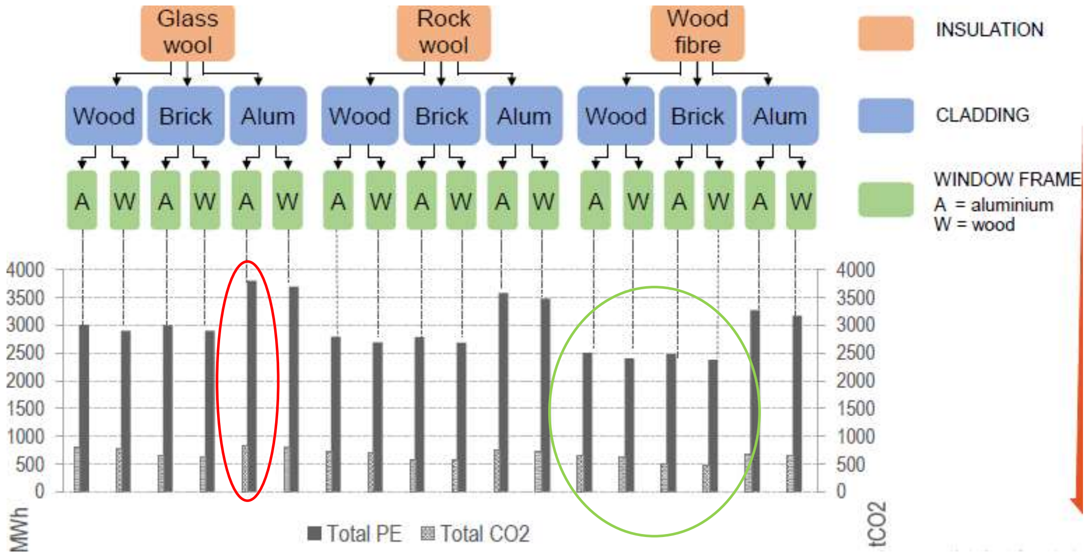

Figure 34: Environmental impact of different materials for a refurbishment in Sweden [53].

In Scotland, Sandstone solid walls are typical in domestic (tenements) and non-domestic buildings before the introduction of cavity wall solutions in 1919. These walls were generally considered as mass masonry wall types with a thickness of approximately 600mm built generally of two skins of rubble or one sandstone ashlar and another of rubble bonded with lime or clay mortar and a filled core. Early examples show internal finishes can be plastered directly to the stone surface or with a lath and plaster lining. Mass masonry wall types allow moisture movement through building fabric. The original internal finishes made from natural and low vapour permeability materials assist the buffering of any humidity accumulated from occupants, machinery/ equipment or its use (cooking, bathing/ showering). When considering thermal interventions it is therefore recommended that low vapour permeable insulants are used such as flexible or rigid wood fibreboard to allow the movement of moisture and avoid vapour accumulation in the colder part of the wall, typically internally as it reached the external layers of the wall. Also of consideration is the wall exposure to prevailing weather, especially wind-driven rain [47].

Interventions similar to those proposed in Table 10 and include:

1. insulation applied to existing wall linings
2. insulation applied directly to masonry or plaster on the hard
3. insulation held in place by timber framing (see figure 36)

Methods 1 and 2 can include mechanically fixing or use of special adhesives and mortars directly onto the wall finished with a wet plaster (internally) or for external purposes traditional render using lime/ clay mortars or a ventilated rendered board, see Figure 35. Both can be provided with rigid high-density wood fibreboards. Method 3 can use flexible wood fibre insulation between the stud systems and if space allows, covered by a rigid high-density board that can be finished appropriately as shown in Figure 36.

Figure 35: Rigid board directly onto the masonry wall

Figure 36: MDB or rigid wood fibre insulation in a frame.

6.3. Product innovation – new uses

Current wood fibre products exist as a result of the competitive insulation market in the whole of Europe. There is a focus on replicating the product type and uses offered by the synthetic insulation product range and offer a like-for-like solution but with added advantages explained in the product review in Section 2 of this document. Loose fibre insulation has its drawbacks though, primarily when applying it in a wet form as is the case of wet cellulose fibre insulation which requires a drying out time before closed and finished. Injected loose insulation also presents its challenges in making sure cavities are filled completely and in the longer term maintaining an integral fill inside the cavity. Despite this, some leading manufacturers are coming up with new uses and combinations of other materials with wood fibre insulation, providing a variety of products. Also significant are new uses and applications in the retrofit and new build sectors. The following examples are worth considering for future use and commercialisation once homegrown wood fibre in the UK is established further.

