A SENSIBLE APPROACH TO LOW CARBON AND HEALTHY BUILDINGS

David Garlovsky, BSc, MSc, Certificate in Social Phenomenology
Affiliation: Recovery Insulation Ltd – 84 Upper Valley Road, Sheffield S89HE, United Kingdom
Contact: info@inno-therm.com

Abstract

House insulation reduces energy usage, lowering heating costs, and reducing CO_2 emissions. However insulating materials vary in the CO_2 emissions they produce in manufacturing, a fact consumers may not realise. Life Cycle Analysis (LCA) ascertains the CO_2 impact of manufactured goods allowing comparison. Here the results of LCA on a range of environmentally friendly insulators are presented. Natural Fibre Insulators (NFI's) are produced from natural or recycled products unlike conventional materials. How do these products compare in their overall CO_2 impact? What are the benefits of LCA and how comprehensive are they?

Keywords: Life cycle analysis [FDES] LCA, home insulation, CO_2

Introduction: Different insulators, different environmental effects

Improving residential insulation is often considered a panacea. Energy requirements are lessened which reduces heating costs and saves money. The associated reductions in carbon emissions play a valuable contribution to fighting global climate change and preserving precious energy resources (Martin, 2007). Promoting improved insulation provides an ideal opportunity for U.K. policy makers to mediate the impact of rising fuel prices by reducing household energy demand. The U.K. aims to reduce greenhouse gas emissions by over 80% by 2050 (Murphy, R. J., Norton, A. and Campus, S. K., 2008). Using Low Carbon (LC) materials is a critical component in meeting the global challenges of global warming and help in the transition to a low carbon economy.

In addition to the conventional insulation materials traditionally used, there are now naturally based materials available, often referred to as Natural Fibre Insulation (NFI). The market for such "green" building products is growing rapidly. It is projected to reach £354 billion by 2020, according to a report by Global Industry Analysts (Environment Leader, 2014. This rise is being driven by a multitude of factors; including government regulation, increasing energy and resource costs, green building materials becoming less expensive, plus the reduced risk of allergic respiratory infections from natural materials.

The use of such NFI materials is being promoted, for example in the Code for Sustainable Homes (UK Government Department of Communities and Local Government, 2006), which emphasises that building materials are sourced responsibly, and the emissions of CO_2 are considered through the Global Warming Potential (GWP) value. The Energy Performance Certificate Scheme (UK Government Planning Department, 2007) categorizes products according to environmental impact thus aiding consumer choice. The environmental performance of LC insulation is superior to conventional insulation (Schmidt et al. 2004).

However often consumers [e.g. homeowners, construction companies, architects] may not realise nor wish to take into account that different insulating products vary in their CO_2 impact due to material used in the manufacturing supply chain and energy consumption. The manufacture and disposal of insulators results in CO_2 emissions despite their positive influence on CO_2 emissions by aiding energy saving. Insulating material can also have negative environmental effects as they influence air quality and increase indoor pollution (Spengler and Sexton, 1983). There is a correlation between poorly conceived energy efficiency efforts, indoor air quality, and the rise in asthma and allergic diseases in the U.K. (Sharpe et al., 2015). It is acknowledged that there is a lack of reliable, independent data about the environmental impact of both NFI materials and more traditional insulators (Murphy et al., 2008). This means little comparison has been made between the two types of products. How can the environmental effects of insulators be assessed and compared?

Method: Life Cycle Analysis

What is an LCA?

A Life Cycle Analysis (LCA) is a method to assess the entire CO_2 impact of any manufactured product. CO_2 emissions resulting from manufacture, use, and disposal are included (USEPA, 2010; PAS 2050, 2008). Such a LCA thus quantifies the overall CO_2 impact of a product. This better represents the true value of materials in environmental protection rather than simply considering values during its active use. Applying an LCA is vital to following the principles of a Circular Economy (Ellen Macarthur Foundation, 2013). This is one that is restorative by design, and which aims to keep products, components and materials at their highest utility and value, at all times. Different forms of LCA exist, including those including only manufacture of products ready for delivery to suppliers at the factory door (cradle-to-gate), or encompassing manufacture and use of the product until it no longer functions (cradle-to-grave), or even including disposal of the product or recycling (cradle-to-cradle).

