POTENTIAL FOR RESEARCH ON HEMP INSULATION IN THE UK CONSTRUCTION SECTOR

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Abstract: Hemp based thermal insulation has the potential to reduce CO2 emissions from buildings and to be 'carbon-negative' in its production and manufacture. Hemp has been in use to produce bio-based natural fibre insulation in the UK in recent years. With further development in hemp agronomy, production process and selection of raw materials in the production, hemp-based insulation materials are likely to become environmentally and functionally superior products to other insulation materials developed from petrochemical and mineral based sources. This paper looks at the research works on the present and future housing scenario in the UK, reductions in embodied energy of insulation materials, techniques for increasing thermal performance and ways in which the environmental impact can be lessened.

1. Introduction:

The United Kingdom, under its Climate Change Act 2008, has established the grand target of reducing greenhouse gases by ensuring that the net UK carbon account for the year 2050 will be at least 80% lower than the 1990 baseline. This new approach is important in relation to playing the UK's part in avoiding a global temperature rise of more than 2° Celsius by stabilizing atmospheric CO_2 concentration to 400 ppm. On September 2009, UK scientists predicted that the global average temperature could rise by 4°C as early as 2060 (British Broadcasting Corporation, 2009)-which requires more robust mitigation strategies.
In the United Kingdom, the domestic sector is the second largest consumer of energy with annual consumption of 28.5% of the total energy and it represents 27% (Boardman, 2007) of total greenhouse gas (GHG) emissions. The domestic sector with most of the existing buildings, according to the former Department for Business, Enterprise & Regulatory Reform (BERR), uses four times more energy than the commercial sector and seven times more than public administration (BERR, 2008). Therefore to keep up with the UK government's GHG reduction target, it is imperative that the residential sector becomes pro-active in reducing its energy consumption.

2. Why insulation matters:

GHG emissions from buildings can be reduced by the following ways: using materials with low embodied energy during building construction and maintenance, minimising energy consumption, using low-carbon and renewable energy in building operation, reducing the emissions of non-CO_2 GHG gases.
Thermal envelope of a building determines the relationship between the exterior and interior of a building in terms of heat or mass transfer (Givoni, 1998, p.107). Therefore use of energy depends much on

the level of thermal protection of the building envelope. Thermal protection can be increased by using insulation with better thermal performance, draught proofing and using efficient glazing.
UK Carbon Attribution Model (Jackson et al, 2005) shows that, of the total carbon emissions of 176.4 million tonnes of carbon (MtC) in the UK, space heating represents 24 MtC and is mainly emitted directly in the home. This is the second highest emission after 'Recreation and Leisure'. This finding conforms to the study by Building Research Establishment (BRE) which highlighted that cost-effective measures could save 25% energy of which 65.4% savings could be achieved by improved insulation standards for thermal envelope (Halliday, 2008, p.63).

3. British Houses and insulation: Present Context and Future Scenario:

Market for building thermal insulation in the UK can be viewed from two perspectives:

- Insulation market based on the elements of building thermal envelope.
- Insulation market based on building types and numbers in 2050.

These two scenarios are discussed below:

3.1 Market based on the major elements of building thermal envelope:

The major elements of building thermal envelopes are walls and roofs and most of the thermal insulation market concentrates on insulating and draught-proofing these two elements. Based on a recent report (Mintel, 2007), table 3.1 is developed to explain the trends in the insulation market for different elements of building envelopes.

3.2 Market based on building types and numbers in 2050:

At present there are about 25.6 million dwellings in the United Kingdom with an average floor area of $74m^2$/dwelling. About 17 million of these houses are with cavity walls and cavity-walls are uninsulated in 8.5 million of these houses. About 5 million houses are built of solid brick walls and most of these lack wall-insulation. According to one estimate, there were 6.3 million homes in England without any or with very minimal loft insulation in 2005 (Boardman, 2007).