6.3.1. New products

A company that is expanding its product range from the conventional types is Unger Diffutherm, creating a series of wood fibre hybrid panelised systems called UdiSystems. These are mainly internal partition panels or dry lining finished boards in combination with other fibre materials. Three wood fibre bonded boards are offered. The first UdiINRECO and UdiRECO, provide a high-density rigid OSB board attached (pre-bonded) to wood fibre rigid board to provide external and internal thermal efficiency. Although these two products on their own are not uncommon, the assembly of both offers a quick solution for dry lining or external cladding without mechanically fixing secondary boards on-site, see Figure 37.

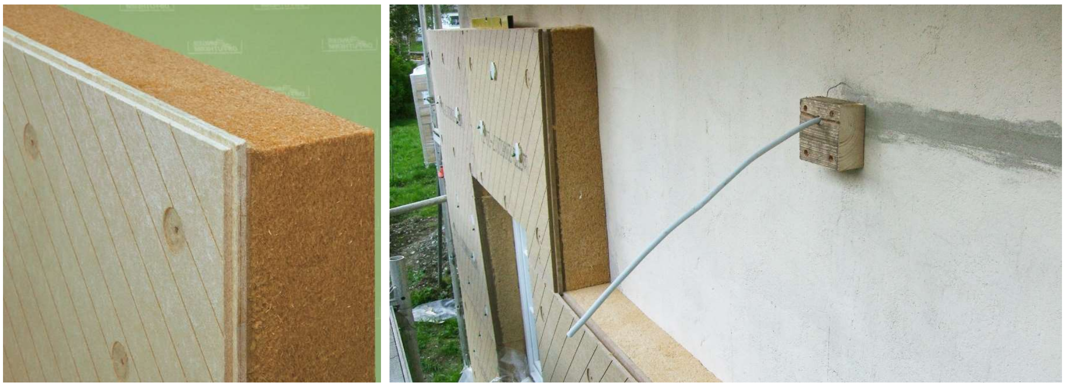

Figure 37: The UdiNRECO and UdiRECO systems offered by UngerDiffutherm.

The other two products are shown in Figure 38, they include insulation boards that are slim in profile but add extra thermal and acoustic performance between partition and external walls. The UdiIN and UdiCLIMATE are high-density composite wood fibreboards attached to a cellulose honeycomb board. They are also suitable for retrofit interventions that require thin solutions in small spaces as it has a total thickness of 23mm and 30mm respectively.

Figure 38: The UdiIN (left) and UdiCLIMATE (right) combining wood fibreboard and a honeycomb board.

6.3.2. New Uses

Innovation in the use of wood fibre insulation has brought in new solutions to both new build and existing building retrofits. Two systems have been analysed which are sure to enhance the uptake and use of such products.

In the new build sector, particularly in the manufacture of off-site wall panel solutions and timber homes in Scotland, MAKAR in Inverness has used thin strips of wood fibre that are sold to correct unevenness under floors or perimeter wall insulation, see Figure 39 & 40. Mr Neil Sutherland, founder of Makar integrates these strips in all his building designs and uses them between panels as a thermal bridging strip and for acoustic purposes instead of joining timber to timber between panels. Although this is an existing product, it’s the innovative use and application that is important which can be passed on as a key detail in the manufacture of off-site panels in the UK.

Figure 39: Wood fibre strip 20-30mm thick

Figure 40: MAKAR timber panels with wood fibre strip between panels

To increase the thermal performance of existing buildings, a system developed by Edinburgh University, School of Engineering, has been the 3D scanning of inaccessible and often difficult to fill holes throughout the building envelope. These holes are typically created by poor workmanship during repairs and new plumbing systems installed which are left unattended creating uncontrolled infiltration which is a cause for ventilation heat loss in buildings. The holes create drafty and cold spaces that require to be blocked and sealed. The method includes the accurate scanning of the hole followed by the creation of a wood fibre insulation insert that often connects with other more accessible insulation. The research is in its early stages and research and development were funded by the Edinburgh Climate Change Institute (ECCI) and the Construction Scotland Innovation Centre (CSIC) in 2021 with further insights and testing due for 2022.

The 3D scanned shape is defined into a volumetric object and the digital file is transferred to 3D printers or to a CNC milling machine to obtain a physical object to install in-situ. Figure 41 shows the existing uneven holes followed by Figure 42 showing the scanning trial of the hole. Figures 43 and 44 show how the CNC milling machine carves out the shape using a 120mm medium density wood fibreboard and the finished sample in a section of the hole.

Figure 41: Undefined hole in the building envelope.

Figure 42: Manual 3D scanning of hole

Figure 43: CNC milling machine carving the wood fibre insulation hole

Figure 44: Sample (section) positioned in the

7. Conclusions & recommendations

The primary aim of this project was to explore the potential for the manufacturing, commercialisation and innovation of Scottish wood fibre insulation. To achieve this, it was critical to understand market leaders, current drivers and the concerns faced by industry to increase the uptake and awareness of such products. This report outlined the current manufacturing and performance levels of existing wood fibre insulation products, all from mainland Europe and some of which are imported to the UK through company subsidiaries and other natural product re-sellers. The study goes beyond the parametric analysis of each product by outlining the methods of production (wet and dry process), its environmental characteristics and cost compared against each other and similar synthetic products.