Performing an LCA

Criteria have been established for the conducting of a LCA (e.g. PCA, 2050). There are typically four stages (Curran, 1996). Firstly, the aims and goals of the LCA are established. Secondly, the steps in the manufacture process are ascertained. Thirdly, an assessment of the environmental impact of each step is made. Lastly, the results are interpreted and decisions made on the basis of the effects seen at each step.

Example One: LCA comparing Natural Insulators

Murphy et al. (2008) performed a 'cradle-to-grave' LCA on a number of natural fibre insulating materials and compared them to conventional materials, following the standard protocol laid down in ISO 14040. The products examined were:

- *Thermafleece,* produced in Bradford is produced from Sheep's Wool;
- *Isonat,* produced in Lyon is made from hemp (Murphy et al., 2008).
- Plus the conventional products, *Rockwool* and *Knauf Crown Loft*.

They also performed a marginal analysis, examining the carbon production at each stage of the manufacturing process to identify where optimisation could occur. This provides a Global-warming potential (GWP), which is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. A GWP is calculated over a specific time interval, commonly 20, 100 or 500 years. As it is perceived that NFI materials will have an inherently low environmental impact, the chosen benchmark products were BREEAM A rated. Information on market leading materials produced by Knauf and Rockwool were used as benchmarks for evaluating environmental performance of the NFI's.

They found that the environmental impact of NFI and the conventional fibres studied was broadly similar. The results can be seen in Table 1. Generally NFI's were broadly similar to "A" rated products in the Building Research Establishment (BRE) Green Guide to Specification. However the GWP_{100} of Thermafleece was particularly low. The GWP_{100} of Isonat suffered because of transportation and its greater density. The products of Knauf and Rockwool had poor GWP_{100} in comparison.

NFI offered great potential in lowering GWP_{100}. With Isonat, drying out the product, adding polymers, and transportation causes much impact. Another feature of the Murphy et al. (2008) study is the identification of the impact of the end of life stage of the products. Landfill is identified as the most likely destination of products and the effect of this is ascertained. Most carbon emissions were caused through manufacture, such as the addition of flame-retardants. Efforts at reducing impact should be concentrated here. The replacing of polymer, reducing insulator thickness, and choosing another flame retardant material, could all aid in reducing CO_2 emissions further.

Example 2: Inno-therm®/Metisse®

***What is* Inno-therm®/Metisse®**

In July 2013, production of Inno-therm® was transferred to Le Relais in northern France, and offers Metisse® under the Inno-therm® brand as a thermal and acoustic insulation range. Inno-therm®/Metisse® is an insulation material manufactured from recycled denim/cotton (Jordeva et al., 2014). Over 80% of the product is recycled cotton/denim. The raw material is sourced from France. It is a proven LC insulation product in energy requirements both in manufacturing and performance. It has met all the required requirements of UK and European Technical standards. Being recycled it reduces textile waste sent to landfill. It is estimated that 619kt consumed textiles is collected for reuse and recycling every year, and an additional 820kt of clothing and household textiles, which is currently consigned to landfill, could be diverted (WRAP, 2013). The manufacturing process uses 80% recycled cotton/denim [3 jean's/m² for 100mm thickness].

Inno-therm®/Metisse® has low embodied energy and can be recycled (WRAP, 2013). In comparison with conventional products such as wood wool board (980kg/tonne) and mineral wool (1,050kg/tonne) Inno-therm®/Metisse® has an embodied CO_2 of 393kg/tonne of insulation product. The material is non-itch/toxic and will not cause allergic reactions. Its thermal properties [0.039 Wm-1K-1], in the design of new build or refurbishment allows one to reduce timber sizes, thus having cost savings while still achieving good U – values. It has end user benefits, as in installing, it won't itch or irritate the installer and there are no health concerns with cotton.