Table 3.1 Market for thermal insulation based on the major elements of building thermal envelope

	% Market share in 2006	Market share in 2006 by £ million
Cavity	20%	153.8
Loft	21%	158.7
Draught Proofing	16%	121.2
Roof	19%	144.9
Internal Wall	6%	46
External Wall	6%	43.5
Floor	8%	62
Other	4%	31

It has been estimated that the total numbers of British houses in 2050 will be 31.8 million ($74m^2$/dwelling) of which 20.6 million will be from the existing housing stock and about 11.2 million will be new-built. It can be estimated that, of this existing housing stock, about 6.8 million houses will require cavity wall (or internal) insulation and 4 million houses will require solid wall insulation. In total, by 2050, 10.8 million older houses and 11.2 million new houses will require insulation in the envelope.

4. British insulation market and need for low-energy insulation:

By 2050, in line with 80% GHG reduction scenario, about 22 million houses in the UK need to be insulated. This indicates a robust market for insulation materials and potentially huge amount of material and energy flow through the supply chain. Therefore it has to be ensured that the insulation materials do not become an environmental burden per se by carrying high embodied energy, depleting non-renewable natural resources during production and creating environmental and health hazards during and after installation.
Many argue that synthetic and mineral based insulation material are unsustainable as these products use a lot of fossil fuel and non-renewable resources during production while there is a strong commitment by the UK government to reduce energy-use(Bevan et al, 2008). One of the peak oil predictions states that conventional oil production appears to have peaked in 2005 (Hopkins, 2008) and downward trend has begun. Therefore it can be argued that a shift from hydrocarbon economy to carbohydrate economy in terms of production and use of insulation is necessary.

5. Types and forms of Insulation materials:

Insulation materials are classified mainly on the basis of forms and in some cases on the basis of any functional attribute.Based on a previous study (Al-Homoud 2004, Sustainability Victoria, 2009), table 5.1 is developed to show the major types of insulation materials and their applications.

Table 5.1 Types of Insulations based on form

Type	Main Products	Use
Rigid Boards	Polystyrene (Styrofoam, EPS, EPS-Foil), polyurethane, polyisocyanurate, Fibreglass, Phenolic Foam.	Walls, flat roofs, loft, pitched roof and perimeter insulation.
Batts and Blankets	Glass fibre, Mineral wool, Natural wool, Natural fibre, Polyester matt	Flat roof, pitched roof, loft, timber floor, framed wall.
Loose Fill to be blown-in and poured-in	Glass fibre, Mineral wool, Natural wool. (natural wool is not applicable to cavity type)	Flat roof, pitched roof, loft, framed and masonry wall
Reflective	Plastic film, Aluminium foil with glass fibre reinforcement, Aluminium foils on polyethylene bubbles, Multi-cell foil batts,	Flat roof, pitched roof, loft, framed wall (but not all products are suitable for all the uses).
Poured-in with concrete	Perlite, vermiculite	Masonry wall, loft space.
Foamed or sprayed in-place	Polyurethane, polyisocyanurate, Phenolic Foam.	Pitched roof, flat roof, loft space, wall and floor.
Blocks and Hollow forms	Aerated blocks, Hollow EPS blocks and panels filled with concrete.	Masonry wall insulation
Weather-proof house-wrap	Polyethylene fibres sheeting added to buildings during construction.	Flat roof, pitched roof, framed wall.

Another useful categorisation of insulation materials is based on organic and inorganic materials as shown in the following table (table 5.2).

Table 5.2 Types of Insulations based on organic/inorganic variations

Organic Insulation	Inorganic Insulations
Fibrous materials like hemp fibre, cotton, wood, cellulose, synthetic fibre etc.	Fibrous materials like glass fibre and rock wool.
Cellular material like polyurethane , foamed rubber etc.polystyrene, polyisocyanurate.	Cellular materials like calcium silicate, ceramic products, bonded perlite and vermiculite.

However the classification mentioned in above two tables (table 5.1 and 5.2) does not provide a clear perspective of environmental aspects of insulation materials. Hence, a broad-brush ecological classification of insulation materials is proposed in table 5.3.