7.1. Key insights, benefits and barriers

7.1.1. Parametric analysis

- A parametric analysis of existing wood fibre products manufactured in European countries outlined the different products to understand their material composition and main use. This analysis was able to break down the amounts of material used in each product type; essential for the homegrown equivalent samples to be produced. Three main insulation types emerged from this; loose fibres, flexible low-density batts and rigid boards which can come as medium-density and high-density boards.

- Wood fibre insulation undergoes a thermo-mechanical pulping process (TMP) and mainly spruce and other coniferous species are used (Pine or Douglas fir).

- Within this analysis, the manufacturing process identified two different methods; dry and wet, which determine the product type, the machinery and the production capacity required. Most EU manufacturers use both methods, however, there are distinctive steps in both which incur energy use and production outputs. Dry process low-density flexible batts can be produced 2-3 times faster than wet process high-density boards due to the increased steps and processes.

- The main purpose of all insulation products is to limit the flow of heat and reduce thermal conductance, however wood fibre products have other qualities such as improved heat storage, moisture balance with low vapour permeability. The study conducted a full hygrothermal analysis of the existing products outlining their main qualities.

- Thermal diffusivity proved to be a more suitable performance parameter to compare products against each other, combining the heat storage, thermal conductivity and density. Rigid boards are more thermally diffusive than flexible batts, mainly due to their high density and resultant ability to store heat for longer. Thermal conductivity or resistance on their own should not be used to compare products as it neglects other properties which wood fibre products tend to provide.

- The rate of liquid transport also proved to be a distinctive characteristic; where wet process products with a high density were better than the dry process products. This meant that wet process products can transport liquid through them better, making it less probable for condensation build-up and its thermal performance to deteriorate.

- Other parameters analysed showed that there are many standards and certifications required to comply with EU requirements of the performance. Fire, acoustics and waste standards are all additional requirements that need to be considered for homegrown products.

- A distinctive parameter that shows the environmental footprint of materials is the global warming potential and embodied energy characteristics of materials. Within the available data available a cradle to gate boundary condition was the best way of assessing these products against each other and other similar synthetic ones.

7.1.2. Testing and scope for new research

- Within the available literature, there is research that evaluates the composition and required chemical treatments to avoid them degrading and making them more durable.

- Identifying the specific characteristics of wood fibres is important as it provides a technical approach to the creation of the products which will be needed in the creation of wood fibre samples and trials.

- By-products for the chemical pulping process provide the required hygrothermal properties that most products have. The binders also assist the compression process. Synthetic insulation products tend to use polymers to achieve this, however, for wood fibres, some bio-sourced binders are being researched using natural wood lingnin and others.

- Most studies of wood fibre focus on the thermal conductivity properties and how they compare with other natural and synthetic products. Other studies focus on the moisture balance of wood fibres, scoring favourably against synthetic insulation.

- Studies on the embodied energy associated with the production of insulation products demonstrated that larger amounts are required for wood fibre products than for synthetic products (XPS insulation). However, wood fibre insulation resulted in being less impactful to the environment as its global warming potential was negative compared with synthetic equivalent products.

- Some studies show that wood fibre insulation has benefits beyond hygrothermal performance. This is particularly evident in the reduced toxic off-gassing and volatile organic compounds (VOCs) expelled during manufacture and installation in buildings. Despite this, there needs to be more research on the use of more natural-based fire retardants without hindering performance.

- On the wet and dry manufacturing processes using softwoods, there are studies around the different energy requirements and the adhesives or binders used, however, it's with the hardwoods that there needs to be more analysis. Research shows that hardwood fibres have a lower mechanical strength which means more binding material is needed, however, hardwood fibres tend to manage (water absorption) and vapour better than softwoods.

- The thermal conductivity of hardwoods resulted in being higher than softwoods, meaning more heat loss. Despite this, a mixture of hardwood fibres with at least 20% softwoods showed better results when compered with softwood fibre products.

7.1.3. Market, industry uptake & cost

- The information obtained on the market uptake of natural materials is not clear and is often mixed with data from synthetic insulation products. A clear distinction is difficult to obtain.

- In 2013 the UK insulation market as a whole was worth £1.5 billion. More recent figures show that there was a 16% decline in insulation demand and the market fell from €1.93bn (£1.61bn) in 2019 to €1.62bn (£1.35bn) in 2020 mainly due to COVID-19 restrictions in 2020. Despite this, it is expected that in 2021 there was a 6% increase with a 9% increase in 2022 to follow.

- In 2018, according to the Alliance for Sustainable Building Products (ASBP), the market share alone for natural insulation products in the UK is worth less than 0.1% of all insulation sales compared with 6% in Germany. Partly due to government policy on such product use, incentives and funding.