First LCA: Initial research, conducted by a doctoral candidate, was begun in 2011 at the School of Architecture, University of Sheffield. This investigated the supply chain and manufacturing processes of the recycled cotton/denim insulation (Timmis, 2011). The production steps in Inno-therm®/Metisse® were identified, systems boundaries defined, and carbon emissions quantified following the Carbon Trust (2008). The data of the conventional insulation product was directly accessed from the Ecoinvent database (ECOINVENT, 2015), the world's leading database of consistent, transparent, and up-to-date Life Cycle Inventory data. However, the database did not offer information as detailed as the company that manufactures the recycled insulation, and only the result of LCA was given. The GWP_{100} value (Global Warming Potential) of conventional insulation obtained was an average value. This lack of specific product information and data lowered the credibility of the research.

Timmis (2011) identified four discrete stages in the production of Inno-therm®, each of which accounted for carbon emissions. These stages are illustrated in Figure 1. In the first stage recycled material is retrieved. Secondly, it is processed into fibres; flame retardants are added and the new material is mixed with polyester. Thirdly the new fibrous material is processed and packaged into a form suitable for distribution. Fourthly and finally the new product is transported and distributed.

The study found that the first stage, namely obtaining material for recycling caused the emission of the greatest amount of carbon, 244 kg/tonne. Manufacturing resulted in 123.8 kg/tonne. Processing into a form for sale accounted for only 13.0 kg/tonne and distribution 12.1 kg/tonne. Thus obtaining the raw material caused most damage in carbon emission terms. Transportation, followed by electricity use were the main components of obtaining the raw material that accounted for these carbon emissions. Later transportation and packaging of the Inno-therm® itself resulted in little carbon dioxide emissions.

Second LCA*:* Heyuquing (2014) performed a second, more ambitious, study in 2014 within the Management School, at the University of Sheffield. This extended this research and compared the total carbon emissions of the recycled insulation to a selected conventional insulation product. A 'cradle-to-cradle' LCA, examining carbon emissions from sourcing to disposal of the product was performed. This LCA extended the scope of the initial research begun in 2011 and also identified areas where emissions could be reduced.

Data on Inno-therm®/Metisse® was obtained direct from Recovery Insulation Ltd., a social enterprise company, the distributors primarily in the UK of Inno-therm®/Metisse®. Information of the conventional product was obtained from the Ecoinvent inventory which lists CO_2 emissions from various insulators. The end-of-life phase emissions were taken into consideration, which covered the disposal activity of any waste produced in manufacturing supply chain. Although LC insulation is recognized to have lower impacts on the environment than conventional products, this final stage of a product's lifespan still needed to be examined. A GWP_{50} over 50 years was used as the standard for carbon emissions. Data was obtained direct from manufacturers. Where data could not be obtained directly BUWAL, Ecoinvent databases were utilised. The BUWAL database allows transport costs to be ascertained.

All stages of production from sourcing of natural material to disposal of final product were assessed and amounts of carbon produced estimated. Manufacturing of Inno-therm®/Metisse® was found to be the stage at which most carbon emissions were produced, with a GWP_{50} of 1.24 kg CO_2. Figures for transport were 0.038 kg CO_2, installation 0.001 $CO_{2,}$ and at the products end of life 0.03 kg $CO_{2.}$ Inno-therm®/Metisse® compared well with the conventional insulator examined in terms of CO_2 emissions.

A feature of both analyses was that they identified that carbon emissions were lower or comparable with conventional products. The recycled nature of the product meant that Inno-therm®/Metisse® was seen as a more sustainable product than conventional products.

Discussion: What are the benefits of LCA?

The studies show the potential benefits of a LCA, and the limitations.

- *Comparison*: As the study by Murphy (2008) shows LCA allows comparison of materials, providing an easy to compare figure for the environmental impact of a product. Murphy (2008) was able to compare natural fibre insulators with conventional types.
- *Quantification of environmental impact*: An LCA is an attempt to place numbers on the environmental impact of a product, thus making an abstract concept more concrete.
- *Identifying improvements*: LCA allows areas where CO_2 could be saved and identified, thus improving the manufacturing process. For example Timmis (2011) identified stages in the sourcing of materials where emissions could be saved. Timmis (2011) identified the locally sourcing of materials as the most important stage to consider, as this stage contributed most to carbon emissions. Heyuqing (2014) however, found that manufacturing processes was responsible for most carbon. A one-step recycling and a reduction in the input of additives during the production process were suggested. Murphy et al. (2008) made a number of recommendations including the scaling up of production, reducing the amount of flame retardant chemicals used.