Table 5.3 Types of Insulations based on sourcing

Natural insulation	Synthetic and mineral insulation
Bio-based insulation: Plant and wood based insulations like hemp fibre insulation, cork diffutherm, etc.	Synthetic insulation: Various non-natural polymers like polyurethane polystyrene, polyisocyanurate etc.
Animal based insulation: wool insulation like thermafleece.	Mineral insulation: Glass fibre and rock wool insulation

6. Bio insulations and hemp:

Bio-based natural insulation materials have been in use ever since the advent of man-made dwellings. Thatched roofs are considered to be the earliest kind of roofing systems (Encyclopaedia Britannica, 2009). Straw-Bale buildings were first built in late 1800s (Woolley, 2006, p.71, Borer and Harris, p.104). Cork barks had been used as roof covering in the 1st century AD and the Spanish people used to line the inner surfaces of stone houses with cork (Thomas, 1928, p.25). In contrast, hemp fibre insulation is a comparatively recent innovation even though hemp fibres had been processed in China since the 28th century BC and used in Europe since the 16th century for producing marine cordages, twines, textiles and papers. The importance of hemp as a fibre crop declined in the 19th century. The interest has been renewed recently in Germany, France, the Netherlands, the UK, Spain and Italy, and some other countries in the world (Struik et al. 2000). Cautiousness is required to interpret the word 'hemp', as historically the term used to refer to the bast and leaf fibres of different plants including 'true' hemp (cannabis sativa), manila hemp, sisal, henequen, Indian Sunn etc (Imperial Economic Committee, 1932, p.9).

7. Hemp Botany, Agronomy and Hemp Fibre:

The word 'hemp' in this paper refers to 'industrial hemp' that contains very low level of delta-9 THC (tetrahydrocannbinol) and therefore is not a psychoactive substance. Hemp is an annual crop and belongs to the Cannabinaceae family. The stalk height and thickness depend on the following factors: daily exposure to sunlight, geographical race, soil condition and available nutrients, supply of water, spacing of plants and sex of the plant. Hemp crop requires minimal biocide, suppresses weeds and requires limited amount of fertiliser

(Van der Werf, 1994). In the UK, hemp is planted in late spring and sometimes reaches a height of 3 metres by August. Highest yields of 9 tonnes per hectare have been achieved in the UK. Hemp grown for fibre produces 29% fibre, 66.7% shive and 4.3% dust by mass (Murphy et al, 2008). Hemp straw can be retted in the field, or unretted straw can be processes in the factory. Hemp can be grown in a number of rotational situations. Nitrogen is a vital component of yield. There are two possible harvest routes, these are: Dual hemp when both seed and straw are harvested and hemp for straw.

The stem of hemp consists of wood and bast tissue. Bast tissue forms the exterior layer of the stalk and functions as the plant's transport system. In bast tissue, groups of fibre cells are formed whose outer cell walls are strengthened with thick layer of cellulose. The main purpose of this fibre cells is the reinforcement of the stalk by providing tensile strength and torque resistance. Fibre cells are held together in bundles by pectin. This bond is broken down during processing by biological, mechanical or chemical mechanism. In addition to primary bast fibres, hemp forms secondary fibre bundle systems to provide elasticity and stability. The secondary fibre bundles are shorter in length and diameter and less valuable than the Primary fibres. Bast fibres are used as raw materials of thermal insulations.

8. Performance requirements for crop based construction materials:

Some critical performance requirements to determine the best application for crop-based construction materials (Van Wyk, 2007), are:

- **Economic performance**: Low embodied energy in manufacture and in use, low water use in manufacture, low wastage in manufacture and in assembly, and recycling potential.
- **Social performance**: Overcoming consumer resistance, health and safety during manufacture and assembly, facilitating the participation of small, medium and micro enterprises, rural workers and women in the supply chain and life-cycle.
- **Environmental performance:** Bio-degradability of the material at the end of its life-cycle, using materials with low toxicity levels and low emission.

The strength of the above analysis lies in the identification of social performance. Any discussion of economic potential of hemp insulation will be inadequate if social performance is not considered.

9. Life Cycle Assessment (LCA) of the insulation materials:

LCA is the compilation and evaluation of the inputs, outputs and potential environmental impacts throughout a product's life cycle, from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (ISO, 2006). The four phases of LCA study are: Goal and Scope Definition, Life Cycle Inventory Analysis (LCI), Life Cycle Impact Assessment (LCIA), and Interpretation.