- Various forums and through UK distributors of natural insulation products estimate that between 2021 and 2022, the UK market has grown and is worth between £2 million to £3.5 million or less than 0.20% of the total insulation UK market.

- A recent sales report for Steico, a major wood fibre producer, indicated that in the UK comparing the first quarter of 2021 with that of 2020, there was a decline of 2% in revenue from €7.5 to €7.4 million. However, this included all their products and not only wood fibre insulation.

- Overall the revenue of wood fibre insulation alone experienced an increase of 30% from 2020 to 2021 which indicated the uptake from the rest of the EU on the use of such products. This represents an increase of €15 million in sales from €47 million to €62 million.

- This study conducted questionnaires and interviews with key industry figures as well as existing distributors and EU manufacturers.

- Respondents highlighted the benefits of wood fibre insulation beyond the thermal conductance and reduced U-values, however, there was a need for the industry to recognise other qualities such as moisture control and heat storage.

- They all recognised that in the UK there are no current manufacturing facilities for homegrown wood fibre and that having this in place would increase the security of supply, lower embodied energy of the products and market increase with better representation in the UK.

- The current situation faced by Brexit does present some challenges, but most are not proving to be onerous and currently don't impact cost or supply into the UK.

- Scottish industry leaders, in the housebuilding sector, are aware of the potential of wood fibre insulation, particularly in retrofit interventions. Most are worried about having the material readily available for larger projects and specifications.

- All recognised the embodied energy benefits to reach Net-Zero performance and targets in Scotland.

- Mixed response in switching to all wood fibre insulation was obtained, where some would do it in the next 5 to 10 years but some are reluctant until the product is mature enough in the UK.

- In terms of current costs of products, an analysis of the cost (£) per mm of a 100mm board thickness, and a cost (£) per m2 of the product was made.

- Most flexible wood fibre insulation products cost around £0.09/mm and £14/m2 compared with mineral wool at £0.07mm - £10/m2, stone wool £0.05/mm - £7/m2 and for glass wool, £0.09/mm - £17/m2.

- Although currently, synthetic products are cheaper, if produced more locally, these figures could be competitive and worthwhile to users.

- Rigid wood fibreboards were more expensive with an average costs of £0.20/mm and £25/m2 compared with XPS insulation at £0.10/mm and £14/m2.

7.1.4. Comparisons in environmental impact

- All products analysed reported on global warming potential (GWP) and embodied energy using a cradle to gate boundary condition.

- Most wood fibre products (loose, flexible and rigid) presented a negative GWP meaning that during its production there weren't any emissions released into the atmosphere which could contribute to climate change. This is achieved mainly as the raw materials of these products capture and lock CO_2 and even once balanced with emissions during its manufacturing and transportation they emerge beneficial to the environment.

- This is in contrast to synthetic materials that release a lot of carbon emissions during their manufacturing process.

- Overall, high-density products store and lock more carbon than loose and flexible wood fibre products. Flexible products store on average 50-40 $kgCO^2e/m^3$ whereas high-density products on average 150 $kgCO^2e/m^{3.}$ With some exceptions in products where transportation between raw material extraction and manufacturing proved to be impactful.

- In terms of embodied energy using this same boundary condition (cradle to gate), wood fibre insulation products tend to use more energy than synthetic equivalents. However, most manufacturers of wood fibre use more renewable sources of energy that can be deducted.

- The high energy use may be attributed to the manufacturing method, particularly using machinery to make wet process products.

7.1.5. Innovation and best practice

- Besides the existing product ranges by all wood fibre manufacturers, most will provide products with rendered boards as an external finish. Some products have emerged that bond to other composite boards for rigidity and ease of fixing, however, some have acoustic honeycomb boards (cardboard) for internal linings in confined spaces.

- Innovation in the use of insulation products has brought in new ways of installing or modifying to fit a shape in a retrofit intervention. This is the case of wood fibre strips used between off-site timber closed panels, to reduce friction and thermal bridging. Also, bespoke 3D scanned spaces where wood fibre insulation is carved out using a CNC router which accurately fits into uneven holes in existing properties.

- There are other uses and methods such as the recovery and re-use of waste OSB and MDF boards from construction sites. The recovered off-cuts can be turned back into wood fibre and re-used into insulation boards.

7.2. Recommendations

The following recommendations are based mainly on the review made of current wood fibre products, the current market uptake and the future industry shift to low embodied carbon materials as well as meeting some of the government targets on net-zero performance. To begin to explore the manufacture of homegrown wood fibre insulation it is important to take two important steps:

1. Have discussions with existing supply chains: forest owners, both national and private landed estates and the recycling wood waste streams composed of sawmills and post-production of wood products (MDF, OSB).
2. Forge agreements for the manufacturing of wood fibre insulation. As a first approach for the research and development stages, discuss the possibility to use existing manufacturing set-ups. These include those that already use wood fibre to produce high-density composite boards (MDF & OSB) and those who produce other natural fibre insulation products in the UK (Hemp).