Positives of the* Inno-therm®/Metisse® *LCA's

The LCA's on Inno-therm®/Metisse® showed a number of positive benefits of LCA:

- *Identification of manufacturing steps:* Both Timmis (2011) and Heyuqing (2014) successfully identified steps in the manufacture of Inno-therm®/Metisse® where CO_2 emissions were caused. For example Timmis (2011) successfully identified treatment of recycled cotton fibre with flame retardant chemical as a step in the manufacturing process. This demonstrates the value of LCA's in breaking down complex processes into simpler stages where CO_2 emissions can be easily identified.
- *Quantification of CO_2 emissions:* The study by Timmis (2011) most thoroughly provided exact measures of CO_2 emissions. For example differentiation of transportation emissions were most meticulously broken down into those produced through ferries and lorries. LCA's thus help place concrete values on previously abstract concepts.
- *Final destination*: Most LCA's on insulators are 'cradle to grave', and thus cease to consider what happens when the product leaves the factory. Heyuqing's (2014) attempt to study CO_2 impact after this, considering disposal, was laudable, but ultimately relied on guesswork. The study shows the importance of considering the CO_2 impact of products in all stages of their life.
- *Identification of areas for improvement*: Timmis (2011) identified many areas where reductions in CO_2 emissions could be made, For example reducing the low melt polyester binder content would result in a reduction of 11.9 kg CO_2 per tonne of insulation.

But the studies on Inno-therm®/Metisse® illustrate the challenges and limitations of LCA's:

- *Identifying steps:* The study by Heuyqing (2014) which although ambitious was unrealistic due to lack of information. Ascertaining CO_2 emissions for long lasting products such as insulation once they have been manufactured can be difficult.
- *Statistics*: Alterations in the production process are often not taken into account. For example Inno-therm®/Metisse® is now manufactured in France with the brand name Inno-therm®/Metisse®, where 80/90% energy resource is from nuclear as compared to UK, meaning its production results in lower carbon emissions. The studies on Inno-therm®/Metisse® fail to take this change into account.
- *Lack of data*: The studies on Inno-therm®/Metisse® are limited by the data which is available to them. Timmis (2011) mentions the problems with lack of data in the assessment made. Insufficient data may result in false conclusions being made. For example Timmis (2011) performed a 'cradle-to-grave' analysis because of the difficulties in obtaining information for products postproduction. Heyuqing (2014) used a mean value of GWP for comparisons based on data from the ECOINVENT website, as more detailed data was lacking for Rockwool and thus made doubtable conclusions. If more extensive data was available a more exact comparison could be made.
- *Varied Environmental Impacts:* The studies illustrate the limitations of considering only one aspect of a products environmental impact; namely CO_2 emissions. Often the environmental benefits of such products are many and various. Recycled or natural fibre materials are benign, making them easier and cheaper to install and dispose of. Although the overall environmental benefits were not considered by Heyuqing (2014).

Similarly when examining a product’s carbon impact, thought must be given as to all ways in which a product may influence carbon emissions. For example Heyuqing (2014) failed to take into consideration that Inno-therm®/Metisse® is a much better insulator than conventional products, meaning a substantially lesser amount is required than for conventional materials or that the reduced heating required lowers carbon emissions. This has associated advantages regarding costs and a products carbon impact.

What are the advantages of LCA for natural insulators?

LCA's allow easier comparison for consumers of naturally based and conventional products. Even though there are a number of alternative LC insulation products currently available, the suppliers of conventional insulation are well established. Contractors are familiar with the products. LC insulation products are often produced by small insulation manufacturers and thus unable to increase market presence.