9.1 The LCA of hemp insulation:

A cradle to grave assessment of Natural Fibre Insulation (NFI) materials based on ISO 14040 standards for LCA has been carried out recently (Murphy et al, 2008). A comparison has been made between the following insulation materials: RockWool (Mineral Wool), Thermafleece (Sheep Wool), Crown Loft (Glass Fibre) and Isonat

(Hemp and Cotton mix). The Isonat hemp insulation is a blend of 35% hemp fibre, 35% waste cotton fibre, 15% bi-component polyester fibre and 15% fire retardant. (Murphy et al, 2008). The LCA study shows that the hemp insulation has lower Global Warming Potential but performs poorly in other impact categories. Marginal analysis shows that heat gas, bi component polyester binder and transport are the main contributor to the impact categories. Combination of most likely optimization proposed in the LCA study is:

- Reduction in product density from 35kg/m2 to 20km/m2
- Production in the UK
- A hemp only product, omitting the recycled cotton fibre portion
- Reduced fire retardant usage with reduced drying requirements
- A switch to a polylactic acid (PLA) based bi-component binder
- An increased throughput in primary processing

9.2 The limitations of the LCA studies:

Some limitations of the LCA study are:

- Data for the NFImaterials was acquired from site specific sources and generic databases. In contrast, for the mineral and glass wool insulation materials, aggregated system LCI data were obtained from the manufacturers- which makes direct comparison less reliable.
- It is not clarified whether the LCA is attributional or consequential.
- Emerging LCA methods like Economic Input-Output LCA and hybrid LCA (Hendrickson et al, 2006) methods are more comprehensive in relation to system boundary.
- Indoor air pollution has not been taken into account in the life cycle assessment.
- LCIA does not address the other two dimensions of sustainability – the social impacts and the economic aspects in the life cycle.
- The life cycle data analysis of NFI materials were not peer reviewed.

10. Further Research Potential:

An optimization-trajectory of hemp insulation is presented below:

10.1 Development of environmental profile:

- **Replacement of binder:** Binder is the second highest contributing in terms of global warming potential. PLA based binder suggested in the LCA analysis is not economically viable. Therefore further research is required to identify a cost-effective natural binder.
- **Heat Gas:** Heat gas is used for drying during the process of blending binder and fire retardant with the fibre matrix. Reduction of heat gas or changing the source of heat gas can contribute to reduce GWP.
- **Fire Retardant**: Applying fire retardant on the surfaces only will not be effective as installers can cut and expose the untreated internal surfaces. A bio-based additive with twin function of binder plus fire-retardant, that can be applied homogeneously, will be most advantageous.

10.2 Development of performance:

- **Hygrothermal performance:** The way that the building envelope responds to the fluctuations of temperature, humidity and air flow, determines its hygrothermal performance. There are two aspects to this performance. The first is in the way that it influences energy use and thermal comfort in the building. The second is the longevity of the envelope in terms of its ability to cope with moisture. Some current researchers (Pavlík, Z.and Cˇerny, R., 2009) are looking at these performances in terms of its contribution to air quality, tempering of internal air humidity and avoidance of mold growth, as well as the thermal performance.

- **Application:** It is important to recognise the different needs of new-build and refurbishment markets. For example, thermal refurbishment of an old building requires thin insulation and dry method of installation; therefore research, in this case, needs to be directed towards developing rigid insulation boards.
- **Hybrid hemp insulation:** Novel insulation material like PCM (Phase Change Materials, for better thermal storage capacity), aerogel (for better λ value) or aeroclay (98% air and 2% clay) can be incorporated into the fibre matrix of hemp. However in all cases following issues need to be considered:
  - The hygrothermal performance of the hybrid material, with respect to moisture transfer and condensation.
  - The potential risk of producing a ‘monstrous hybrid’ (Mcdonough et al, 2009)-mixture of materials both technical and biological.
  - The viability of producing hybrid insulation while there is market presence of aerogel and PCM insulation as plaster board and other forms.
  - Health issue with regards to using nano particles.

11. Conclusion:

In the UK about 11 million older houses need to be insulated which can be the potential refurbishment market for hemp insulation. In addition about another 11 million new houses will be built by 2050 requiring huge amount of insulation. With the increasing awareness of low-energy and environmental benign goods, eco-efficient bio-based natural fibre insulation materials hold the prospect of being successful mainstream products. However, to enter into the mainstream market the products have to be economically competitive, thermally efficient and contextually relevant. Some research potential that can determine the future of hemp insulation is therefore explored.

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