   The current MDF & OSB manufacturers within the UK, can do the following:

   - Pulverise timber logs into particle size to specification
   - Manufacture using dry forming with pressure and temperature controlled methods
   - Apply binders, fire retardant treatments and other additives

Other recommendations are as follows:

- **Generate a future framework for the production of wood fibre insulation:** Forge agreements with existing supply chains and manufacturing facilities to develop a better understanding of the manufacturing needs at the scale that the homegrown market requires.

- **Produce samples of homegrown wood fibre** exploring the following variables and methods:

    - replicate the composition of existing wood fibre products imported from the EU (softwoods);
    - all fibres from available and suitable hardwood species;
    - a mixture of softwood and hardwood fibres with varying compositions and species;
    - explore varying low VOC, natural and non-petrochemical binders adhesives and fire retardants;
    - differences in fibre quality directly from virgin timber and recycling sources.

- **Test and compare the performance of the samples:** Evaluate the samples in a laboratory under similar conditions and standards used by those currently for fire, thermal, acoustic, waste, etc.

- **Evaluate the global warming potential (GWP) and embodied energy of the new variations in samples:** consider the cradle to gate methodology based on the available manufacturing alliances. These new values can be compared with EU products and the current UK made synthetic insulation products.

- **Creation of a Scottish wood fibre alliance (SWFA)**: with representatives from the supply chain members, existing manufacturers, government representatives (Scottish Forestry), wood use promoters (Confor, Timber Trade Federation, TRADA), home building federations, associations (SEDA, CarbonLite, ASBP, STBA) academics and wider industry (architects (RIBA/ RIAS), builders, Passivhaus Trust).

- **Organise awareness sessions and up-skilling** to make the use of wood fibre insulation a feasible option in the Scottish construction industry. Create group sessions composed of:

    - **Government:** Local and central government learning from other EU countries on incentives, legislation and up-take (Germany, France);
    - **Contractor groups:** Identify contractors who are keen to drive the net-zero agenda to up-skill their workers and other sub-contractors;

- **House builders:** deliver training to private house builders and registered social landlords on the benefits and requirements;
- **Architects:** Approach architectural practices to discuss the benefits of wood fibre, best practice use and integration to designs to change perceptions by clients and means to meet net-zero performance.

7.3. Future work

Future work in this field seeks to explore some of the recommendations mentioned above in three different ways. The first is to explore the different thermal performance values with variations in wood species. Also planned is a long term approach through a PhD studentship with specific laboratory testing and innovation in the use and products from homegrown wood fibre. A shorter-term second phase of this project will explore the alliances with existing supply chains, manufacturing set-ups and outreach with industry on the up-skilling and support needed to make wood fibre competitive against available synthetic products.

7.3.1. Outline of further studies:

MSc (2022) and PhD (2022-23 start)
Future studies will look at the effects of thermal conductivity, mechanical strength, and water absorption. Using the following variables:

- Lignin – soft vs hardwoods
- **Softwoods**:- lignin polymer is made from approx. 100% Guaiacyl (G) units
- **Hardwood**:- lignin polymer from approx. 50% Guaiacyl (G) and 50% syringyl (S) units
- Note:- small amounts of p-hydroxyphenyl (H) can be found within both.
- Different mixtures and ratios of both.

Explore different characteristics such as:

- material density
- strand sizing
- compaction ratio
- binders and additives used

For UK soft and hardwoods, proposed categories for each are:
- Hardwood: birch and ash
- Softwood: British spruce [WPCS], Larch [WLAD], British pine [WPNN], Douglas fir [PSMN].

7.3.2. Phase II of the Homegrown wood fibre project

Proposed funder: Scottish Forestry, Construction Scotland Innovation Centre (CSIC) and Construction Leadership Forum.

Work Package outline:
WP 1: Review of samples required, supply chain and manufacturing needs

WP 2: Homegrown materials sourcing and sample equipment review
WP 3: Product prototype manufacture & testing
WP 4: Skills and outreach
WP 5: Final report

Appendices

Appendix A - Matrix of existing wood fibre insulation products

Appendix B – Sample interview questionnaire

Dear participant,

As part of the Homegrown Wood fibre insulation project commissioned by Scottish Forestry, we are exploring the market uptake and barriers to adopting wood fibre insulation in buildings.

Your company/ local authority (LO) is at the forefront of this drive to achieve net-zero performance in domestic/ non-domestic buildings and the following scenario and questions would help us formulate some understanding of the barriers we face.