Price provides a further market barrier for LC insulation. Conventional products are sold to the public at subsidized rates, which creates a distortion in the market. LC products do not benefit from this subsidy. There is no technical reason why LC insulation products should not be offered in DIY stores with similar subsidies. Use of LCA would allow better comparison for consumers and aid their establishment in the market.

Future research

In light of the research that has been conducted gaps were identified that will require further research in 2015. For example, lack of available data from conventional insulation manufacturers for example on energy usage during the production process, hindered research in 2014. There were limitations to the reliability of the data that could be obtained.

Research in 2014 did not look into how the different thermal insulation performances would affect the functional unit. The correct functional unit would need to be re-established to remove any variability. As we need to compare like with like - e.g. convert results into units of insulation. The economic benefit of adopting recycling activities was not identified in the research. The result of the research concentrated on the LCA. Data related to the end-of-life phase of the conventional insulation product was absent and the CO_2 emission amount of insulation that goes to landfill was not accessible.

One objective of future research for this recycled-based insulation will focus on low-energy processing in reducing emissions during manufacturing through the substitution of the synthetic temperature activated binder fibre using thermoplastic proteins from biological sources or recycled alternative.

A doctoral candidate will again extend the research in 2015 by:

1. Reassessing LCA and environmental performance of the recycled insulation and comparing to conventional insulation.
2. Further study how the manufacturing processes of the recycled insulation could be optimized to reduce its carbon emissions in the manufacturing supply chain.
3. Finally, look at the full economic benefit by establishing a £ value in the use of an LC insulation.

Conclusion

LCA is invaluable in showing the lifetime carbon costs of recycled insulated material. LCA highlights where significant quantities of carbon emissions are released and where emissions could be reduced. They also show the impacts the supply chain and manufacturing processes have on carbon emissions in recycled-based insulation. Though the values of carbon emissions by conventional insulation products have been calculated, lack of available data hinders comparison with recycled products. There is a lack of reliable information on the impact of Natural Fibre Insulation materials in general (Murphy et al. 2008).

The LCA's used, as examples did not consider the economic benefits to adopting NFI, LC and recycled insulation. LCA primarily focuses on the environmental benefits in terms of CO_2 emissions of adopting recycled-based insulation. It would be beneficial to expand the analyses of the recycled-based insulation into a full LCA allowing direct comparison with other conventional and LC insulation products (e.g. Thermafleece, Sheep's Wool and Rockwool, etc.) taking this into account. Comparison with naturally derived binder product and/or product with 100% recycled content would be pertinent.

In summary, the principles of a Circular Economy, namely using low carbon materials and resources, should be followed at all stages of a products manufacture, including sourcing energy from sustainable sources when insulation is manufactured and in the supply chain of such materials. The full life cycle costs of products should be considered.

In a world where lower carbon and healthy buildings are valued, to quote W.E. Deming (1994):

> *"If you improve quality costs will go down and value goes up".*

REFERENCES

Building Research Establishment (BRE), 2015. Green Guide to Specification Accessed from http://www.bre.co.uk/greenguide/podpage.jsp? Id=2126.

Carbon Trust, 2008. Guide to PAS 2050: How to assess the carbon footprint of goods and services. *British Standards Institute, London*.

Curran, M. A., 1996. Life Cycle Analysis: Principles and Practice. Scientific Applications International Corporation.

Deming, W. E., 1994. The New Economics for Industry, Government. *Education*, 1994-1997.

ECOINVENT, 2015. Accessed from: http://www.ecoinvent.org/home.html .

Ellen Macarthur Foundation, 2013. The circular model - an overview. Accessed from: http://www.ellenmacarthurfoundation.org/circular-economy/circular-economy/the-circular-model-an-overview.

Environmental Leader, 2014. Green Building Materials Market to Reach $529bn by 2020. Accessed from: http://www.environmentalleader.com/2014/09/22/green-building-materials-market-to-reach-529bn-by-2020/#ixzz3aTY4K6bg

Fiche De Declaration Environnementale Et Sanitaire Du Produit Metisse Rt [Environmental and health product declaration]. FDES conforme à la norme NF EN 15804+ A1 et le complément national XP P01-064/CN Editée en juin 2015

Fiorino, D. and Bhan, M., 2013. Environmental Regulation with Supply Chains: Comparing Private and Public Regulation. *Available at SSRN 2317342*.

Hammond, G., 2007. Time to give due weight to the 'carbon footprint' issue. *Nature*, *445*(7125), 256-256.

Heyuqing, A., 2014. Logistics and Supply Chain (Dissertation). Management Research Centre, Management School, University of Sheffield.

Jordeva, S., Tomovska, E., Trajković, D. and Zafirova, K., 2014. Textile waste as a thermal insulation material. *Tekstil: Journal of Textile & Clothing Technology*, *63*.

Martin, J., 2012. *The meaning of the 21st century: A vital blueprint for ensuring our future*. Random House.

Murphy, R. J., Norton, A. and Campus, S. K., 2008. Life cycle assessments of natural fibre insulation materials. *Imperial College London, prepared for the National Non-Food Crop Center (NNFCC), London, England*.

Schmidt, A. C., Jensen, A. A., Clausen, A. U., Kamstrup, O. and Postlethwaite, D., 2004. A comparative life cycle assessment of building insulation products made of stone wool, paper wool and flax. *The International Journal of Life Cycle Assessment*, *9*(1), 53-66.
Scientific Applications International Corporation, 2006. Life cycle assessment: principles and practice.
Sharpe, R., Thornton, C. R. Nokolaou, V. and Osborne, N. J., 2015. High energy efficient homes are associated with increased risk of doctor diagnosed asthma in a UK sub population. *Environment International,* 75, 234-244.
Silvestre, J. D., de Brito, J. and Pinheiro, M.D., 2010. *Life-cycle assessment of thermal insulation materials used in building's external walls*. International CIB Student Chapter Conference 2010.
Srivastava, S. K., 2007. Green supply-chain management: a state-of-the-art literature review. *International journal of management reviews,* 9.1, 53-80.
Spengler, J. D., and Sexton, K., 1983. Indoor air pollution: a public health perspective. *Science*, *221*(4605), 9-17.
PAS 2050, 2008. Specification for the Assessment of Life-cycle Greenhouse Gas Emissions of Goods and Services
Timmis, A., 2011. Carbon Footprint of INNO-THERM® Insulation Product (Dissertation). School of Agriculture, University of Sheffield.
WRAP, 2013. Business Development Support (BDS) Report. Issue Number 1. 17/04/2013.
Wiedmann, T., and Minx, J., 2008. A definition of 'carbon footprint'. *Ecological economics research trends, 1*, 1-11.
U.K. Government Planning Department, 2007. Energy Performance Certificate Scheme, http://www.planningportal.gov.uk/buildingregulations/greenerbuildings/epc
U.K. Government Department of Communities and Local Government, 2006. Code for Sustainable Homes, http://www.planningportal.gov.uk/uploads/code_for_sust_homes.pdf
U.S. Environmental Protection Agency. 2010. Defining Life Cycle Assessment (LCA).