Considering the specification of materials in domestic and non-domestic projects that have a low embodied carbon (i.e. sourced locally and with a low carbon footprint) and a drive for a more naturally sourced and environmentally conscious building, please answer the following questions:

Q1. Has your company/ LO considered changing to low embodied carbon (CO_2) materials such as natural, homegrown insulation (Wood fibre)?

o Yes
o No
If No, please expand on why?

Q2. What timeline have you set to change from synthetic materials/ insulation products to more natural or recycled materials such as wood fibre insulation?

Please only select one option.
o Within the next 2-3 years
o Within the next 5-10 years
o Long term plan, beyond a 10-year plan.

Q3. What principal barriers do you foresee in switching over from synthetic insulation products to wood fibre or other natural insulation types?

Please select as many as you think and answer the questions that are relevant.
o Lack of technical knowledge (Go to Q4)
o Not enough skills in its appropriate use and installation (go to Q5)
o Can't source the insulation easily, lack of supply streams. (go to Q6)
o Higher purchasing cost (go to Q7)
o Prior long-term agreements with existing synthetic insulation companies/ distributors (go to Q8)
o Other, please specify what barrier.

These questions are linked to the ones selected in Q3.

Q4. Is the lack of knowledge due to being unsure about its:

Please select as many as you think and answer the questions that are relevant.
- o thermal performance
- o condensation and humidity performance
- o acoustic performance
- o Skills on how to install it (go to Q5)
- o All of the above

Q5. Are you concerned that your contractors and subcontractors will not be able to install it appropriately? The adequate skills to install it aren't there?

Please select one and answer the questions that are relevant.
- o Yes
- o No
- o If Yes, please expand on this.

Q6. Do you consider it will be difficult to source large quantities of wood fibre insulation for your projects?

Please select one and answer the questions that are relevant.
- o Yes
- o No
- o If Yes, please expand on this.

Q7. Is a negative barrier the cost of wood fibre insulation in your project? Will adaptation of wood fibre or other natural insulants increase capital costs of the projects?

Please select one and answer the questions that are relevant.
- o Yes
- o No

If Yes, please expand on this.

Q8. Some companies have long withstanding agreements with insulation suppliers, hence difficult to terminate them without penalties, would this be a barrier to switching over?
- o Yes
- o No

If Yes, please expand on this.

Please answer this last question, not linked to Q3.

Based on the UK and Scottish targets imposed to reach net-zero performance and the pressure for our homes to be more environmentally conscious, please answer the following:

Q9. Do you consider this a driver for you to specify and switch to natural and wood fibre based insulation?

- Yes
- No
- If Yes, please expand on this.

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Appendix A: Matrix of existing wood fibre insulation products

Origin	Component	Product Name	Density [kg/m3]	THERMAL ATTRIBUTES: Thermal Conductivity λD [W / (m*K	Thermal Diffusivity [mm2/s]	Specic heat capacity [J/(kg * K)]	Water vapour diffusion resistance value	ENVIRONMENTAL ATTRIBUTES: Functional Values: Functional unit [FU]	Density [kg/FU]	Material Moisture [%]	Global warming potential [kgCO2-eq]: A1	A2	A3	A1-A3	A4	Total	Embodied energy [MJ]: Renewable: A1	A2	A3	A1-A3	Non-renewable: A1	A2	A3	A1-A3	Totals A1-A3
LOOSE INSULATION																									
Germany	Wood Fibre (loose) A	Steico Zell	30-60	0.038	-	2100	1-3	1 m3	40		-54.40	61.60	378.00	385.20	55.48	440.68	616.00	0.48	47.60	664.08	234.40	8.52	476.00	718.92	1383.00
Germany	Wood Fibre (loose) B	Best Wood Air injected	28-38	0.038	0.48	2100	1-3	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-
Germany	Wood Fibre (loose) C	GUTEX Thermofibre	25-50	0.038	0.36	2100	1-2	1 m3	35		-54.25	0.25	13.93	-40.07	48.55	8.48	602.00	0.17	64.40	666.57	35.70	3.54	304.15	343.39	1009.95
Italy	Wood Fibre (loose) D	FiberTherm Zell	32-45	0.038	0.40	2100	1-2	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-
Norway	Wood Fibre (loose) E	Hunton Nativo® Wood Fibre Blow-in	32-45	0.038	0.40	2100	1-2	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-
Czech Republic	WF cellulose (OSM) A	Climataizer plus Warmcel	30-90	0.038	-	2020 ± 6%	1-3	1 m3	50	-				13.49	69.34	82.83				21.31				293.62	314.93
Austria	WF cellulose (OSM) B	Thermofloc	30-60	0.039	-	-	2	1 m3	60	-	2.59	1.14	1.08	4.81	83.22	88.03	780.00	0.90	35.76	816.66	45.12	15.78	36.03	96.93	913.59
United Kingdom	Glass Wool Blow in	Knauf insulation, blow in		0.034		1000	1	1 m3	24					23.30	6.66	29.96				8.85				491.00	499.85
FLEXIBLE INSULATION																									
Germany	Wood Fibre (flexible) A	Steico Flex 036	60	0.036	0.29	2100	2	1 m3	51.7	4	-79.00	0.79	17.10	-61.11	71.71	10.60	895.00	0.63	142.00	1037.63	170.00	10.90	591.00	771.90	1809.53
Germany	Wood Fibre (flexible) B	Best Wood Schneider flex 50	50	0.037	0.35	2100	1-2	1 m3	50	8				-56.00	69.35	13.35				969.00				134.00	1103.00
Switzerland	Wood Fibre (flexible) C	PAVAFLEX 575	50	0.038	0.36	2100	2	1 m3	55	4.5				1.63	76.29	77.92				937.00				1650.00	2587.00
Germany	Wood Fibre (flexible) D	GUTEX Thermoflex	50	0.036	0.34	2100	2	1 m3	50	6.5	-67.50	0.31	29.30	-37.89	69.35	31.47	810.00	0.21	134.00	944.21	234.00	4.40	663.00	901.40	1845.61
Italy	Wood Fibre (flexible) E	Beton Wood Fibertherm flex 50	50	0.038	0.36	2100	1-2	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-
France	Wood Fibre (flexible) F	Isonat Flexi 40	40	0.038	0.78	1220	3	1 m3	40	-				39.00	55.48	94.48				1070.00				780.00	1850.00
France	Wood Fibre (flexible) G	Isonat Flexi 55	55	0.036	0.53	1230	3	1 m3	55	-				55.00	76.29	131.29				1365.00				1145.00	2510.00
Italy	Wood Fibre (flexible) H	Natural BAU NaturlFlex	50	0.038	0.36	2100	2																		
Germany	Wood Fibre (flexible) I	Sonae Arauco's AGEPAN® flex	50	0.038	0.36	2100	3																		
United Kingdom	Glass Mineral Wool A	Knauf, Glass mineral Wool	16	0.036	2.65	850	1	1 m3	16	-				15.60	4.44	20.04				38.70				345.00	383.70
United Kingdom	Stone Wool B	Rockwool, rollbatt	22	0.044	1.94	1030	1	1 m3	22	-				31.82	6.05	37.87				52.28				431.87	484.15
Italy	Glass Mineral Wool C	Isover roll	30	0.032	1.07	1000	1	1 m3	30					60.31	41.61	101.92				199.06				1315.63	1514.69
RIGID INSULATION																									
Germany	Wood Fibre (Rigid) Dry Process A	Steico Therm Dry, Special Dry and Top	110-140	0,037-0,041	0,136-0,160	2100	3	1 m3	140	5	-185.00	2.43	101.00	-81.57	194.19	112.62	2380.00	1.89	431.00	2812.89	1450.00	33.60	1320.00	2803.60	5616.49
Germany	Wood Fibre (Rigid) Dry Process B	Best Wood Schneider Multitherm 110, 140, Wall	110-160	0,039-0,043	0,122-0,169	2100	3	1 m3	163	8_12	-186.00	3.91		-186.00	0.00	-186.00				4890.00				1600.00	-3290.00
France	Wood Fibre (Rigid) Dry Process C	PAVATHERM 110, PAVATHERM-COMBI, PAVATHERM-FORTE 140	110-145	0,038-0,041	0.15	2100	3	1 m3	210	7				-255.90	0.00	-255.90				5593.12				3178.68	-2414.44
Germany	Wood Fibre (Rigid) Dry Process D	Gutex Thermosafe, Thermoflat, Thermoinstall, Thermoroom, Themowall	110-160	0,038-0,040	0,136-0,165	2100	4	1 m3	167	8				-198.40	0.00	-198.40				3218.00				1478.00	-1740.00
Italy	Wood Fibre (Rigid) Dry Process E	Beton Wood FiberTherm Dry, FiberTherm Install, FiberTherm Top, FiberTherm Roof dry,	110-160	0,037-0,040	0.16	2100	5	1 m3	157.49	6	-221.00	0.37	47.50	-173.13	0.00	-173.13	2520.00	0.01	1190.00	3710.01	299.00	5.20	1520.00	1824.20	-1885.81
France	Wood Fibre (Rigid) Dry Process F	Isonat Multisol 110	110	0.041	0.296	1260	3	1 m3	110					170.00	0.00	170.00				5790.00				4040.00	9830.00
France	Wood Fibre (Rigid) Dry Process G	Isonat Multisol 140	140	0.042	0.238	1260	3	1 m3	140					106.25	0.00	106.25				3550.00				2506.25	-1043.75
Italy	Wood Fibre (Rigid) Dry Process	Natural BAU NATURATHERM,	115-150	0,038-0,040	0,111-0,136	2100-2400	3_5							0.00		0.00				0.00				0.00	0.00
Germany	Wood Fibre (Rigid) Wet Process H	Steico Term, Floor and Internal	160	0,038-0,039	0,113-0,116	2100	5	1 m3	237.84	5	-381.00	3.86	263.00	-114.14	0.05	-114.09	4260.00	3.00	794.00	5057.00	781.00	53.40	2910.00	3744.40	-1312.60
Switzerland	Wood Fibre (Rigid) Wet Process I	PAVAPOR, · PAVAWALL 155, PAVATHERM 140, SWISSTHERM 150	135-155	0,038-0,039	-	2100	5	1 m3	140	7				-165.10	#VALUE!	#VALUE!				3465.00				1612.00	-1853.00
United Kingdom	Rock Mineral Wool	Knauf Rock Mineral Wool	106-160	0,035-0,039	0.27	1030	1	1 m3	136					196.00	37.73	233.73				414.00				2250.00	1836.00
Slovenia	Rock Mineral Wool	Smart Roof Top Knauf	120-140	0.038	0.28	1030	1	1 m3	130					154.00	180.32	334.32				111.00				2480.00	2369.00
Germany	Stone wool	ROCKWOOL stone wool insulation materials in the medium bulk density range	61-120	0,032-0,05		-	1	1 m3	96					121.79	133.16	254.95				175.66				1137.14	961.48
Netherlands	Foam Plastic	Kingspan Kooltherm® K20	35	0,020-0,021	0.55	1030	-	1 m3	35					70.37	48.55	118.92				276.25				1987.50	1711.25
United Kingdom	Foam Plastic	Xtratherm, PIR insulation	32	0,020-0,021	0.61	1030	1	1 m3	32					169.38	9.71	179.09				116.25				3406.25	3290.00
Belgium	Extruded Polystyrene (XPS) Foam	Exiba	20-50	0,03-0,041	-	-	-	1 m3	33.7	-				94.03	46.74	140.77				72.31				2859.36	2787.05
Norway	Hemp Fibre	Ekolution Hemp Fiber	35	0.04			2	1 m3	35		-30.60	3.85	4.51	-22.24	48.55	26.31	457.00	0.16	23.30	480.46	161.00	55.50	33.50	250.00	-230.46
Germany	Wood Fibre (Rigid) Dry Process K	Steico Universal DRY	180-210	0,045-0,048	0,102-0,127	2100	3	1 m3	140	5	-185.00	2.43	101.00	-81.57	194.19	112.62	2380.00	1.89	267.00	2648.89	1450.00	33.60	1320.00	2803.60	154.71
Germany	Wood Fibre (Rigid) Dry Process M	Best Wood Schneider WALL 180, Top 180, 220,	180-220	0,043-0,047	0,102-0,114	2100	3	1 m3	163	8_12	-186.00	3.91		-186.00	0.00	-186.00				4890.00				1600.00	-3290.00
Germany	Wood Fibre (Rigid) Process P	GUTEX Standard-n, GUTEX Thermowall®-gf	185-250	0,043-0,046	0,088-0,111	2100	4	1 m3	167	8				-198.40	0.00	-198.40				3218.00				1478.00	-1740.00
Italy	Wood Fibre (Rigid) Q	Beton Wood FiberTherm Isorel, Special	230-240	0,046-0,050	0,091-0,104	2100	5									0.00									
France	Wood Fibre (Rigid) R	Isonat Duoprotect	180	0.049			3	1 m3	180					141.61	0.00	141.61				4489.87				3,305,29	7795.16
Germany	Wood Fibre (Rigid) S	Sonae Aruco AGEPAN® THD T+G, AGEPAN® UDP	230-270	0,047-0,052	0,097- 0,108	2100	3_5	1 m3	384					-423.00	0.00	-423.00				8948.86				4794.98	13743.84
Germany	Wood Fibre (Rigid) Wet Process L	Steico Universal, Protect, Special,	230-270	0,046-0,048	0,085-0,095	2100	5	1 m3	237.84	5	-381.00	3.86	263.00	-114.14	0.00	-114.14	4260.00	3.00	794.00	5057.00	781.00	53.40	2910.00	3744.40	-1312.60
Switzerland	Wood Fibre (Rigid) Wet Process N	PAVATHERM-PLUS, PAVATHERM-	175-190	0,043-0,046	0,107-0,117	2100	5	1 m3	140	7				-165.10	0.00	-165.10				3465.00				1612.00	-1853.00
Switzerland	Wood Fibre (Rigid) Wet Process O	pavatex ISOLAIR, Swissisolant, Pavaboard	200-240	0,044-0,047	0,097-0,105	2100	5	1 m3	240	7				-252.60	0.00	-252.60				5842.00				2920.00	-2922.00
Italy	Wood Fibre (Rigid) T	Natural BAU	180-270	0,043-0,050	0,085-0,114	2100-2250	3_5							0.00		0.00				0.00				0.00	0.00