FIGURES AND TABLES

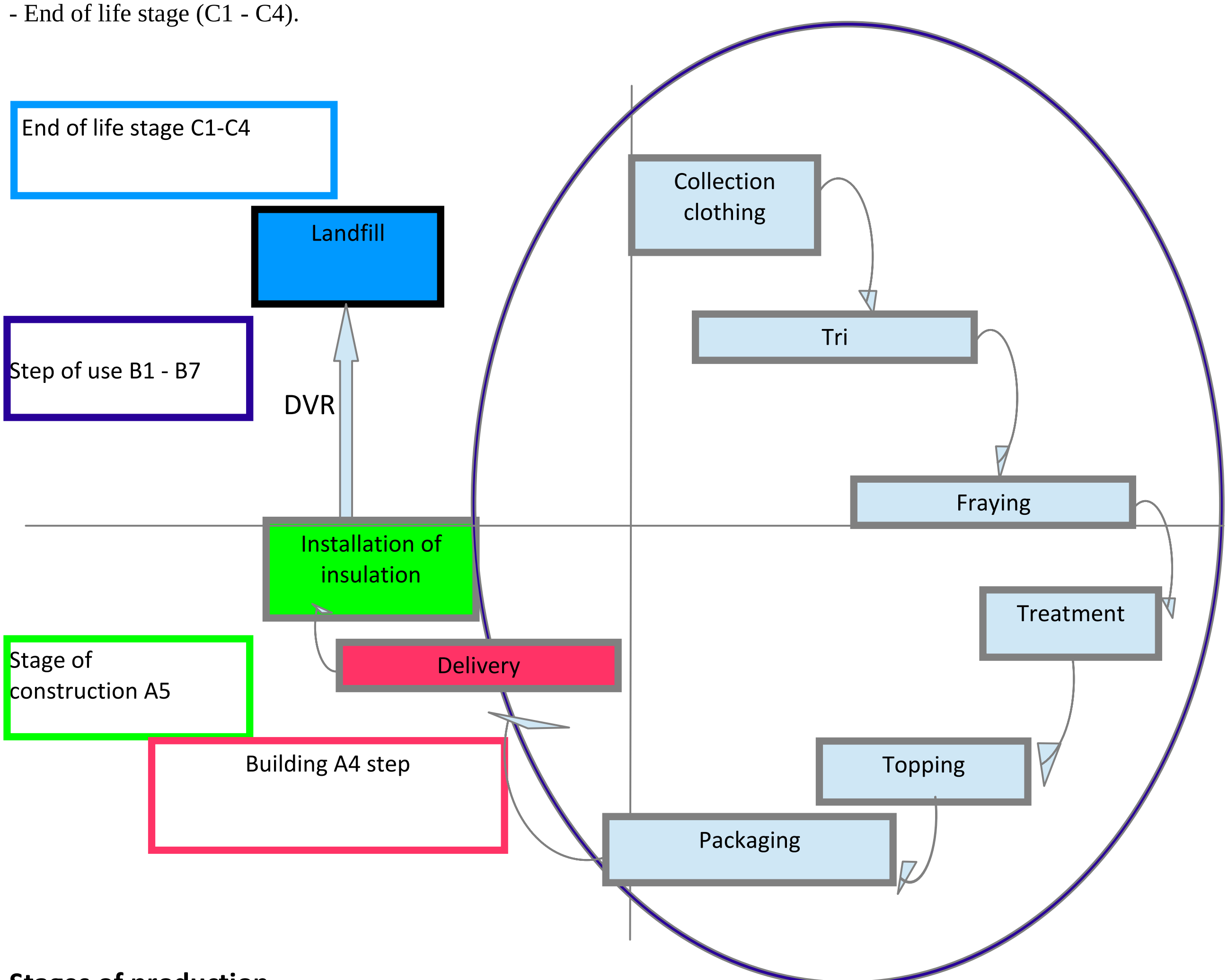
Table 1: Summary of the main products discussed. Information accessed from products websites.

Product	Raw Material	Production	u-value	Thermal Conductivity W/m/k	Density
Thermal Inno-therm®/Metisse®	Blue Denim Cotton	France	0.19	0.039 W/mK	20-25
Thermafleece Original	Sheepwool	UK	0.13-0.16	0.038 W/mK -	25
Isonat	Hemp fibre	France	-	0.039 W/mK	35
Rockwool	Minerals	Wales	0.13-0.25	0.039W/mK	25
Crown Loft	Glass Fibres	Wales	0.2	0.044W/mK	10

Figure 1: The manufacturing process of Inno-therm®/Metisse®- re: Environmental and Health Product Declaration, June 2015

Stages of life cycle

As described in the diagram below, it takes into account the impacts throughout the life cycle of the product, that is to say:
- Production step (A1 - A3)
- Stage of construction (A4 - A5)
- Life (B1 - B7) implementation stage
- End of life stage (C1 - C4).



Stages of production

The manufacture of the Inno-therm®/Metisse® is based on the 5 steps in the diagram below: