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Towards a low carbon future

2014

NEES Demonstration Project, Cloyne, Co. Cork
Evaluation Report

South Kerry Development Partnership Ltd.

Northern Periphery Programme 2007–2013

Innovatively investing in Europe's Northern Periphery for a sustainable and prosperous future

European Union
European Regional Development Fund

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Background

The Natural Energy Efficiency and Sustainability (NEES) project is funded by the Northern Periphery Programme. As part of the project, a demonstration project is being used to test six of the 'NEES best practices'. The project involves refurbishing an existing Parnell cottage at a rural location outside Cloyne, County Cork, and building a new extension. The six best practices are:

1. Timber frame construction
2. Hempcrete external insulation
3. Cellulose insulation
4. Triple glazed wooden windows
5. Green (sedum) roofs
6. Gravel reed bed for wastewater treatment

Methodology & Metrics

This report is an evaluation of the demonstration project and the above best practices. The architect provided a set of general arrangement tender drawings and some annotated details for the NEES demonstration project. The evaluation involved comparing the NEES design with a 'conventional' design; and, as no drawings or details were provided for a conventional design, the evaluation team devised a comparable specification by matching the architectural form and U-values of the building envelope (i.e. the thermal performance of the floors, walls, roofs).

The evaluation metrics included mass, energy, carbon and cost. Energy consumption and carbon emission arise from:

i) making, transporting, installing and disposing of a material – termed 'embodied' energy or carbon emissions
ii) people living in a house using electricity and fossil or renewable fuels – termed 'operational' energy or carbon emissions

With regard to the building envelope, three types of carbon have been calculated separately, namely: those arising from the combustion of fossil fuels; those arising from the combustion of biomass; and the amount of carbon that can be stored in timber and cellulose based materials.

The Cloyne demonstration project has been evaluated on a life cycle basis (tender requirement) and with a second technique called carbon profiling (not a tender requirement, but provided as it is perhaps a better method for illustrating the relative merits of carbon assets against the typical lifespans of different building elements).

Building Results

The table below presents the summary results of the NEES design against the conventional design with regard to materials and a 100 year life cycle assessment. The 'cradle-to-gate' impact of materials includes extraction or harvesting of raw materials, transportation of raw materials to a factory, and processing these materials into a building material or product. While the 100 year life cycle assessment (LCA) adds the remaining life cycle phases to this including: transportation from factory gate to site; construction; operation (house being lived in); and end-of-life (final disposal of building elements).

Based on the assumptions detailed in this report, the materials in the NEES specification are a third of the mass of the conventional specification, save 8% embodied energy (cradle-to-gate), save 1.4% carbon emissions (including biomass emissions as it is not clear that timber is from sustainable sources, and excluding positive effect of carbon sequestration), and making a 20% labour saving which is principally due to the greater ease of construction resulting from use of timber frame construction (i.e. less use of teleporter to carry heavy blockwork materials, less excavation for larger foundations, quicker erection of timber frame as against conventional blockwork construction).

Building Envelope Comparison	Cradle-to-Gate				100yr LCA
	NEES	Conventional	Saving	%	% Saving
Mass (tonnes)	57	157	100	64%	59%
Embodied Energy (GJ)	581.4	630.3	49	8%	1%
Embodied Carbon (tCO_2e)					
Fossil & biomass	36.6	37.1	0.5	1.4%	
Fossil only	27.8	34.3	6.5	19%	8%
Fossil, biomass & sequestration	-6.8	26.1	32.9	126%	
Fossil & sequestration	-15.6	23.4	38.9	167%	
Cost (€)	€ 72,422	€ 80,000	€ 7.5k	9.5%	
Labour (man days)	179.2	224.2	45	20%	

The transport impact of the NEES specification is 185% greater than that of the conventional, largely because niche products must be sourced further afield (particularly green roof substrate and hempcrete materials). In this respect, the NEES specification needs more careful consideration.

BER

A Building Energy Rating (BER) assessment was integral to the analysis of the building in use. Although the NEES design cannot be considered energy efficient as it received a D1 rating, it does however represent a significant improvement before the works commenced (see savings outline below). Principal reasons for the poor D1 rating include having larger than normal ratios of window to floor areas, and external surface area to floor areas, as well as not specifying heating controls. Although the heating system can be considered low-carbon, DEAP bases its energy value calculations on primary energy consumed, regardless of the fuel type being biomass or fossil fuels.

	Before	After	Savings			
BER rating	G	D1				
Energy value (kWh/m2/yr)	848.02	256.02	592	70%		
CO2 Emissions Indicator (kgC02/m2/yr)	195.29	14.21	181.08	93%		
Floor area	55.01	80.4	-25.39	-46%		
Energy value (kWh/yr)	46,649.58	20,584.01	26,065.57	**56%**	**2.24**	**toe/yr**
CO2 Emissions Indicator (kgC02/yr)	10,742.90	1,142.48	9,600.42	**89%**	**9.60**	**tCO2e/yr**

Biodiversity & Human Health

Impacts to biodiversity and human health are considered, and while the NEES best practices generally perform well, it is notable that the NEES specification pays no attention to securing chain of custody certificates for timber products, rather, it specifies tropical hardwoods with very questionable green credentials (i.e. Iroko).

With regard to human health, ventilation is considered a disimprovement to conventional practice (which would typically have mechanical extract fans), as moisture build up will increase the likelihood of mould.

Wastewater Treatment Results

The gravel reed bed has double the mass burden of conventional wastewater treatment systems but compares favourably in terms of cost by presenting a possible 11% cost saving against a comparable biofilter system. Embodied energy and carbon emissions are broadly similar between all options considered. It should also be pointed out the gravel reed bed, constructed wetland and willow facility options all require significantly more space than comparable conventional systems, and the cost of land is not factored into the calculations contained in this report.

NEES Best Practice Results

	NEES Best Practice	Evaluation
1	Timber frame construction	lower mass, higher EE, lower EC, esp. allowing for sequestration
2	Hempcrete external insulation	Higher mass, higher energy, higher emissions even if allowing for sequestration
3	Cellulose insulation	Higher mass, lower energy, lower emissions
4	Triple glazed wooden windows	Lower energy, lower emissions
5	Green (sedum) roofs	Higher mass, energy & emissions as it is an add on
6	Gravel reed bed (wastewater treatment)	higher mass, slightly higher energy, slightly lower emissions

Broad Conclusion

In considering the title of the project – Natural Energy Efficient and Sustainable – the broad conclusion to the demonstrator project as against a conventional build is that:

- Yes, the building is more natural
- No, the building is not energy efficient, as it has a low BER rating
- Yes, the building is arguably more 'sustainable' as:
    - People: it attempts to generate jobs locally
    - Planet: it has lower carbon emissions
    - Profit: the cost analysis seems to indicate that the NEES costs are lower than the conventional. In terms of contributing more to the local economy, further consideration is needed to source materials that are required by the NEES best practices more locally

Perhaps a more appropriate title would have been – Natural Low Carbon and Sustainable.

1 INTRODUCTION

Following an open invitation to tender published by the South Kerry Development Partnership (SKDP) in October 2013, Sustineo was appointed in March 2014 to complete this evaluation report. SKDP is a local action group involved in rural development in South Kerry; and is also is a partner in the Natural Energy Efficient and Sustainable (NEES) project. SKDP is tasked with managing the various demonstration projects under the NEES project which is funded by the Northern Periphery Programme (NPP).

This report sets out the methodology, assumptions, calculations and results in evaluating a demonstration project at Cloyne, Co. Cork (latitude 51.840762, Longitude -8.090400) against a given set of metrics. It also draws some conclusions that it intends will result in a greater awareness of the mass, embodied energy and carbon impacts arising from the materials used in the demonstration project against an equivalent building constructed with conventional materials. It is hoped that this evaluation will provoke greater attention to the design and specification of greener buildings.

1.1 OBJECTIVES

The objective of this evaluation as outlined in the tender requirements is to evaluate the 'NEES best practices' against conventional construction practices as follows:

1. To estimate the Weight of the proposed Works, versus that of a generic equivalent
2. To estimate the Embodied Energy of the materials and processes used in the proposed Works, versus that of a generic equivalent
3. To estimate the embodied Global Warming Potential (GHG emissions) of the materials and processes used in the proposed Works, versus that of a generic equivalent
4. To estimate the BER of the property before and after the proposed works and before and after equivalent "generic" works, using best estimated product U-values
5. On the basis of the above, to estimate Energy Consumption and GWP for the property after the proposed Works and after "generic" retrofit works over a Life Cycle of 100 years (LCA)
6. To compare the Impact to Human Health and Biodiversity of hazardous or potentially hazardous materials in the proposed Works in comparison with "generic" equivalent
7. To compare the Cost of the proposed Works in comparison to a generic equivalent, both in carrying out (costs of works) and over the life-cycle (cost of maintenance and disposal)
8. To compare the Ease of Construction and Ease of Maintenance of the proposed Works in comparison to a generic equivalent, both in carrying out (costs of works) and over the life-cycle (cost of maintenance and disposal)
9. To draw general conclusions regarding the sustainability of both the proposed Works and the generic equivalent, over the Life Cycle of the property, and the benefits and obstacle to the replication of the proposed Works.

'Generic' - hereafter referred to as 'conventional' - construction practices are considered to be external blockwork cavity walls, concrete floors, cut timber roof, and petrochemical based insulation products as generally used in rural areas throughout Ireland.

1.2 BACKGROUND TO PROJECT

1.2.1 NORTHERN PERIPHERY PROGRAMME

The Northern Periphery Programme (NPP) 2007-2013 was set up to help peripheral and remote communities on the northern margins of Europe to develop their economic, social and environmental potential. The programme has been focused on building on joint projects which create innovative products and services for the benefit of the programme partner countries and Europe as a whole.

The NPP's 2007-2013 Priorities are to promote:

1. Innovation & competitiveness
2. Sustainable development of natural and community resources

Figure 1-1: Northern Periphery Programme region

€ 35m out of a € 45m programme fund has been made available to EU member states under this programme, from which the NEES project has received funding.

1.2.2 NEES PROJECT

The NEES project has been investigating the use of services and materials based on natural or recycled materials and aims to identify and promote products and services which:

- improve energy efficiency in existing domestic buildings
- make use primarily of renewable or recycled materials and services based on natural processes
- originate and are normally accessible in the Northern Periphery Programme region
- potential for being mainstreamed / rural jobs

The NEES project is lead by the Cork Centre for Architectural Education (CCAE), which is jointly run by University College Cork (UCC) and the Cork Institute of Technology (CIT). The NEES Project is also CCAE's concept and the school of architecture now hopes to build on the work already done, perhaps with further funding from Horizon 2020.

The other NEES Project partners are:

- Glasgow Caledonian University in Scotland
- Umeå University in Sweden
- Arctic Technology Centre in Greenland
- University of Ulster
- South Kerry Development Partnership
- Claremorris Irish Centre for Housing
- Northside Enterprise Centre in Cork

As part of the project, a 'demonstration' building in Cloyne, County Cork is being refurbished and extended using materials and services identified by the partners as 'NEES best practice'.

1.2.3 'NEES BEST PRACTICES' & DEMONSTRATOR SITE

Six of the 'NEES best practices' identified in the NEES Project are to be demonstrated as follows:

1. Timber frame construction
2. Hempcrete
3. Cellulose insulation
4. Triple glazed wooden windows
5. Green (sedum) roofs
6. Gravel reed bed for wastewater treatment

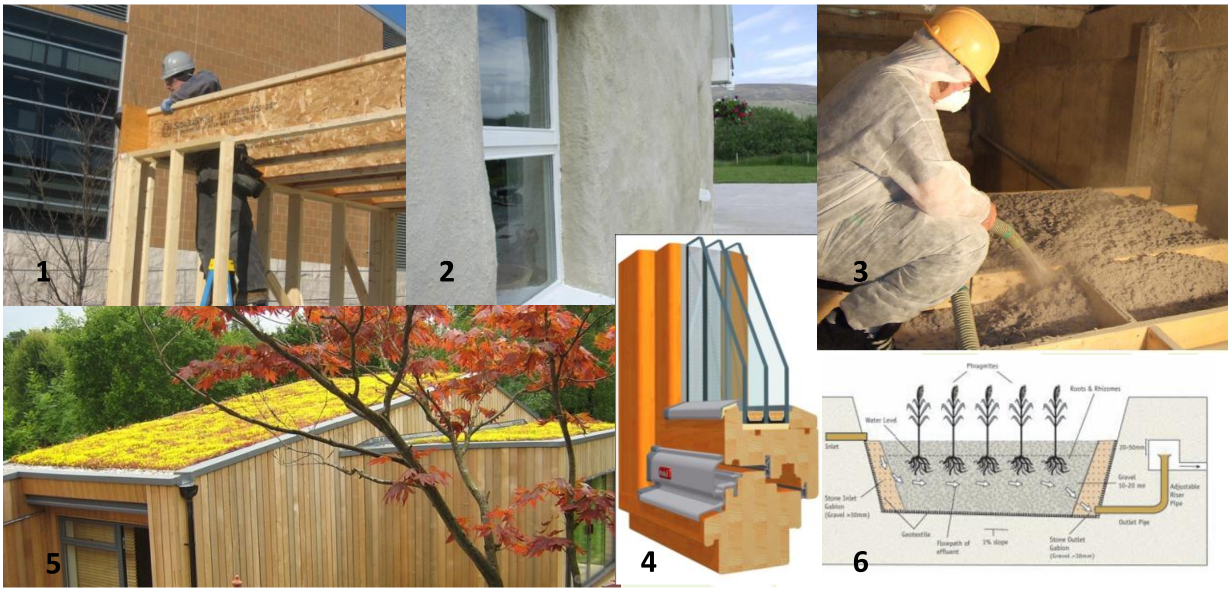

Figure 1-2: NEES Best Practices (numbered as above)

The first five best practices are being demonstrated at a site in Cloyne, County Cork while the gravel reed bed is being demonstrated at the lighthouse on Valentia Island, Co. Kerry.

The site at Cloyne is an existing Parnell cottage. The building is about 100 years old, and the demonstration project involves demolishing existing extensions that are not part of the original Parnell cottage, refurbishing the cottage, and constructing a new timber framed extension to adjoin the cottage. The refurbishment and new extension has been designed by Kevin Gartland Architects.

Figure 1-3: Existing 'Parnell' Cottage with Outhouses (outhouses subsequently demolished)

Figure 1-4: Architect's Model of Refurbished Existing Cottage (duopitch roof to left) and New Extension (monopitch roof to right)

1.2.4 EVALUATION TEAM

The evaluation of the demonstration project at Cloyne is being lead by Raoul Empey, principal of Sustineo, with input Fergal McGirl and Joseph Little who both run architectural practices in Dublin.

Raoul Empey, Chartered Engineer

Role: *Mass, Energy, Carbon, Cost, Life Cycle Aspects*

Expertise:

- Chartered Civil & Structural Engineer
- Low carbon projects
- Quantification of sustainability through numbers
- Carbon footprinting & Energy Management

Fergal McGirl, FMcG Architects

Role: *BER & U-value calculations*

Expertise:

- SEAI registered BER assessor since 2007
- RIAI grade II conservation accreditation
- Energy conservation in historic buildings
- Heritage Council Conservation Panel, 2009

Joseph Little, Building Life Consultancy

Role: *Health, Biodiversity and Hazardous Impacts*

Expertise:

- RIAI, IGBC & ÉASCA
- Passive House Association of Ireland
- Hemp-Lime Construction Products Association
- Publications on thermal bridging & moisture movement

1.3 PRINCIPLES OF GREEN BUILDING

The following principles of green building, as postulated by Professor Tom Woolley in 2006,[1] underpin a genuinely green building.

The main principles of green building are:

- *a) To make the buildings as energy efficient as possible to minimise the use of fossil fuel;*
- *b) To design the building to act passively, absorbing energy from the sun, ventilating naturally and allowing the insulated fabric and thermal mass to work effectively;*
- *c) To put the building on the site in a way that acts in harmony with the landscape and setting and minimizes disruption to the ecosystem;*
- *d) To take responsibility for all the upstream and downstream impacts of the decisions*
- *e) To minimise water usage and waste*
- *f) To select building materials and methods that are low energy and minimise resource depletion*
- *g) To avoid the use of materials and methods that cause pollution*
- *h) To select materials that do not damage the health of manufacturing workers, building workers, building occupants and wildlife.*

Introduction, Chapter 11, p.181, Woolley, T. (2006)

It is worth continuing the quote from Woolley, T. (2006) as it has direct relevance to the evaluation process undertaken and the credentials of the building evaluated.

These principles are fairly straightforward but hard to adhere to unless you use natural, renewable materials. However the vast majority of building projects address only some of these principles. Most architects and clients seem happy to cherry-pick these topics and use them when it is convenient. Even many buildings that are claimed to be green or that win green awards usually only address only some of them. To deal with all of them means working holistically, *an awkward word that simply means addressing all of them at the same time. In general, the technology and knowledge required to address all of these precepts is simple: it is 90% commitment and 10% expertise. It is the commitment that is missing in so many projects because it is easier to opt for conventional solutions and standard practices.*

Introduction, Chapter 11, p.181, Woolley, T. (2006)

Although the above principles are not specified as tender requirements to the evaluation, both the NEES best practices and their conventional alternatives should really be judged closely against this set of principles. In the context of the dominance of the conventional construction industry it is an ambitious list but so too should the aims and achievement of exemplar programmes like NEES.

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[1] Woolley, T., *Natural Building – a guide to materials and techniques*, Crowood Press, Wiltshire, UK (2006)

1.4 CARBON, ENERGY AND ENVIRONMENTAL ASSESSMENT OF BUILDINGS

Controlling and reducing greenhouse gas (GHG) or 'carbon' emissions is the critical issue of our time. Twinned with this is a rising concern about energy costs and security of supply. Buildings account for one third of global carbon emissions and 40% of the world's energy consumption.[2]

Figure 1-5: One Tonne of Carbon Dioxide, Street Exhibit at Copenhagen, 2009.
One tonne of CO_2 occupies 556.2 m^3 of volume, which is about the volume of a three bedroom house.[3]

The majority of carbon emissions and energy consumption arise from two key aspects of a building's life:

1. *Operational carbon and energy*: the lighting, heating, cooling and ventilation arising from the day to day use of a building.
2. *Embodied carbon and energy*: emissions and energy consumption arising from the extraction of raw materials, manufacturing and transportation of products, as well as the construction and ultimate deconstruction processes

1.4.1 OPERATIONAL CARBON - BUILDING ENERGY RATING (BER)

Building legislation in Ireland and the UK is currently focused on the operational energy efficiency and emissions associated with buildings through the Building Energy Rating (BER) methodology. Low or zero carbon buildings refer to buildings with close to zero emissions resulting from their day-to-day operations (i.e. lighting, heating, cooling, and ventilation).

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[2] United Nations Sustainable Buildings and Climate Initiative, *Common Carbon Metric for Measuring Energy Use and Reporting Greenhouse Gas Emissions from Building Operations,* (2009)

[3] Boyle's law at 25°C and 1 atmosphere pressure, http://www.icbe.com/carbondatabase/CO2volumecalculation.asp accessed on 17th October 2013

The BER is an asset rating of a building's expected theoretical energy usage, evaluated from plans mostly. A BER certificate lasts for 10 years and is only required if the owner is selling, renting, or leasing out a building (there are exceptions for certain categories e.g. protected structures and temporary buildings).

A BER is based on the calculated energy performance and associated carbon dioxide emissions for the provision of space heating and cooling, ventilation, water heating and lighting under standardised operating conditions. The characteristics of the major components of the building including dimensions, orientation, insulation, lighting, space heating and cooling, hot water system and building use are entered in the calculation. The BER is not dependent on the current building occupant behaviour. A BER is only an indication of the energy performance of a building, similar to the concept of the fuel economy for a car.

1.4.2 EMBODIED CARBON

Studies, however, have shown that embodied carbon emissions can constitute up to 60% of a building's whole life cycle carbon footprint. For example[4]:

Building Type	Embodied Emissions
Supermarkets	20%
Houses	30%
Offices	45%
Warehouses	60%

Acknowledging the importance of the embodied emissions, the Sustainable Energy Authority of Ireland (SEAI) recently tendered a methodology for calculating the life cycle emissions associated with building products and construction services.[5]

1.4.3 WHOLE LIFE CARBON ASSESSMENT

Combining the operational and embodied carbon emissions together constitutes whole life carbon assessment. As legislation drives for increased operational energy efficiency, the embodied emissions will form an increasingly important fraction of the carbon burden. Sturgis et al notes: 'There is a danger that the pressure [to move toward zero operational carbon buildings] will have the unintended consequence of adversely affecting embodied emissions, by requiring the use of increasingly carbon-intensive solutions, the closer we get to zero operational carbon emissions.'[6]

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[4] S. Sturgis, G. Roberts, *Redefining Zero: Carbon Profiling as a Solution to Whole Life Carbon Emission Measurement in Buildings*, RICS Research Report (May 2010)

[5] *Development and delivery of a methodology for calculating the life cycle energy and greenhouse gas emissions associated with building products and construction services and Creation of databases listing the embodied energy and embodied CO2 characteristics of such products and services*, Request for Tender published by SEAI (5th August 2011). This methodology and an accompanying database have yet to be published.

[6] S. Sturgis, G. Roberts, *Redefining Zero: Carbon Profiling as a Solution to Whole Life Carbon Emission Measurement in Buildings*, RICS Research Report (May 2010)

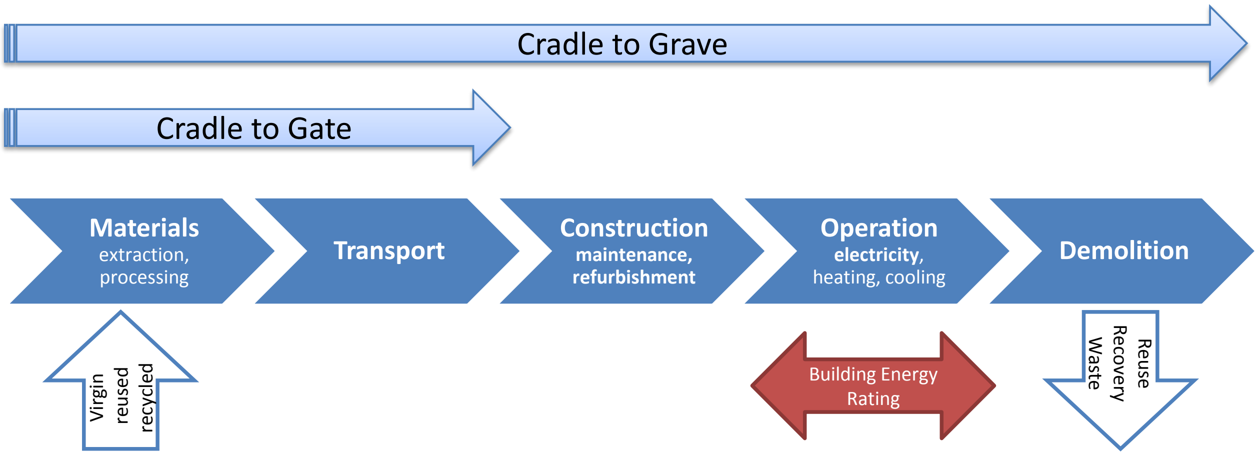

Figure 1-6: Whole Life Carbon or Life Cycle Assessment

Figure 1-6 above illustrates the scope of whole life carbon footprinting and where the Building Energy Rating (operational carbon) fits into the assessment. A 'cradle to grave' assessment considers all the processes from extraction and processing of raw materials up to the final deconstruction or demolition of a building, whereas a 'cradle to gate' assessment considers the emissions associated with the production of materials up to the point when they leave the factory.

1.4.4 CARBON PROFILING

The term *Carbon Profiling* was coined by Sturgis and Roberts in a Royal Institution of Chartered Surveyors (RICS) research report entitled *'Redefining Zero: Carbon Profiling as a Solution to Whole Life Carbon Emission Measurement in Buildings'* (May 2010).

The Carbon profiling methodology goes beyond whole life carbon assessment in that it not only considers the embodied carbon emissions of a building's constituent parts, but also the lifespan of the products used as well as the internal floor area. That is, carbon profiling considers the 'embodied carbon efficiency' of the different parts of the building. For example, two facade products could have the same embodied carbon, but one might have a lifespan of 10 years and the other 20 years. The second product would therefore have twice the embodied carbon efficiency of the first (units are same as the BER: kWh and $kgCO_2e/m^2/yr$).

1.4.5 LIFE CYCLE ASSESSMENT (LCA)

This report is a 'part' LCA as it only considers the whole life phases of certain environmental aspects (i.e. mass, energy and carbon). It is important to mention, however, that in addition to these metrics, a full Life Cycle Assessment includes many other environmental aspects. For example, the environmental issues considered by the Building Research Establishment's (BRE)

LCA Methodology for generating Approved Environmental Profiles[7] of building products are listed in Table 1-1 below:

Table 1-1: List of Environmental Issues Considered in the BRE Environmental Profiles Methodology 2008

	Issue	Unit	Considered in this Evaluation
1.	Climate Change	$kgCO_2e$ (100yr)	**Yes**
2.	Stratospheric Ozone Depletion	kg CFC-11 eq	no
3.	Eutrophication	kg PO_4 eq	no
4.	Acidification	kg SO_2 eq	no
5.	Photochemical Ozone Creation	kg ethene eq	no
6.	Human Toxicity	kg 1,4-DB eq	no
7.	Ecotoxicity to Freshwater	kg 1,4-DB eq	no
8.	Ecotoxicity to Land	kg 1,4-DB eq	no
9.	Fossil Fuel Depletion	MJ	**Yes**
10.	Waste Disposal	kg	**Yes**
11.	Water Extraction	m^3	no
12.	Mineral Resource Extraction	tonnes	**Yes**
13.	Nuclear Waste (higher level)	m^3 high level waste	no

1.4.6 LCA VS CARBON PROFILING

LCA and carbon profiling are both environmental tools, and not triple bottom line (people, planet, profit) sustainability tools. That is, LCA and carbon profiling only consider impacts to the environment (planet) and do not consider impacts to society (people) or the commercial aspects of a project, product or process (profit).[8]

LCA looks at all the life phases of a product, process or project in great detail. A part LCA can be conducted which looks at particular environmental aspects (e.g. this evaluation considers mass, energy and carbon), while a full LCA relies on software analysis based on extensive databases with hundreds of environmental impact categories.

A problematic aspect to LCA, however, is that the evaluator must make difficult value judgments on what happens to a product, process or project in the future, i.e. maintenance, operation and end-of-life stages. These value judgments can lead to a wide range of output results that need complex statistical calculations, known as 'uncertainty analysis', to ascertain the margins of error.

[7] BRE Environmental Profiles Methodology 2008 is used to create 'Approved Environmental Profiles' of building products. Typically the assessment is a Cradle to Grave assessment for a unit of product/material over a 60 year period (excepting carbon emissions which are considered over a 100 year period)

[8] For the people and profit 'pillars' of sustainability, one might consider the following methods:

- People: Social LCA is under development and is intended to assess social implications or potential impacts
- Profit: Life Cycle Cost Analysis (LCCA)

Although LCA is considered the most comprehensive environmental tool available, we consider that 'carbon profiling' may be a more suitable method to assist in minimising a construction project's contribution to global warming. With specific regard to emissions, carbon profiling informs the client on the best use of resources by highlighting carbon hotspots and whether it is better to refurbish or rebuild. In contrast to LCA, carbon profiling considers the building in the present, rather than attempting to make difficult and uncertain predictions as to what might happen a building in the future (i.e. maintenance and end-of-life/refurbishment).

1.4.7 OTHER ASSESSMENT METHODS FOR THE CONSTRUCTION INDUSTRY

There are various assessment methods including BREEAM, the Code for Sustainable Homes, LEED, Green Star that consider the wider range of sustainability issues, but they only deal partially with embodied and operational emissions. 'For example the placing of bat and bird boxes on a building may gain more points under some assessment procedures than retaining the structural frame of a building, which may embody many tens of thousands of tonnes of carbon.'[9] The figure below illustrates how the various methods above compare with regard to greenhouse gas emissions from a building's lifespan.

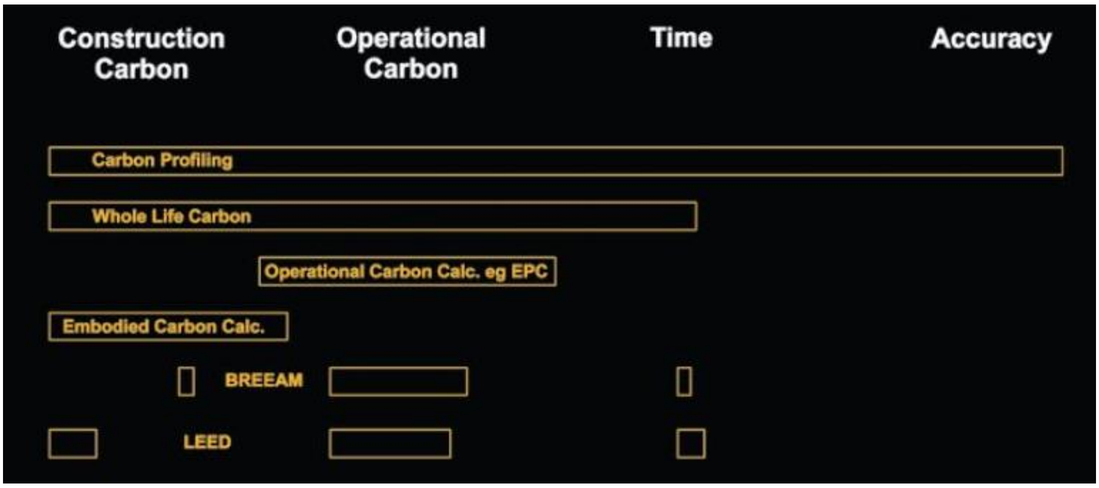

Figure 1-7: Overview of Different Types of Metrics (Sturgis, Roberts, RCIS Research Report May 2010)

Finally (and not included in the figure above), the German Sustainable Building Council established the DGNB Certification System in 2008 which is more based on life cycle thinking; while the Living Building Challenge™ is a green building certification program that defines the most advanced measure of sustainability in the built environment possible today and acts to diminish the gap between current limits and ideal solutions. As such, the Living Building Challenge considers embodied carbon and energy in more depth.

[9] S. Sturgis, G. Roberts, *Redefining Zero: Carbon Profiling as a Solution to Whole Life Carbon Emission Measurement in Buildings*, RICS Research Report (May 2010)

2 SCOPE OF THE EVALUATION

This evaluation is a streamlined and part Life Cycle Assessment (LCA) (Figure 2-1)Figure 2-1: Life Cycle Stages of a Construction Project of two comparable buildings, one using NEES best practices (the demonstration project at Cloyne), and the other built with conventional building materials typical of present day construction in rural Ireland. The latter is not being built but is a theoretical comparison with exactly the same architectural form and energy performance as the demonstrator. A complete and full LCA is beyond the scope of this evaluation and would require a more detailed study of the various products and building systems involved.

The carbon profiling methodology is also use to demonstrate a better understanding of a carbon asset. Sustineo has developed the carbon profiling methodology further to illustrate, not only the carbon hotspots, but also the relative efficiencies of the two other environmental metrics (i.e. mass and energy, see Section 4).

Figure 2-1: Life Cycle Stages of a Construction Project

2.1 FUNCTIONAL UNIT

The functional unit of the house being evaluated is defined as the provision and use of 1m^2 of useable floor area per year in the context of a 100 year lifespan. The units for energy and carbon are kWh/m^2/year and kgCO_2e/m^2/year respectively, and are the same units as presented on a Building Energy Rating (BER) certificate (Energy units are expressed in kWh for BER and energy profiles and in MJ elsewhere).

2.2 BOUNDARY

Included in the analysis are:

- All Materials & Products (cradle-to-gate) imported to site and used to make the:
  - Building envelope, i.e. floors, external walls, roofs & ceilings, internal walls, windows and external doors
  - Wastewater treatment system (for the purpose of the analysis this is assumed to constructed at the demonstrator site in Cloyne, Co. Cork, although it will actually be demonstrated at the Lighthouse on Valentia Island in Co. Kerry)
- Transport of materials from factory gate to site
- Construction energy used in earthworks (diesel from JCB), demolition of existing structures, and on-site power generation (petrol)
- Construction waste
- Operation of the building over a 100 year period by using the Building Energy Rating (BER)
- Maintenance over a 100 year period
- End-of-life: consideration of how the materials are treated when they must be replaced, i.e. re-use, recycling, combustion or landfill

The following items are not included in this assessment as they are assumed to be broadly the same in both the NEES and conventional builds and therefore do not aid the comparison:

- Office energy & resource consumption resulting from design, project management, site office, evaluation, paper use, etc
- Construction workers and consultants commute to site
- Land use change, footpaths & landscaping
- Floor and wall finishes and decoration (excepting plastering/plaster-boarding),
- Internal doors, fixtures & fittings, e.g. kitchen, bathroom
- Mechanical & electrical equipment, e.g. stove, hot water cylinder, copper pipes, solar panel, electrical works, etc

2.3 METHODOLOGY

U-value calculations and a Dwelling Energy Assessment Procedure (DEAP) analysis were carried out on the NEES design. To establish the buildup and thicknesses of conventional materials, matching U-values were established and equivalent quantities of insulation deduced for a conventional build (assumed to be expanded polystyrene beads in blockwork cavity walls and polyisocyanurate, or PIR, elsewhere). The DEAP analysis also gave a BER rating which indicated the likely energy consumption and emissions that would result from the day-to-day operation of the building, i.e. lighting, heating, cooling and ventilation.

For both the NEES design and the conventional build, quantities of materials were then calculated from the architect's schedule of works drawings (tender package). A timber I-joist cutting list was also provided which allowed accurate calculation of volumetric quantities of softwood and oriented strand board (OSB) used in the I-joists (NEES design only). These quantities were converted to mass, generally by multiplying volume by the density of each particular material. The masses were then use to calculate construction waste (based on assumed wastage rates for different building materials, see Appendix I), tonne-kilometres for transport energy consumption and emissions, and end-of-life emissions for each item in the schedule of works.

The results were summed by material type and by building part. Energy consumption and emissions arising from maintenance were calculated on the assumption that 20% of materials or products would need replacing at the end of a particular building element's typical lifespan (i.e. rather than assuming that 100% of a building element would be discarded and replaced at the end of a typical lifespan, it is assumed that some degree of care and maintenance would ensure that the remaining 80% could be retained and continue to perform its function for another 'typical' lifespan).

The contractor completed an environmental questionnaire which sought information on energy consumption, wastage rates, and origin of materials. The results of the questionnaire were incorporated into the analysis.

All of the above results were then summed by life cycle stage and mass, energy and carbon profiles were generated separately to identify hotspots and comparisons drawn between NEES best practices and conventional practices drawn (note that the profiles exclude construction energy, maintenance and end-of-life stages).

2.4 BASIS FOR COMPARISON

Only tender stage general arrangement drawings for the NEES best practice design were provided, and an equivalent conventional design needed to be proposed by the evaluation team to enable a measurable comparison. It was considered that the conventional design should have the same architectural form and energy performance as the NEES design, and be constructed with materials typically used in a rural Irish setting. In effect, the building envelope U-values of both building options must be the same, and the quantities of insulation required in the conventional building were derived by matching the BERs of both the NEES and conventional build options. The basis of the comparison is therefore as follows:

Table 2-1: Basis of Comparison between NEES and Conventional Build Options

	NEES Design[10]	Conventional Build
Extension Walls	Cedar shingles	18mm sand/cement plaster externally
	SW Battens & counter battens	100mm concrete block
	Breather membrane	215mm cavity with pumped expanded polystyrene insulation
	18mm SmartPly 3	100mm concrete block

[10] from Kevin Gartland Architects' annotated sketch details dated 3/4/14 and U-values from KG Archs' emails of 25/3/2014 & 3/4/14

	NEES Design[10]	Conventional Build
	241mm plyweb joists with cellulose insulation infill	15mm sand/cement plaster internally & skim plaster finish
	OSB & airtight seals	
	SW Battens	
	Plasterboard & skim finish	
U values (W/m²K)	**0.15**	**0.15**
Extension Roof	Green roof buildup	
	Fibreglass roof membrane	Fibreglass roof membrane
	22 OSB	22 OSB
	100 x 44mm joists	175mm PIR insulation board
	Breather membrane	Vapour control layer
	18mm OSB board	22 OSB
	406mm plyweb joists with cellulose insulation infill	200 x 44mm timber joists
	OSB & airtight seals	Airtight membrane
	SW battens	SW battens
	Plasterboard & skim finish	Plasterboard & skim finish
U values (W/m²K)	**0.12**	**0.12**
Extension floor	Sprung timber floor	Sprung timber floor
	SW battens	150mm concrete slab
	18mm OSB board	160mm PIR insulation board
	241mm plyweb joists with cellulose insulation infill	Damp proof membrane
	Breather membrane	50mm sand blinding
	Rodent proof wire mesh	Compacted layers of hardcore - 750mm approx
	Aquapanel	
U values (W/m²K)	**0.13**	**0.13**
Existing Cottage Walls	25mm hemplime plaster internal lining	Plasterboard & skim finish internally
	<existing walls>	<existing walls>
	250mm hempcrete to outside of existing walls on timber dowels	SW battens w/ Airtight breathable VCL membrane
	25mm Limeplaster render externally	Insulation as below
		15 Sand/cement scratch coat finish to inside face of wall
		18 Sand/cement render finish to outside face of wall
U values (W/m²K)	Tradical hemcrete values (conductivity: 0.075 W/mK) **0.24**	70mm PIR insulation board **0.26**
	Evrard & deHerde hempcrete values	50mm PIR insulation board

	NEES Design[10]	Conventional Build
	(conductivity: 0.115 W/mK) **0.36**	**0.34**
	Beton de Chanvre (Steve Allin book) values (conductivity: 0.13 W/mK) **0.40**	40mm PIR insulation board **0.40**
Existing Cottage Roof	Natural slate	Natural slate
	SW battens & counterbattens	SW battens & counter battens
	Breather membrane	Breather membrane
	<existing rafters>	<existing rafters>
	New suspended rafters below to achieve 375mm cellulose insulation void	120mm PIR insulation board between rafters
	Airtight membrane	50mm PIR insulation board below rafters
	SW battens	Airtight membrane
	Plasterboard & skim finish	SW battens
		Plasterboard & skim finish
U values (W/m^2K)	**0.15**	**0.15**
Existing cottage floor	OSB floor	OSB floor
	225 x 44mm joists	Vapour barrier
	200mm injected Ecocel insulation between joists	225 x 44mm joists
	OSB layer below joists (Smartply 3)	120mm PIR insulation board between joists
	Vented cavity below	OSB layer below joists (Smartply 3)
		Vented cavity below
U values (W/m^2K)	**0.2**	**0.2**
Windows	Munster Joinery double glazed hardwood	Munster Joinery double glazed PVC
U values (W/m^2K)	**0.16**	**0.16**

Hempcrete has some insulating thermal properties, and for the comparison of using this on the existing cottage walls, three sources have been used to calculate U-values:

- Tradical hemcrete value[11]: this is a proprietary and, without doubt, the most analysed and measured hempcrete ever formulated. As such, this homogenous hempcrete product likely presents the best possible thermal performance of hempcrete

[11] http://www.limetechnology.co.uk/pdfs/CPD_Hemcrete_Thermal_Performance.pdf accessed on 15th April 2014

- Evrard & De Herde hempcrete value[12]: is from a study of in-situ mixes used in France
- Beton de Chanvre (as quoted in Steve Allin book[13]): these are the most conservative values of thermal conductivity but are the ones used in this evaluation as Steve Allin is the proposed contractor carrying out the hempcrete installation

The above table shows that the equivalent thickness of PIR insulation compared with hempcrete ranges from 70mm (using Tradical value) to 40mm (using Beton de Chanvre). It should also be noted that aside from thermal conductivity, hempcrete has other beneficial thermal properties including good thermal mass and thermal inertia (diffusivity). But as these latter thermal properties are not considered in the BER methodology they are beyond the scope of this evaluation.

With regard to the wastewater treatment comparison, the tender specified a gravel reed bed to be the NEES Best Practice. However, as Feidhlim Harty provided information on a constructed wetland and a willow facility, these are also paid brief attention. Two proprietary domestic wastewater systems that are common in Ireland were considered for a comparison – a biofilter option and fixed film reactor process. All systems assessed were sized on a Population Equivalent (PE) of 5.

2.5 ASSUMPTIONS

All assumptions are contained in Appendix I, but are broadly as follows:

1. **Material Factors:** generic factors for embodied energy (MJ) and emissions (kgCO_2e) per unit mass or m^2 are, for the most part, from:
    a. the Inventory of Carbon & Energy databases published by the University of Bath [1],
    b. excepting window glazing and frames where a Swiss source has been used [2]
    c. factors for hempcrete have been calculated by using, to a large extent, life cycle data contained in Miskin's MSc thesis [5]. Another credible source from European Industrial Hemp Association was consulted[14], but while the embodied energy figures seem higher and more conservative than Miskin's, this report had insufficient detail to generate factors for hempcrete.
    d. Emissions arising from the combustion of biomass in the manufacture of timber products has been calculated separately, as the NEES Project may consider that these emissions do not contribute to global warming if the timber has been sourced sustainably (note that no PEFC or FSC chain of custody certificates have been provided to the evaluation team, nor does the specification request this)
    e. Each of the NEES best practice suppliers were asked for environmental credentials and none had Environmental Product Declarations (EPDs). EPDs

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[12] Belgian research of prof. A. De Herde and A. Evrard (UCL-Architecture et climat), presented in "Sorption behaviour of Lime-Hemp Concrete and its relation to indoor comfort and energy demand", published in the proceedings of the 23rd Conference on Passive and Low Energy Architecture, A. Evrard, pp.I-553-557, Geneva, Switzerland, 2006

[13] Steve Allin, *Building with Hemp*, 2nd Edition 2012

[14] J. Haufe & M. Carus, *Hemp Fibres for Green Products – An assessment of life cycle studies on hemp fibre applications*, European Industrial Hemp Association, (publ. by nova-Institute GmbH, June 2011)

include the energy and emissions resulting from the manufacture of a functional unit of the product (as well as other metrics) but are typically hard to find in the construction sector, so the use of generic material factors is considered reasonable.

2. **Travel distances** by road from factory to site have been assumed to be:
   a. 100km for general building materials
   b. 13.5km for readymix concrete and aggregate (distance from Lagan's at Carrigtwohill to Cloyne)
   c. 30km for cellulose insulation manufactured by Ecocel in Cork city
   d. 155km for precast concrete
   e. 836km for hempcrete is a composite distance based on the tonne kilometres of constituent parts used by the installer (hemp from Bar sur Aube region east of Paris, NHL 5 from Germany, hydrated lime and cement from Ireland)
   f. travel distances for a few specified proprietary products were deduced by using road distances from Google Maps
   g. Fuel combusted by shipping has been excluded
3. **Transport and end-of-life emission factors:** the UK Government conversion factors for company reporting, hereafter referred to as the DEFRA factors, have been used to calculate emissions resulting from transporting materials, products and waste to and from the site [3]. "Well-to-tank" (WTT) emissions for the diesel combusted have also been included from the same source.[15] An energy factor for transport has been generated from these factors based on average fuel mixes.
4. **Carbon Sequestration**:
   Carbon storage amounts have been calculated separately as carbon sequestration in buildings is a debatable subject. The UK PAS 2050:2011 specification notes that carbon sequestration can only be accounted for if the carbon can be considered to be locked away for a 100 year period.[16] While it is possible for timber to last well in excess of 100 years if kept dry and well ventilated, a 100 year life of a house extension conflicts with the typical lifespans used from reference [4] (see item 6 below)
   a. The amount of carbon stored in dry wood is approximately 50% by weight. When burnt, 1 kg of carbon will produce 3.67 tonnes of carbon dioxide. Therefore carbon sequestrated in wood products is roughly 1.835 kg CO_2e/kg. The same value has been assumed for cellulose insulation, and for the quantities of hemp in hempcrete.
   b. Assume 50% of CO_2 release during burning of lime is reabsorbed during carbonation of lime binder
   c. Carbonation of Ordinary Portland Cement (OPC) has been excluded
5. **Grid electricity** has a carbon intensity of 0.528 kgCO_2e/kWh (2012 value from the Sustainable Energy Authority of Ireland[17])

[15] WTT emissions include emissions associated with extraction, refining and transportation of the raw fuel sources to an organisation's site (or asset), prior to their combustion.

[16] *PAS 2050:2011*, *Section 5.5 Carbon storage in products, sub-section 5.5.1: Treatment of stored carbon* which notes, "Where some or all removed carbon will not be emitted to the atmosphere within the 100-year assessment period, the portion of carbon not emitted to the atmosphere during that period shall be treated as stored carbon."

[17] http://www.seai.ie/Your_Business/Public_Sector/FAQ/Energy_Reporting_Overview/What_are_the_carbon_emission_factors_used.html accessed on 15th April 2014

6. **Typical lifespan of building components** is as per guidance from the Royal Institute of Chartered Surveyors in the UK [4]
    a. a **20% replacement rate** of materials and products was assumed once they reached the end of their typical lifespan, e.g. a building product with a 20 year typical lifespan would have 20% x 5, or 100% replacement within a 100 year period

2.6 DATA COLLECTION & QUALITY

The primary source of data is from Kevin Gartland's architectural drawings and annotated details. He also kindly provided details on his U-value calculations. The masses calculated are considered accurate, while all other output values are based on generic factors for energy and carbon and the assumptions as stated above.

All of the NEES best practice suppliers were contacted and, with the exception of Cork Roof Truss Ltd, all provided helpful background information to the build processes, as well as operation and maintenance aspects. Declan Devoy, the contractor was very helpful and kindly completed a questionnaire on energy consumption, wastage and origin of materials. The principal author of this report also visited the site on 23rd April 2014, and both Declan and the client gave input to the cost evaluation and ease of construction and maintenance sections (Section 3.7 and 0).

3 COMPARATIVE ANALYSIS

Detailed mass calculations for both the NEES design and the conventional build form the basis of this evaluation and are tabled in Appendices II and III respectively. Note that all comparisons are based on the same assumptions and it is the comparison that is important, not the absolute numbers calculated which will always vary depending on the assumptions.

Wastewater treatment options have been calculated separately from the building comparisons.

3.1 MASS

'How much does your building weigh, Mr. Foster?', Buckminster Fuller

Buckminster Fuller, the architect renown for popularising the geodesic dome, famously quizzed Norman Foster on the weight of his building. Some experts suggest that mass or resource depletion may be the most pertinent environmental metric with which to evaluate buildings.[18] Indeed, the energy and carbon calculations in this report are all based on an initial mass calculation (mass x conversion factor = embodied energy or embodied carbon).

The mass comparison of the NEES and conventional building is shown graphically in

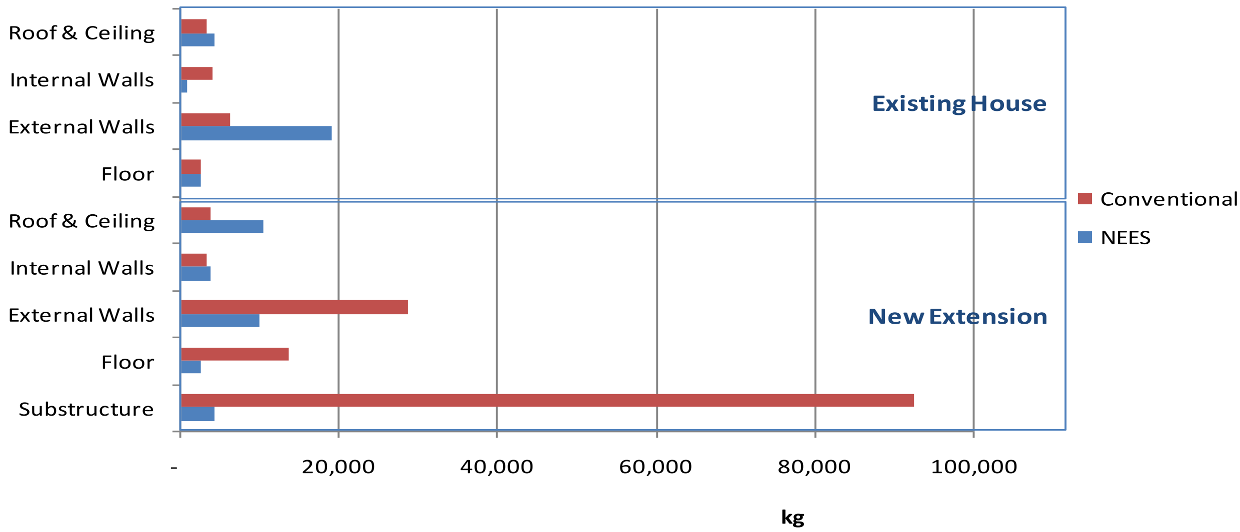

Figure 3-1 below with numerical values and a explanation of the differences in mass in Table 3-1. The NEES design (57 tonnes) is about a third of the mass of the conventional build (157 tonnes) and this is primarily due to using timber framed construction for the extension and avoiding the use of mass concrete trench foundations, a concrete slab and blockwork walls.

[18] For example, Ronald Rovers of Zuyd University, the Netherlands, in answer to a question by the principal author of this report at the Better Building conference at Croke Park, 9th April 2014: Session entitled, *A Strategy Towards Low Carbon Construction and Infrastructure*.

There are a few areas, however, where the NEES best practices have an increased mass over the conventional, namely the green roof on the new extension and the hempcrete external insulation to the existing house. While the design of the extension has resulted in a mass saving of 78%, the NEES treatment to the existing cottage and increased resource consumption by 68%. The overall mass saving for both the new extension and the existing house is 64%.

The wastewater treatment options can be heavier than or as heavy as the weight of materials in the building. This predominantly results from an assumed 35 m^3 gravel for the percolation area, which is required by all the systems except the willow facility. The gravel reed bed has the largest mass burden (160 tonnes) as it requires an additional 35 m^3 / 78 tonnes of gravel for the reed bed, while the conventional systems each have a mass of around half of that (87-90 tonnes) which is primarily due to the percolation area. In contrast, the willow facility (5 tonnes), which is outside the scope of the evaluation objectives, shows the lightest mass footprint.

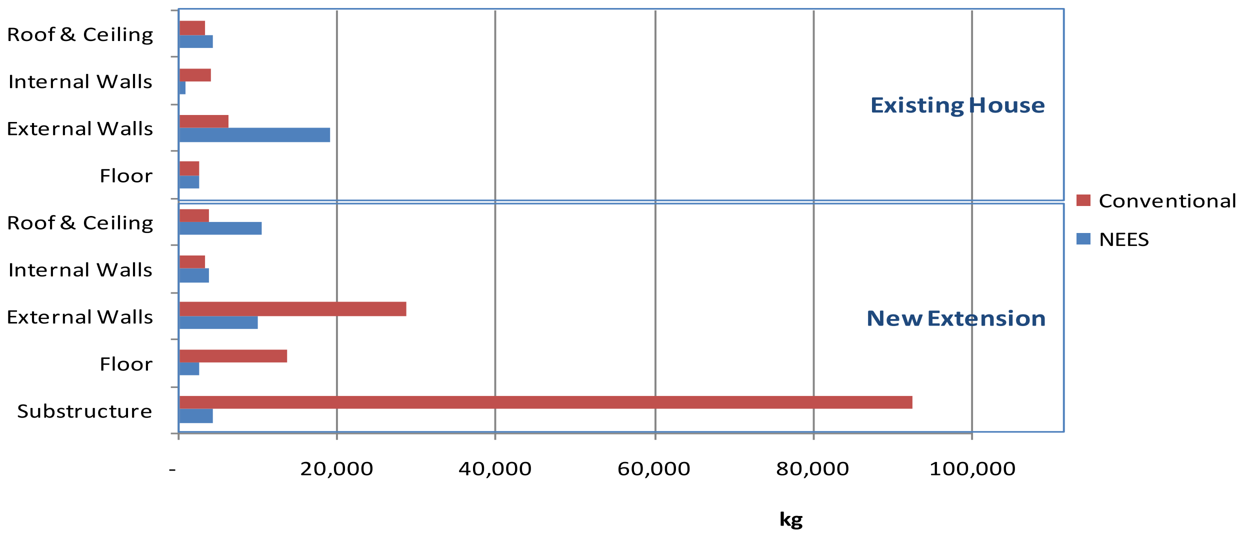

Figure 3-1: Mass Comparison of Building

sustineo

Table 3-1: Mass Comparison

	Mass		Saving	Significant Contributors	
	NEES	*Conventional*	*%*	*NEES*	*Conventional*
New Extension	***30,575***	***141,601***	***78%***		
Substructure	4,091	92,584	96%	6no. concrete pad footings	concrete trench foundations with hardcore fill
Floor	2,566	13,701	81%	suspended timber floor	concrete slab
External Walls	9,829	28,545	66%	timber framed walls	2no. Skins of blockwork
Internal Walls	3,790	3,159	-20%	2x12.5mm plasterboard inner face of external walls	15mm wet gypsum plaster
Roof & Ceiling	10,299	3,611	-185%	Green roof and additional structural depth	No green roof, structural depth halved
Existing House	***26,475***	***15,756***	***-68%***		
Floor	2,349	2,365	1%	175mm cellulose	170mm PIR insulation
External Walls	19,025	6,121	-211%	250mm hempcrete & 25mm lime render externally	18mm cement render externally
Internal Walls	823	3,939	79%	25mm hemplime render internally	15mm cement render scratch coat, 40mm PIR insulation and 12.5mm plasterboard
Roof & Ceiling	4,278	3,330	-28%	375mm injected cellulose	170mm PIR insulation
Building Total	**57,050**	**157,356**	**64%**		
Option 1: Gravel reed bed vs Biofilter	160,938	89,943	-79%	35 cubic meters of gravel for reed bed equates to an additional 78 tonnes + same for percolation area	78 tonnes of gravel for percolation area
Option 2: Constructed wetland vs Fixed film reactor	83,564	87,400	4%	GRP septic tank encased in concrete & 1 tonne gravel; 78 tonnes gravel percolation area	9 tonne precast concrete tank + 78 tonnes gravel for percolation area
Option 3: Willow facility	5,222			Willow facility only requires 1 tonne of sand and liner in addition to septic tank; no percolation area required	

3.2 EMBODIED ENERGY

The embodied energy comparison of the NEES and conventional building is shown graphically in Figure 3-2 below with numerical values and the significant contributors to embodied energy outlined in Table 3-2**Error! Reference source not found.**. Overall, the NEES design makes an 8% saving on embodied energy compared with the conventional equivalent. This equates to 49 GJ or 1.167 toe (tonnes of oil equivalent).

The NEES design makes significant energy savings from having a lighter substructure, the use of cellulose insulation over PIR insulation, and wooden window frames over PVC. The overall savings do not seem that dramatic, however, and this is due to the increased quantities of timber and the use of hempcrete, which actually drive up the embodied energy for the following reasons:

- the embodied energy factor (MJ per kg) for general timber is 15.9 times greater than that for 100mm blockwork cavity leafs (see Appendix I)
- the sedum roof is partly responsible for increased use of timber
- the NEES design requires about 7 tonnes of hempcrete which contains 57% lime products and 10% Ordinary Portland Cement (OPC) (see Appendix X for derivation of hempcrete factors)

Also of note is that plasterboard has 3.75 times the embodied energy factor compared to wet applied gypsum plaster, and the NEES design makes more use of plasterboard than the conventional equivalent although overall volumes of plasterboard and plaster are about the same.

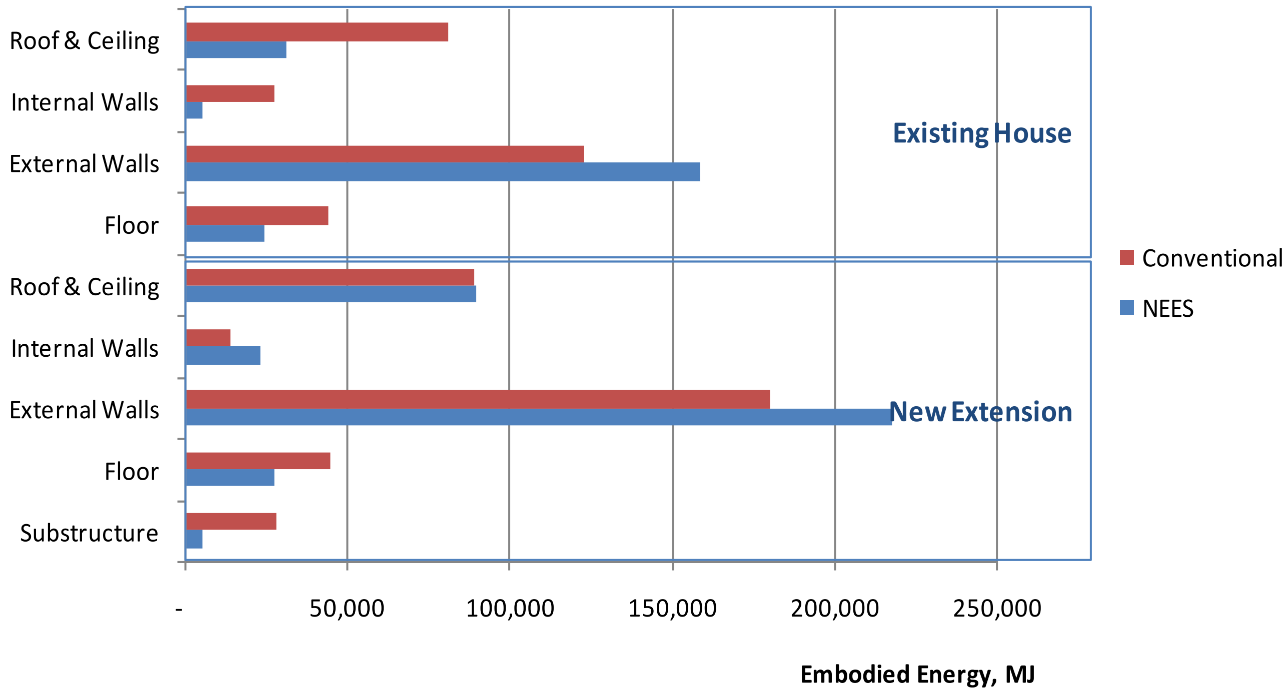

Figure 3-2: Embodied Energy Comparison of Building

As the embodied energy factor for aggregate is relatively low (0.083 MJ/kg), the various wastewater treatment systems do not differ significantly in embodied energy. Naturally if it was possible to use less concrete and/or glass reinforced plastic (GRP) for tanks and encasement the embodied energy could come down for all of the options considered.

Table 3-2: Embodied Energy Comparison

	EE		Saving	Significant Contributors	
	NEES	Conventional	%	NEES	Conventional
New Extension	***362,999***	***355,436***	***-2%***		
Substructure	5,046	27,691	82%	62% EE from concrete and 38% EE from steel reinforcement	81% EE from concrete for trench foundations
Floor	27,218	44,693	39%	65% EE from timber	63% EE due to 160mm PIR insulation
External Walls	218,185	180,536	-21%	43% EE from timber window frames, and 44% from timber frame & cedar cladding	65% EE from PVC window frames; 9% from expanded polystyrene insulation
Internal Walls	23,046	13,512	-71%	80% EE from plasterboard. More use of plasterboard in NEES which has 3.75 times the EE of wet plaster	58% EE from plasterboard and plaster + 18% from wet plaster
Roof & Ceiling	89,504	89,003	-1%	35% EE from timber structure; 31% EE from fibre glass membrane	32% from 170mm PIR insulation; 31% from fibreglass membrane
Existing House	***218,396***	***274,834***	***21%***		
Floor	23,821	43,952	46%	95% EE from timber	45% from 120mm PIR insulation; exactly same quantity timber as NEES
External Walls	158,366	122,935	-29%	41% hempcrete, 46% timber window frames, 9% glazing	80% PVC window frames, 13% glazing
Internal Walls	5,040	26,894	81%	60% from 25mm hemplime render internally	54% from 40mm PIR insulation
Roof & Ceiling	31,169	81,053	62%	33% timber, 24% plasterboard & plaster, 10% 375mm injected cellulose,	64% 170mm PIR insulation
Building Total	**581,395**	**630,270**	**8%**		
Option 1: Gravel reed bed vs Biofilter	32,284	34,198	6%	43% GRP septic tank	GRP septic tank
Option 2: Constructed wetland vs Fixed film reactor	28,030	27,477	-2%	50% GRP septic tank	76% 9 tonne precast concrete tank
Option 3: Willow facility	26,299	-		53% GRP septic tank	

3.3 EMBODIED CARBON

Embodied carbon has been calculated and reported under three separate headings:

1. Embodied carbon from **fossil fuel** use in manufacturing a building product or material
2. Emissions arising from the combustion of **biomass** during the processing of timber. If the biomass used to process timber (e.g. used for kiln drying) arises from sustainably managed sources then one can argue that these biomass emissions do not contribute to global warming. Note that the NEES project did not provide any such proof of sustainable sourcing (e.g. FSC or PEFC chain of custody certificates), nor was it requested in the schedule of works. Therefore no such assumption has been made and biomass emissions have been stated separately.
3. **Carbon sequestration** is the carbon considered to be locked into plant-based materials such as timber, hemp, and even cellulose insulation which is derived from waste newspapers and cardboard. Carbonation of lime has also been included in this, although recarbonation of cement has been excluded.

Carbon sequestration is a topic of some contention in that some believe that if the carbon is not locked away for more than 100 years then it cannot be treated as stored carbon.[19] This is where the lifespan of cellulose based materials is of particular importance as well as the ultimate end-of-life stage.

As the NEES design has taken care to use much cellulose-based material the biomass and sequestration portions are of particular importance. Comparison of Figure 3-3 and Figure 3-4 below illustrate how the NEES design has greater proportions of carbon sequestration and biomass resulting from greater use of timber, as well as cellulose and hemp.

The NEES building design could be said to make the following carbon savings over the conventional equivalent:

1. Fossil & biomass emissions only: 0.5 tCO_2e or 1.4% saving.
2. Fossil fuel emissions only: 6.5 $tC_{O2}e$ or a 19% saving, assuming sustainably sourced timber products. Compared with item 1, this demonstrates the importance of using sustainably sourced timber products
3. Fossil, biomass and sequestration: 32.9 tCO_2e or 126% savings, although carbon storage for 100 years is questionable
4. Fossil & sequestration only: 38.9 tCO_2e or 167% savings, although carbon storage for 100 years is questionable

With regard to wastewater, the majority of embodied emissions result from the use of precast concrete or glass reinforced plastic tanks, and there is not much difference between the treatment systems used.

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[19] See, for example, *PAS 2050:2011*, *Section 5.5 Carbon storage in products, sub-section 5.5.1: Treatment of stored carbon* which notes, "Where some or all removed carbon will not be emitted to the atmosphere within the 100-year assessment period, the portion of carbon not emitted to the atmosphere during that period shall be treated as stored carbon."

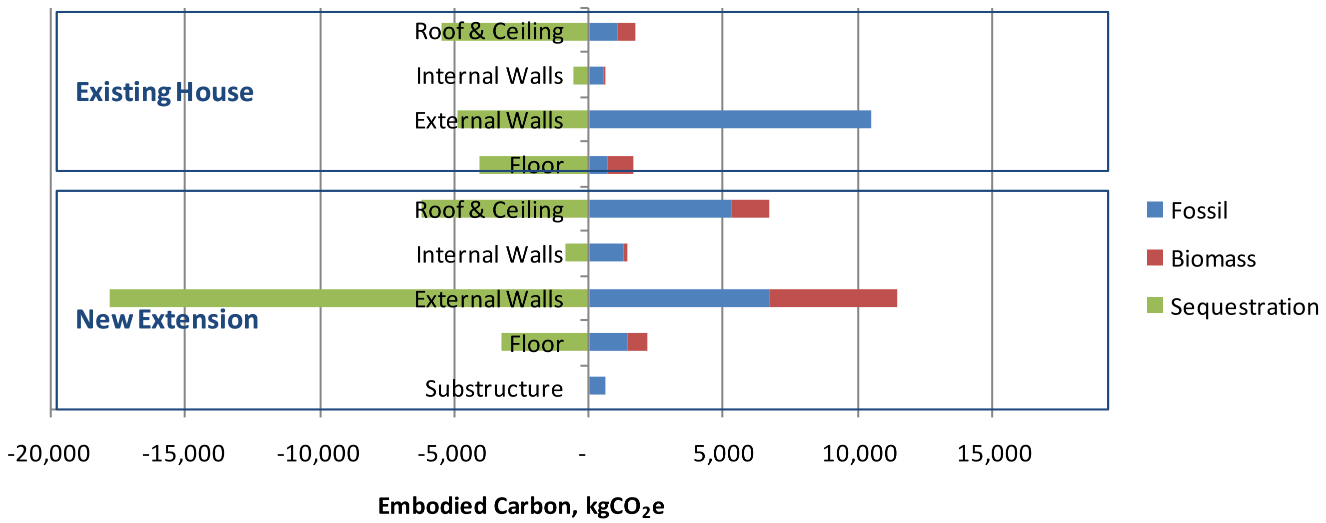

Figure 3-3: Embodied Carbon of NEES Design

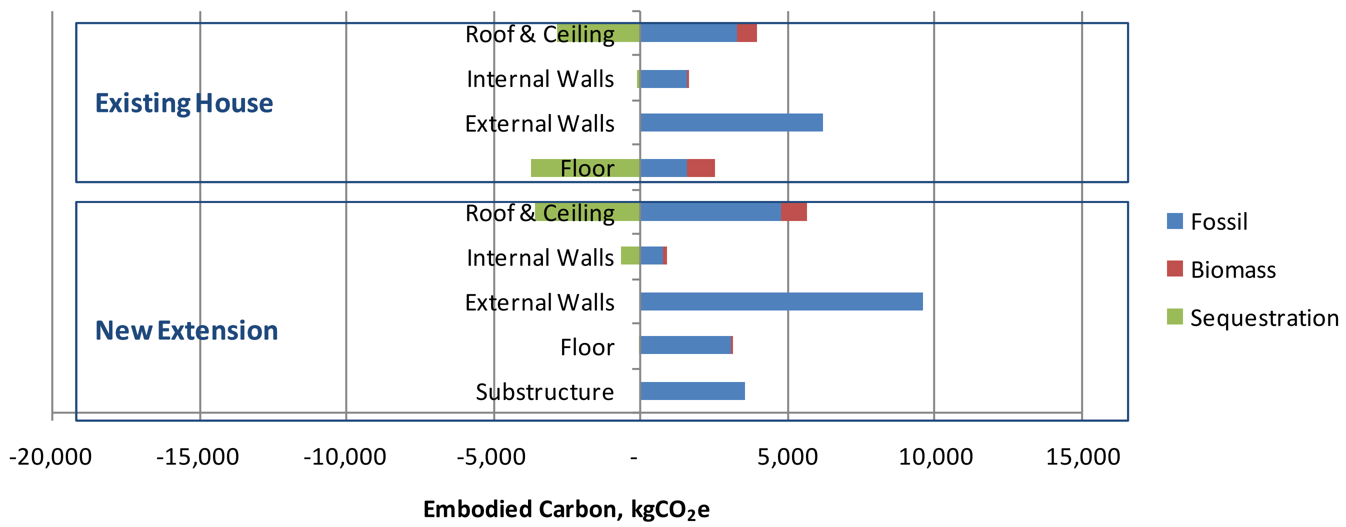

Figure 3-4: Embodied Carbon of Conventional Equivalent

Table 3-3: Embodied Carbon Comparison

	NEES EC			Conventional EC			Saving*	Significant Contributors to EC (Fossil)	
	Fossil	Biomass	Sequestr	Fossil	Biomass	Sequestr	%	NEES	Conventional
New Extension	***15,185***	***7,111***	***- 28,320***	***21,747***	***1,116***	***- 4,329***	***175%***		
Substructure	606	-	-	3,576	-	-	83%	74% EC from concrete and 26% EC from steel reinforcement	91% EC from concrete for trench foundations
Floor	1,420	741	- 3,304	3,074	26	- 75	163%	61% EC from Aquapanel cement board	60% EC due 150mm concrete slab; 38% EC to 160mm PIR insulation
External Walls	6,665	4,800	- 17,867	9,619	-	-	216%	57% EC from timber window frames & glazing	63% from PVC window frames & glazing; 19% 2no. 100mm blockwork leafs
Internal Walls	1,238	187	- 877	737	147	- 690	-666%	86% EC from plasterboard. More use of plasterboard in NEES which has 3.0 times the EE of wet plaster	61% EC from plasterboard and plaster + 29% from wet plaster
Roof & Ceiling	5,256	1,384	- 6,271	4,741	943	- 3,564	186%	46% EC from fibre glass membrane, 28% sedum roof materials	51% from fibreglass membrane; 26% from 170mm PIR insulation;
Existing House	***12,664***	***1,650***	***- 15,113***	***12,626***	***1,650***	***- 6,692***	***141%***		
Floor	679	972	- 4,087	1,540	972	- 3,745	-55%	96% EC from timber	56% from 120mm PIR insulation; exactly same quantity timber as NEES
External Walls	10,431	-	- 4,905	6,180	-	-	11%	68% hempcrete & lime render, 28% timber window frames & glazing	82% PVC window frames and glazing
Internal Walls	523	39	- 622	1,600	39	- 127	107%	91% from 25mm hemplime render internally	38% from 40mm PIR insulation, 31% cement scratch render internally
Roof & Ceiling	1,031	639	- 5,498	3,306	639	- 2,820	1019%	41% plasterboard, 29% timber	66% 170mm PIR insulation
Building Total	**27,849**	**8,761**	**- 43,433**	**34,373**	**2,766**	**- 11,021**	***167%***		
Option 1: Gravel reed bed vs Biofilter	2,533	-	-	2,482	-	-	-2%	47% GRP septic tank	48% GRP septic tank
Option 2: Constructed wetland vs Fixed film reactor	2,196	-	-	2,586	-	-	15%	55% GRP septic tank	84% 9 tonne precast concrete tank
Option 3: Willow facility	1,935	-	-	-	-	-		84% GRP septic tank	

*includes fossil & sequestration portions, excludes biomass

3.4 BUILDING ENERGY RATING (BER)

Before: A BER assessment was submitted onto the SEAI's National BER Register on 21/8/12 before the present owner purchased the cottage at Cloyne. The cottage received a G Rating with energy rating and emissions as indicated in Table 3-4 below.

After: Fergal McGirl Architects assessed the NEES design using the following assumptions:

- U-values as per Table 2-1
- Airtightness value of 5 (Q_{50} @ 50 Pa)
- Efficiency of wood stove/primary heating of 65% with no controls

This resulted in a D1 rating for the NEES design, and the build-up of the 'conventional' building envelope was constituted to yield the same rating (i.e. same U-values, same orientation, same heating controls, etc). The results are displayed below using the different thermal conductivity values for hempcrete discussed earlier which do not affect the overall rating. The most conservative values (from Steve Allin's book) have been used for the purpose of the life cycle analysis and profiles.

Table 3-4: BER Values

	Rating	Energy Rating ($kWh/m^2/yr$)	CO_2 Emissions Indicator ($kgCO_2/m^2/yr$)	Floor area (m^2)
Before	G	848.02	195.29	55.01
After				
Tradical hempcrete values	D1	243.61	13.39	80.40
Evrard & De Herde hempcrete values	D1	252.92	14.14	80.40
Beton de Chanvre (Steve Allin book) values	D1	256.02	14.21	80.40

Comments of the BER rating: Given the high performance (low U-value) building fabric specification, the dwelling is achieving a poor BER rating for the following reasons:

- A default efficiency of 65% has been assumed for the wood stove
- No control systems are proposed for the heating system
- No control systems are proposed for the domestic hot water system and electrical summertime hot water heating has been assumed
- The single storey structure has a high heat loss area to floor area ratio of 3.8 by comparison with a larger, more compact dwelling
- There is a large glazing ratio to floor area ratio of 43%.
- BER rating system favours larger houses with the same characteristics. This is due to the fact that the rating is based on energy consumption per m^2 and the constant losses (hot water energy demand & storage losses, primary heating circuit losses, etc.) are divided across a larger floor area.

- DEAP bases its energy value calculations on primary energy, regardless of the fuel and there is no compensation for biomass

Note that the efficiency of the main boiler and lack of heating controls would not comply with the requirements of TGD L 2011 of the Building Regulations for both the NEES and conventional designs. Likewise, the proposed windows with U-value of 0.16 W/m^{2}k would not comply with table 2 of TGD L 2011. Nevertheless, the house has a reasonably low CO_2 Emissions Indicator due to the biomass heating system.

Although the low BER rating might seem disappointing considering the attention that has been paid to the U-values of the building fabric, if we simply compare the before and after retrofit (i.e. ignoring the comparison of conventional vs NEES retrofit and extension), the savings are perhaps more impressive (see Table 3-5 below). The improvement represents a 56% improvement in energy efficiency and an 89% emissions reduction, despite increasing the floor area by 46%.

Table 3-5: Energy and Emissions Savings from BER Improvement

	Before	After	Savings	% saving		
BER rating	G	D1				
Energy value (kWh/m2/yr)	848.02	256.02	592	70%		
CO2 Emissions Indicator (kgC02/m2/yr)	195.29	14.21	181.08	93%		
Floor area	55.01	80.4	-25.39	-46%		
Energy value (kWh/yr)	46,649.58	20,584.01	26,065.57	**56%**	**2.24**	**toe/yr**
CO2 Emissions Indicator (kgC02/yr)	10,742.90	1,142.48	9,600.42	**89%**	**9.60**	**tCO2e/yr**

3.5 100 YEAR LIFE CYCLE COMPARISON

A 100-year life cycle comparison is presented in Table 3-6. Each life cycle stage has been calculated as follows:

1. Cradle to gate: Based on material factors in Appendix I, and as stated in Sections 3.1-3-3 above, the NEES building shows a 64% saving in mass, an 8% saving in embodied energy and a 19% saving in embodied emissions (excluding biomass emissions and carbon sequestration).
2. Construction Waste: Based on the assumed wastage factors in Appendix I, the NEES building demonstrates a 68% reduction in mass, 13% saving in embodied energy and a 36% saving in embodied emissions.
3. Transport to site: Based on transport distances in Appendix I, and including construction waste, the NEES proposal resulted in an increase in transport energy consumption and emissions of 185% (Appendices IV and V highlight the transport hotspots, which are particularly in relation to hempcrete and the Optigreen substrate (aerated clay) for the sedum roof)
4. Installation: installation energy and emissions from the contractor's questionnaire and is assumed to be the same whether on the NEES or conventional build
5. Operation: is from the BER calculation in Section 3.4 and is the same for the NEES and conventional builds
6. Maintenance: assumes that at the end of a typical lifespan of a building part that 20% replacement of materials is required. The figures here include for construction materials as well as construction waste, transport to site and end-of-life. The calculations illustrate that the NEES build results in a 40% mass saving, 9% energy saving and 24% emissions saving over a 100 year life of the building.
7. End-of-Life: based on the assumptions in Appendix I, the NEES design demonstrates a 72% saving over the conventional build.

Over all the life cycle stages, the NEES building has been calculated to have a 59% mass saving, a 1% embodied energy saving and an 8% saving in emissions. A similar comparison of a gravel reed bed against a biofilter treatment system illustrates an overall increase in mass of 130%, an increase in energy consumption of 1% and an emissions saving of 6%.

The pie-charts in Figure 3-5 and Figure 3-6 show how, over a 100 year period, the embodied energy of the buildings comprise 11.3% (NEES) and 11.9% (conventional) while the proportions of embodied carbon (fossil fuel emissions only) are 30.4% (NEES) and 36.1% (conventional).

Table 3-6: 100 Year Life Cycle Comparison

	Mass			EE			EC (fossil)			EC (biomass)		EC (sequestr)	
	NEES	Conv	Saving	NEES	Conv	Saving	NEES	Conv	Saving	NEES	Conv	NEES	Conv
Building	kg	kg	%	MJ	MJ	%	$kgCO_2e$	$kgCO_2e$	%	$kgCO_2e$	$kgCO_2e$	$kgCO_2e$	$kgCO_2e$
Cradle-to-Gate	57,050	157,356	64%	581,395	630,270	8%	27,849	34,373	19%	8,761	2,766	- 43,433	- 11,021
Construction Waste	1,145	3,560	68%	8,968	10,282	13%	460	723	36%	205	79	- 776	- 319
Transport to Site	-	-		32,971	11,561	-185%	2,797	981	-185%	-	-	-	-
Installation	-	-		5,066	5,066	0%	369	369	0%	-	-	-	-
Operation	-	-		7,410,243	7,410,243	0%	114,248	114,248	0%	-	-	-	-
Maintenance	27,375	45,939	40%	317,651	347,235	9%	16,826	22,224	24%	4,511	1,288	- 20,935	- 5,099
End of Life	-	-		-	-		1,657	5,845	72%	-	-	-	-
Totals	**85,570**	**206,855**	**59%**	**8,356,294**	**8,414,657**	**1%**	**164,207**	**178,763**	**8%**	**13,477**	**4,132**	**- 65,144**	**- 16,439**
Wastewater	**Gravel RB**	**Biofilter**		**Gravel RB**	**Biofilter**		**Gravel RB**	**Biofilter**					
Cradle-to-Gate	160,938	89,943	-79%	32,284	34,198	6%	2,533	2,482	-2%				
Construction Waste	200	199	-1%	263	155	-70%	26	22	-15%				
Transport to Site	-	-		3,866	2,404	-61%	328	204	-61%				
Installation	-	-		-	-		-	-					
Operation	-	-		-	13,140	100%	-	1,927	100%				
Maintenance	128,911	36,057	-258%	29,130	14,703	-98%	2,438	1,120	-118%				
End of Life	-	-		-	-		161	91	-76%				
Totals	**290,049**	**126,199**	**-130%**	**65,544**	**64,600**	**-1%**	**5,486**	**5,848**	**6%**				

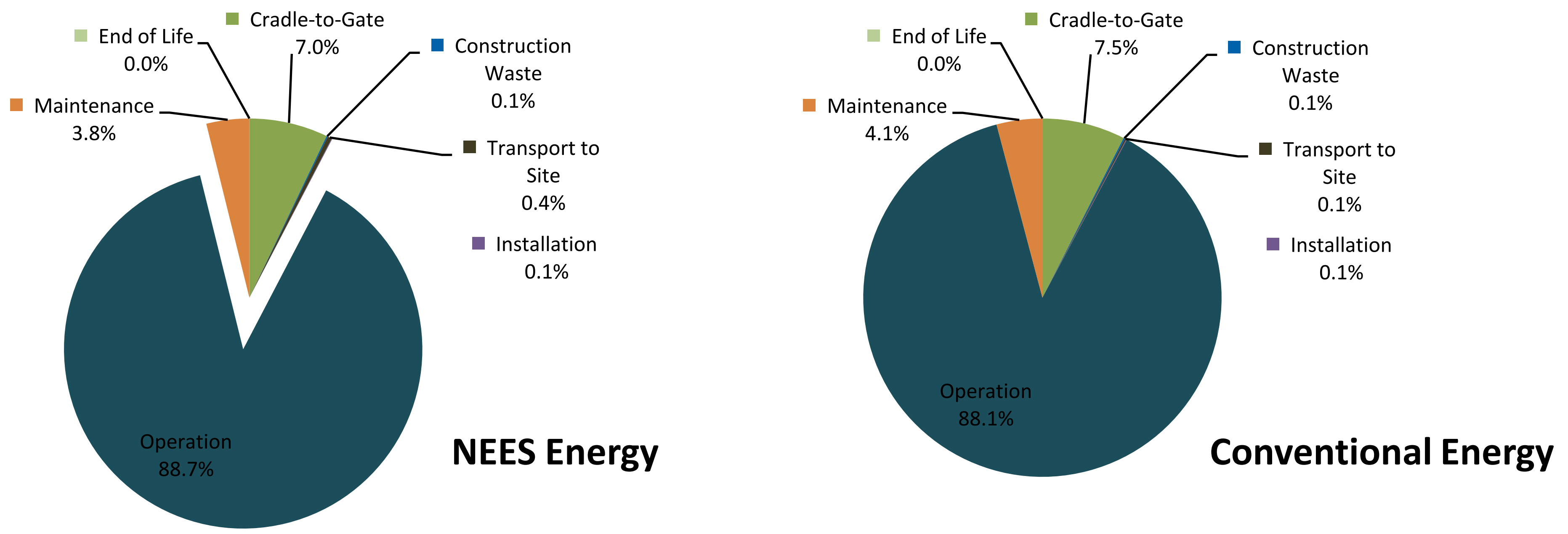

Figure 3-5: Energy Comparison by Life Cycle Stage

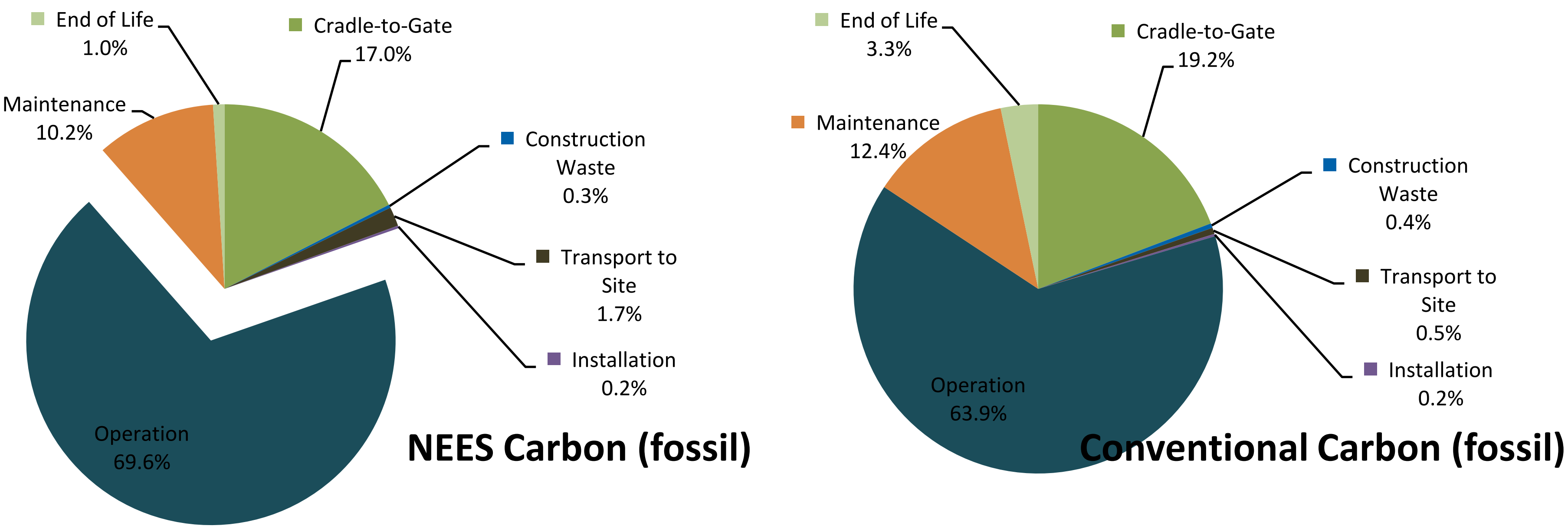

Figure 3-6: Carbon Comparison by Life Cycle Stage

3.6 HUMAN HEALTH, BIODIVERSITY & HAZARDOUS MATERIALS

3.6.1 BIODIVERSITY

Which biodiversity is in question: at the source of extraction or harvest of materials, at the building site, or indeed the building during use? Is the future biodiversity after demolition or disassembly as much a concern as the current biodiversity? Of course one may argue that all are of equal importance. In any case there is a lack of information to judge how it is proposed biodiversity will be protected, let alone nurtured or encouraged, in this project. The following points can however be made.

Green roof

There are many claims about the biodiversity of green roofs due to added flora and fauna. Professor Woolley who is clearly a fan of such roof coverings is nonetheless dismissive of many over-enthusiastic claims.[20] He claims most planted roofs do not add more to bio-diversity than the average lawn: '*the wilder the roof the greater the biodiversity. Yet the concept of replacing the ground that has been destroyed under a building with a green area on top has to be of significant environmental benefit, particularly in cities'*. He agrees however that green roofs result in far less water run-off with 30-50% of rainwater being absorbed for later evaporation which obviously nurtures the roofs flora and whatever fauna is present, besides reducing loads on drainage schemes.

Hemp

An argument may be put forward that using hemp as the external wall insulation and internal plaster may be considered positive for local biodiversity if the hemp is grown locally and the lime is Irish. This is because:

1) Once in place, hemp-lime biocomposite is non-hazardous. Of course sensible safety procedures are followed using the hemp harvesting equipment and processing the lime;
2) The hemp plant does not take from the soil;
3) It does not require fertilisers;
4) Its fast growth (4 meters in 100 days) may encourage crop rotation;
5) It acts as a weed suppressant: it may therefore encourage less use of weed killer by farmers using hemp as a brake crop between food crops;
6) If grown on reasonably marginal land it could improve rural unemployment and possibly provide a viable economic alternative to sheep farming (the over-intensification of which is de-nuding the uplands of Ireland);
7) At demolition the lime and hemp waste can simply de dug into the ground to enrich the soil. There may therefore be no 'downstream' effects.

The investigators have no information on the flora and fauna associated with growing hemp (a key indicator of biodiversity), however it is worth considering that hemp has been grown in

[20] pp. 105-109, Woolley, T.. *Natural Building – a guide to materials and techniques*, Crowood Press, Wiltshire, UK (2006)

Ireland for several hundred years (indicated by the number of dialect names in Irish). It is likely therefore that existing native animal species have lived within or beside hemp fields.

SmartplyOSB

The timber in SmartplyOSB is Irish grown and FSC-certified, however species of pine and spruce gown in Ireland (excluding Scots Pine) are not native. The large mono-crop plantations contribute to the acidification of the soil and are poor supporters of native species of flora and fauna. Smartply OSB, in common with other monoculture based timber products, must therefore be considered negative in terms of biodiversity for the location in which they are grown.

Plasterboard

According to Berge,[21] plasterboard is a largely benign product. It is based on raw materials that have rich reserves. It can also be created from the waste materials of power stations. Its greatest threat to biodiversity is due to its low levels of recycling as sulphur pollution can develop from plaster waste through decomposition by microbes (Berge says this can be reduced be adding lime).

Stepped Grass Path

The stepped grass path is a positive feature in terms of biodiversity as it can support the same flora as a lawn or meadow while having the same drainage ability.

Gravel Reed Bed[22]

Reeds are not only aesthetically pleasing but provide a habitat for frog spawn and birds. Reeds are also good for nitrogen fixing and encourage the home owner to engage with wastewater generation, typically encouraging the use of fewer chemicals and less aggressive cleaning products.

Other Materials

Other materials specified in the NEES demonstration project include airtightness tapes, bitumen-impregnated boards imported from Norway[23] and Iroko window frames imported from Africa: it is hard to argue how these materials contribute to bio-diversity. Some will not break down easily (such as the bitumen or tapes), others are surely associated with industrial processes that have 'upstream' impacts (such as unsustainably felled Iroko).

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[21] pp. 315-316, Berge, B., *The ecology of building materials*. The Architectural Press (2003)

[22] Gravel reed bed section included by Raoul following telecom with Joseph Little on 22nd April 2014

[23] Site visit note by Raoul, 23rd April 2014: OSB boarding used externally without bitumen impregnation as per tender specification

3.6.2 HUMAN HEALTH & HAZARDOUS MATERIALS

Background to material choices

The Client for this project has a low tolerance to toxic materials. As she has a heightened physical reaction to various materials she was able to gauge from her own reaction a product's suitability for use in her own home. This was used by the client and architect in deciding various aspects of the specification (such as choice of external wall insulation).

There was a general desire behind the NEES specification of selecting materials layers in a component that are each sufficiently vapour permeable that they do not act as barriers to the movement of vapour through the component buildup outwards (as the vapour pressure gradient in North European domestic housing for most of the year is from inside to outside). This is in contrast with many conventional construction where vapour movement is controlled by membranes without focus on the vapour permeability (or its inverse, vapour resistance) of other materials in the component which can lead to localised buildups of vapour and condensate.

As can be seen in Table 3-7 below the vapour resistance (measured here by the 'Equivalent air layer thickness') of the materials actually chosen reduces as one moves outwards through the component buildup. This shows that the principles were integrated in practice. Nonetheless the sealed OSB boards and sarking boards 'sandwiching' the insulation can also be highly airtight reducing the unwanted heat loss and vapour movement that can quickly occur through gaps otherwise. The use of an assembly that (a) makes a high level of airtightness easier to achieve, (b) has carefully graded vapour permeability and (c) is composed of hygroscopic materials is likely to result in a resilient, long-lasting and high performing component. It should be less likely to experience mould growth than many conventional alternatives and if wetted due to a rain leak it should have an excellent ability to dry out.

Table 3-7: Assessment of Vapour Resistance of Materials Chosen to Roof Existing Portion of Dwelling

Key materials in roof buildup Listed from outside to inside	**Thickness** (m)	**vapour diffusion resistance factor** Mu, dry cup (-)	**Equivalent air layer thickness** S_d (m)
bitumen-impregnated sarking board	0.018	20	**0.36**
Cellulose (blown)	0.275	1.5	**0.41**
18mm Smartply OSB boards were specified (with T&G joints sealed with silicone, and joints with wall signed with silicon and SIGA tapes)	0.018	50	**0.9**

Comparison of material specifications

Concrete, hardcore and stepped path

The architect has clearly gone to significant lengths to reduce the amount of concrete used in the project by specifying suspended timber floors in the new and existing portions of the project. This has resulted in the existing slab of the original house being removed. The load of the extension is transferred down onto six modestly sized concrete pads. If the load of the green roof was not in question these pads may have been smaller.

Conventional specification	Comment
OPC Concrete on quarried hardcore	Cement manufacturing is the world's largest source of carbon emissions after fossil fuel burning (accounting for about 8-10% of the world's total emissions). Reducing its use and carbon intensity should therefore be an important goal of all demonstration projects.
Path clad with concrete flags or paviors on hardcore	Concrete processed materials on quarried broken stone possibly with concrete kerbs and concrete haunchings
NEES specification	Comment
OPC Concrete on salvaged hardcore	It is positive that hardcore was salvaged from demolished slab however the 100% OPC content of the cement is a missed opportunity in terms of embodied carbon, as GGBS (a waste product) can be substituted up to 70% to make a significant carbon saving with some delay on setting time but an improvement in colour and long-term strength
Stepped path of earth	Stepped path made of shaped earth with hardwood retaining boards

External wall insulation

Conventional specification	Comment
Climatech Ext. Wall Insulation	MSDS of Climatech Polymer Adhesive Mortar *Contains Portland Cement Bulk* • *R38 Irritating to skin.* • *R41 Risk of serious damage to eyes.* • *R43 May cause sensitisation by skin contact.*
NEES specification	Comment
Hempcrete EWI	If the hemp plants are grown locally and Irish lime is used (such as Clogrennan 'White Rhino') this should be a carbon-positive, bio-composite material

Client and architects initially considered use of ClimaTech mineral wool EWI from Bostic: this would have ensured a grant under the Better Energy Homes Scheme. However the Client put a sample in her house for a few days and had a reaction: she felt the adhesive was the chemically aggressive element. She had previously dismissed woodfibre EWI due to cost. She therefore went with an externally applied hempcrete installed by local hemp builder/supplier Steve Allin.

Allin fixes metal expanding anchors onto the outside of rubble walls then sprays hempcrete EWI onto the wall – the anchors act as pegs that pin the hempcrete back to the masonry. The investigating team has no experience of sprayed hempcrete used in this way.

Boards acting as air barriers

Conventional specification	Comment
Plywood	Often uses a (urea-, phenol-, melamine- or resorcinol-) formaldehyde resin to create physical bond. From Weyerhaeuser plywood datasheet: *Wood dust may cause respiratory irritation, nasal dryness, coughing, sneezing and wheezing as a result of inhalation. Formaldehyde may cause temporary irritation of skin, eyes, or respiratory system. Formaldehyde may cause sensitization in susceptible individuals.*
NEES specification	Comment
OSB-3 Smartply	FSC-certified and virtually formaldehyde-free From Smartply datasheet: *Zero added formaldehyde, uses a resin chemical bond.* *Formaldehyde release: ≤ 8.0 mg/100g* From MSDS Smartply: *(i) Mild skin and eye irritant to sensitive individuals* *(ii) No experimental data available OSB products may ignite if exposed to temperatures exceeding 400F.* *This material is biodegradable, may be suitable for composting, landfill or energy recovery.*

'Resin binders in composite boards have been found to yield measurable amounts of formaldehyde, particularly when the board has not been treated with an impermeable surface. Measurements in buildings are far lower than those found in industry but there is concern over the long hours of exposure in the domestic environment. For use in poorly ventilated areas or bedrooms, it may for health reasons be worth finding and alternative board which doesn't contain formaldehyde. '

ref: p.85, Woolley et al. (2001)

Timber windows & panelling

Conventional specification	Comment
Iroko hardwood or (slow growth) Scandinavian pine windows	Both are considered high quality and long-life timber specifications
Western Red Cedar cladding	Sourced from Canada or USA. (Note: approach to planting and felling cedar in US is considered much less sustainable than that in Canada)

NEES specification	Comment
Iroko hardwood windows	No change. Ireland imports more African hardwoods than any other country in Europe. There are good arguments for avoiding them even when FSC- or PEFC-certification is available, as there are ample cases of forged papers and timber shipped across borders from countries experiencing civil war or unrest. Arguably (slow growth) Scandinavian pine windows are more sustainable as they are sourced from closer countries with stable governments and economies with long-term policies under EU regulation.
Western Red Cedar cladding	No change. Once again there is no mention of FSC- or PEFC-certified timber. In fact Irish grown FSC-certified Western Red Cedar is available at times through Coillte sawmill in Dundrum, Co. Tipperary

Finish to windows

Conventional specification	Comment
Conventional paint sprays used in EU have all reduced in VOC content in recent years	EU VOC limit value: < 150 g/l (2007); < 130 g/l (2010)
NEES specification	Comment
SikkensRubbol WF 380 HP from Akzo Nobel	This is a low emission product (max. 50 g/l VOC), however it is not listed on the Ecolabel Catalogue (http://ec.europa.eu/ecat/). The European Eco label for indoor paints & varnishes paint lists a wide range of criteria (e.g. free formaldehyde ≤ 0.001% (m/m) after tinting, max. 30 g/l VOC for certain paints)

Plasterboard & skim finish

Conventional specification	Comment
Gypsum plasterboard & skim coat	While gypsum plasterboard acts as a useful moisture regulator when used as wall finish facing a room, it can become a biohazard if trapped behind internal insulation, especially if an air supply from the room is delivering oxygen and warmth and moisture through gaps in an internal wall insulation to the (entombed) gypsum surface.
NEES specification	Comment
No change	This is a conventional selection

Wall finishes

Conventional specification	Comment
Commercial water-based paint	VOCs of commercial internal paints have been reduced by EU regulation
NEES specification	Comment
Dulux 'Simply Colour'	This is a conventional selection. The Ecolabel Catalogue (http://ec.europa.eu/ecat/) lists a very large range of products may available in Ireland, examples include NBT, Auro, Agglaia, Earthborn.

Finish to timber floor

Conventional specification	Comment
Varnish	These are commonly plastic coatings and can have a measurable VOC content (through this has been reduced by EU regulation). The coating reduces the vapour permeability of the substrate and typically delaminates.
NEES specification	Comment
Oiled	Oiled finishes allows localised repair and can be fully organic

Ventilation

Indoor air quality (IAQ) has been cited by the US Federal Health Authority as one of their top five health concerns. In the northwest maritime regions of Europe IAQ is principally a matter of controlling humidity which otherwise would result in condensation and mould – a cause of allergenic illness. Adequate thermal insulation is needed to raise surface temperatures, in conjunction with adequate heating and adequate ventilation. In addition there is a need to limit CO_2& also the buildup of volatile organic compounds (VOCs) that off-gas from many contemporary building materials and furnishings. Any good ventilation system needs to ensure IAQ while limiting energy loss

BS 5250(2011) has identified the maintenance of room conditions below 70% relative humidity (%RH) as desirable for occupant health because these ambient conditions often result in room surfaces of external walls and thermal bridges being~80% RH, an accepted threshold for mould. However dust mite populations begin to thrive at conditions over60-70% RH so it would appear desirable to try to limit room RH levels below 60%. This agrees with the Sterling bar graph in Figure XX below. The fact that the mean annual external %RH levels in southern parts of Ireland are~82% RH definitely makes this kind of control harder. Based on measurements of many Irish dwellings with inadequate ventilation systems, the peak moisture load in bathrooms can frequently exceed 90% and result in mean %RH levels of 75 – 80 for a week at a time (particularly in Summer when space heating is turned off but moisture generation continues): very unhealthy conditions.

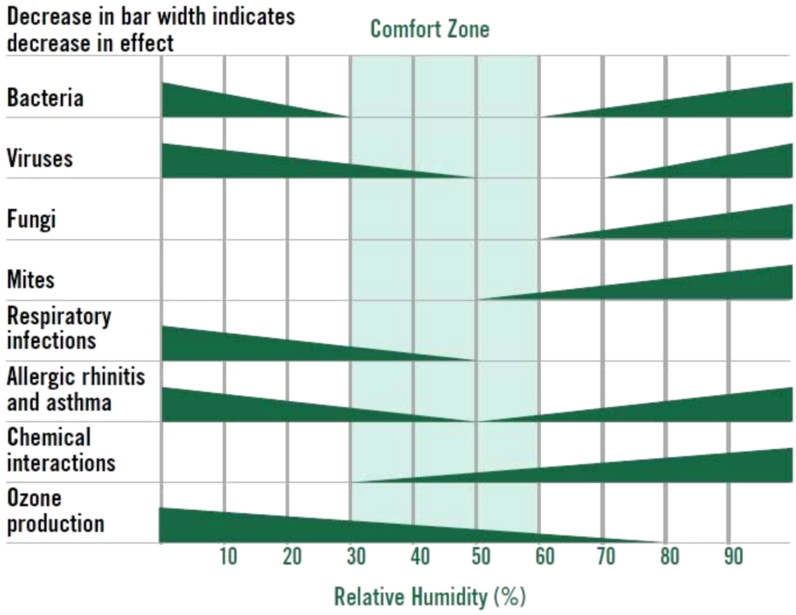

Figure 3-7: Sterling bar graph (1986) showing link between indoor air quality and relative humidity

Conventional specification	Comment
Natural ventilation system with extraction provided by an intermittent fan	Rapid ventilation via windows and (window or wall-mounted) trickle vents providing supply air with extraction provided by an intermittent fan. Most intermittent fans with associated ducting are badly fitted (e.g. fan may be too weak, duct may be too long, or terminate pointing downwards in fascia soffit etc.).
NEES specification	**Comment**
Natural ventilation system (including 'Duco' background vents in bedrooms) with no mechanical extraction	This is a disimprovement on the conventional specification. An open window during a shower is as likely to bring air into the house (entraining the moisture on its way through the dwelling) as to provide an egress point. Without mechanical extraction of some kind external air pressures to either side of the house dominate air movement within the house. Fit a humidity-triggered extract vent directly over source of moisture generation in bathroom and kitchen (separate to cooker hood): consider Aereco or Lunos systems with modulating air supply and extract fan speeds.

3.7 LIFE CYCLE COSTS

The best way to get an accurate cost comparison between the NEES design and a conventional build would have been to get tenderers to quote for both building projects. This would provide the fairest comparison in that the same builders would have to cost up two options and would treat materials and labour on a comparative basis. Of course this would require two sets of tender drawings, one for NEES and one for the conventional equivalent; and while not possible for this evaluation it is recommended that the NEES partners consider this method for further demonstration projects.

3.7.1 BUILDING COMPARISON

At a site meeting on the 23rd April 2014 cost information for the NEES build was provided, and this is presented in Table 3-8 below. The labour and material costs were provided by the client and the man days by the contractor. The totals illustrate a 56/44 ratio between labour and materials.

Table 3-8: Cost of NEES Build

NEES build	Contractor	Man days	Labour	Materials	Subtotal
Declan Devoy, builder	Main	122	€ 27,000		€ 27,000
Stonemason	Main	inc	€ 2,750		€ 2,750
1. Timber frame	Main	inc		€ 3,300	€ 3,300
Other timber, OSB, concrete	Main	inc		€ 2,308	€ 2,308
Western red cedar	Main	inc		€ 2,000	€ 2,000
2. Hempcrete, supply & install	Sub	20	€ 3,000	€ 3,460	€ 6,460
3. Cellulose, supply & install	Sub	4.5		€ 5,000	€ 5,000
4. Windows, supply & install	Sub	1		€ 10,000	€ 10,000
5. Sedum roof	Sub	1	TBC	TBC	
Fibreglass membrane to roof	Main	inc	€ 3,300		€ 3,300
Drains & Blockwork	Sub	10.7	€ 1,600		€ 1,600
Plumber	Sub	20	€ 3,000	€ 3,000	€ 6,000
Shower tray	Sub			€ 324	€ 324
Tiles	Sub			€ 80	€ 80
Slates	Main	inc		€ 2,300	€ 2,300
Total		**179.2**	**€ 40,650**	**€ 31,772**	**€ 72,422**

International quantity surveying consultancy, Turner & Townsend give an average cost of €1,000 per m2 for a conventional detached house in Ireland,[24] that is, € 80,000 for a conventional equivalent. Thus, the NEES build appears to represent a 9.5% cost saving against the conventional build.

[24] *International Construction Cost Survey 2012*, Turner & Townsend plc 2012: file:///C:/Users/User/Downloads/TT_ICC_2012_Report_Single_Pages_zKJM-.pdf accessed on 27th April 2014

The contractor, Declan Devoy, was further questioned on the time it would take to complete the conventional build, allowing for blockwork, increased wet plastering, cutting rigid insulation to size, etc. Having summed his response, the 122 man days required for the NEES design increased to 191 man days for the conventional, or, a total of 224.2 days including the input from subcontractors. Table 3-8 gives an average labour rate of €226.88 which is close to that listed by Turner & Townsend (€232 for an 8 hour day). The average NEES labour rate multiplied by the man days required to build the conventional design increases the labour cost from €40,650 up to € 50,866. Therefore the NEES demonstration project may represent a 20% saving in labour costs.

The operational costs are the same between the NEES and conventional as the BER rating is equivalent. Maintenance costs are broadly similar, but it is considered that a conventional build would be painted, and the fact that the NEES design does not require painting (both to the Western Red Cedar cladding and to the lime render over the hempcrete) could therefore represent a maintenance cost saving.

3.7.2 WASTEWATER TREATMENT OPTIONS

The life cycle costs of the various wastewater treatment options (PE of 5) shown in Table 3-9 overleaf are based on the following assumptions:

Assumptions			Source
All systems desludged annually in accordance with Environmental Protection Agency guidelines			
Pumps, if used, require replacing every 20 years			
Cost of electricity (AUP per kWh)	€ 0.23	inc VAT	Band DC: >=2,500 <5,000 kWh per annum
Cost of desludging/ annual inspection	€ 195.00	inc VAT	
Biofilter medium lifespan	15	years	
Cost of replacing biofilter medium in 1 module	€ 212.81		
Cost of replacing gravel in reed bed	€ 1,000.00		
Cost of replacing pump	€ 448.33		
Cost of one man day	€ 120.00		

The gravel reed bed compares favourably with other conventional systems and presents a possible 11% cost saving over a comparable biofilter system. The willow facility calculation does not include the benefit of offsetting heating costs if the willow chip can be burnt on site or even sold.

It should also be pointed out the gravel reed bed, constructed wetland and willow facility options all require significantly more space than comparable conventional systems, and the cost of land is not factored into these calculations.

Table 3-9: Cost Comparison of Wastewater Treatment Systems over 100 year Life Cycle

		Gravel Reed Bed	*Constructed Wetland*	*Willow Facility*	*Biofilter*	*Fixed Film Reactor*
CEN Type		**Septic tank & 50m2 gravel reed bed**	**Septic tank & 100m2 CW**	**Septic tanks & 6mx35m = 210m2**	**Septic tank & 2no. biofilter modules**	Fixed film reactor process
Septic tank		Yes	Yes	Yes	Yes	No
Percolation area		Yes	Yes	No	Yes	Yes
Pump Electricity (kWh/d)		0	0	0.1	0.1	2
Costs						
Design inc VAT @23%		€ 615.00	€ 615.00	€ 861.00	inc	inc
Capital cost inc VAT @ 13.5%		€ 3,500.00	€ 3,500.00	€ 17,500.00	€ 4,534.33	€ 7,800.00
includes		inc VAT, delivery & installation	inc VAT, delivery & installation	inc VAT, delivery & installation	pump chamber, concrete lintels, delivery & installation	inc VAT, delivery & installation
Septic tank, supply & install		€ 1,000.00	€ 1,000.00	€ 1,000.00	€ 1,000.00	
Percolation area		€ 3,150.00	€ 3,150.00		€ 3,150.00	€ 3,150.00
Capital cost total		***€ 8,265.00***	***€ 8,265.00***	***€ 19,361.00***	***€ 8,684.33***	***€ 10,950.00***
Annual running cost inc VAT @ 13.5%		€ -	€ -	€ 8.40	€ 8.40	€ 167.90
Desludge frequency (yrs)		1	1	1	1	1
Pump replacement frequency (yrs)				20	20	20
Maintenance days				1		
Other maintenance (gravel/biofilter medium replacement) (yrs)		25		.	15	
Life Cycle Period (20 yrs)	**20**	**€ 12,165.00**	**€ 12,165.00**	**€ 26,277.23**	**€ 13,768.05**	**€ 18,656.33**
Life Cycle Period (60 yrs)	**60**	**€ 22,365.00**	**€ 19,965.00**	**€ 40,109.68**	**€ 23,935.50**	**€ 34,068.98**
Life Cycle Period (100 yrs)	**100**	**€ 31,765.00**	**€ 27,765.00**	**€ 53,942.13**	**€ 34,102.95**	**€ 49,481.63**

Note 1: cost of land excluded

Note 2: in the case of the willow facility, the benefit of willow chip to offset fossil fuel costs is not included

3.8 EASE OF CONSTRUCTION & MAINTENANCE

Ease of Construction

The contractor, Declan Devoy, was interviewed on site on 23rd April 2014. As the NEES demonstration project was an unconventional build, the contractor would have preferred to have more details and steer from the architect, to the extent that having an architect on site would have been of help to answer the numerous queries that continuously arose. Declan acknowledged, however, that the first time doing a new method is always 'awkward'.

Specific problems included, for example, fixing to the existing cottage which would have been easier with blockwork, and the weathering details around windows & shingles.

The timber frame proved particularly positive, being quicker to erect and thus representing a significant saving in labour time (see section Table 3-8. A conventional build would have required more excavation and the use of a teleporter because of its greater mass. The cellulose insulation appears to be far simpler an installation as it does not require cutting rigid insulation to size to fit between joists.

Maintenance

The builder did express concern that the timber was not treated with preservatives in the skirt below extension floor level. The reason for this detailing was that the client did not wish to use any chemicals; indeed, the architect was apparently happy that the underfloor area was sufficiently ventilated to prevent rot and ensure the longevity of the timber stud structure to support the Western Red Cedar cladding.

4 DISCUSSION OF ENVIRONMENTAL HOTSPOTS

This section goes beyond the tender requirements which were addressed in section 3 of this report. Here, the carbon profiling methodology has been developed to illustrate resource depletion (mass), energy and carbon hotspots. The profiles show the typical lifespan of the building parts on the horizontal axis (substructure, floors, external walls, internal walls, roof & ceiling) and the environmental metric per unit floor area within the house divided by the typical lifespan of each building part. The areas of colour representing each building element on the chart therefore indicate the environmental impact per unit area of house, i.e. kg / MJ or $kgCO_2e$ per m^2. The floor area of the house is $80.4m^2$.

In calculating these profiles, cradle-to-gate, construction waste and transport to site have been considered in the 'embodied' portion, while end-of-life and maintenance have been excluded. The operation is represented by the outputs from the BER. This is in line with the carbon profiling methodology where unknown events in the future are not considered, rather, the profiling methodology concentrates on putting a value on the carbon asset in the present.

4.1 MASS PROFILE

The mass profiles in Figure 4-1 illustrate how the area occupied by the building on the NEES profile is approximately a third of the area on the conventional chart. Foundations have a typical lifespan of 100 years and the conventional profile for substructure is far more prominent that the light pad foundations used in the NEES design. The floor and walls of the extension show a heavier mass footprint than that of the NEES design as they are constructed of concrete and blockwork rather than timber frame. Although the mass of the NEES extension roof is heavier than that of the conventional design, the sedum roof is thought to protect the fiberglass membrane and extend the roof's life from 20 years to 30 years. The existing cottage refurbishment for the NEES design has a larger mass profile due to the large quantities of hempcrete.

The wastewater treatment system for the NEES design is thought to have a lifespan of between 20 and 30 years before the gravel needs replacing (shown as 25 years here), while a package treatment system has a 50 year life span by being somewhat protected underground. The package treatment system is half the mass of the gravel reed bed and therefore occupies half the area in the mass profile.

4.2 ENERGY PROFILE

The energy profiles in Figure 4-2 distinguishes between embodied energy and energy consumed by the operation of building (BER calculation). The units are in kWhs rather than MJ (1 kWh = 3.6MJ). The embodied energy on the vertical axis represents 22% of the total NEES energy and 24% of the total conventional energy (in $kWh/m^2/yr$). A small amount of energy is consumed in operating the package treatment system ($0.45\ kWh/m^2/yr$) whereas the gravel reed bed is gravity fed and uses no energy in operation.

4.3 CARBON PROFILE

The three types of carbon discussed in Section 3.3 are illustrated in the carbon profiles in Figure 4-3. Carbon sequestration is shown on a negative vertical axis and is slightly greyed out to indicate carbon storage for the typical lifespan of each building part. On the positive axis the fossil fuel and biomass emissions are summed together and show that 53% of the annual carbon profile is embodied, as by having a wood stove the carbon emissions indicated from the BER analysis are very low. If the reader believes that the timber is sustainably sourced and that biomass emissions should be ignored, the dotted red line shows the reduced embodied carbon footprint due to fossil fuel combustion only.

Most distinguishing between the NEES and conventional carbon profiles is that the NEES design has significant carbon storage, and the area of carbon sequestration on the profile more than cancels out the embodied carbon. Both charts indicate a 'carbon profile' number which is broadly the same, but if the carbon sequestration is subtracted from these numbers then the resulting carbon numbers contrast strongly:

- NEES 'net' carbon profile number = 30.61 – 17.37 = 13.24 $kgCO_2e/m^2/yr$
- Conventional 'net' carbon profile number = 30.72 – 5.19 = 25.53 $kgCO_2e/m^2/yr$

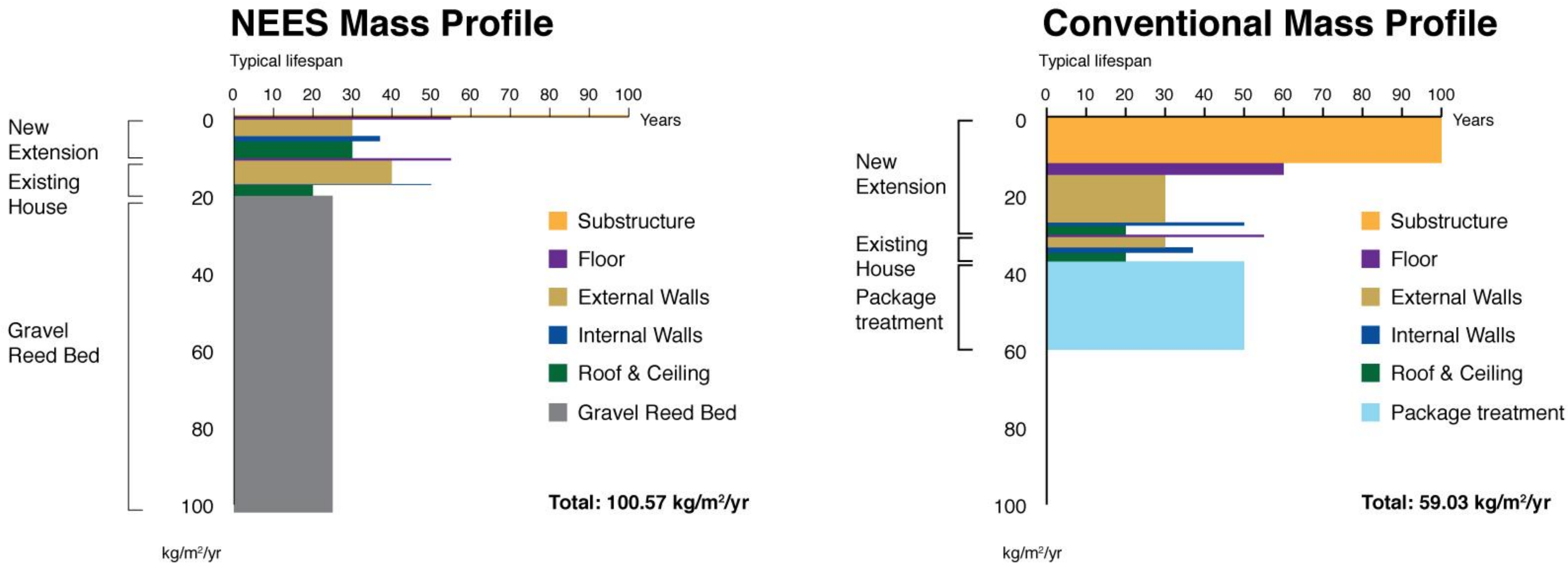

Figure 4-1: Mass Profiles

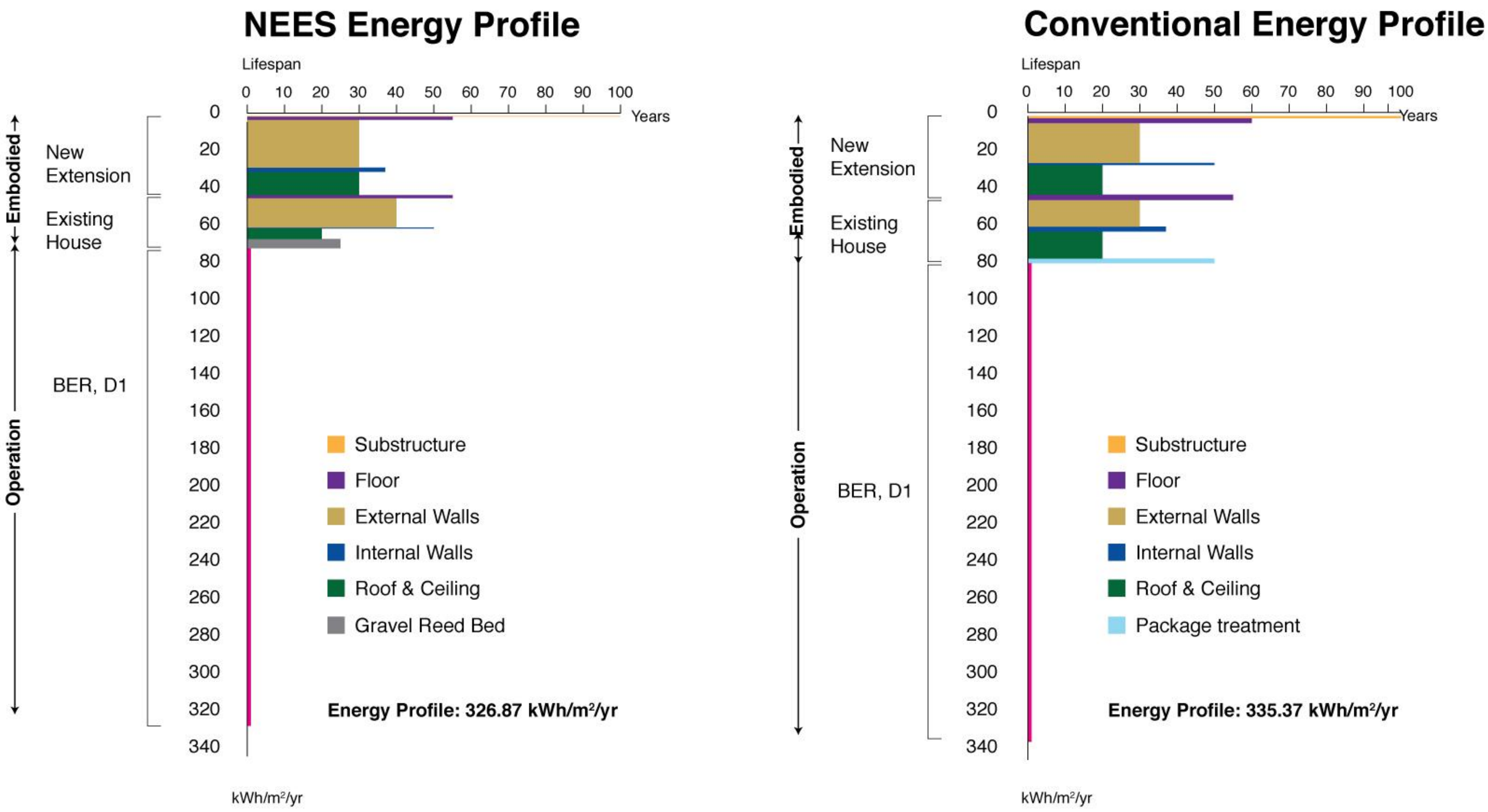

Figure 4-2: Energy Profiles

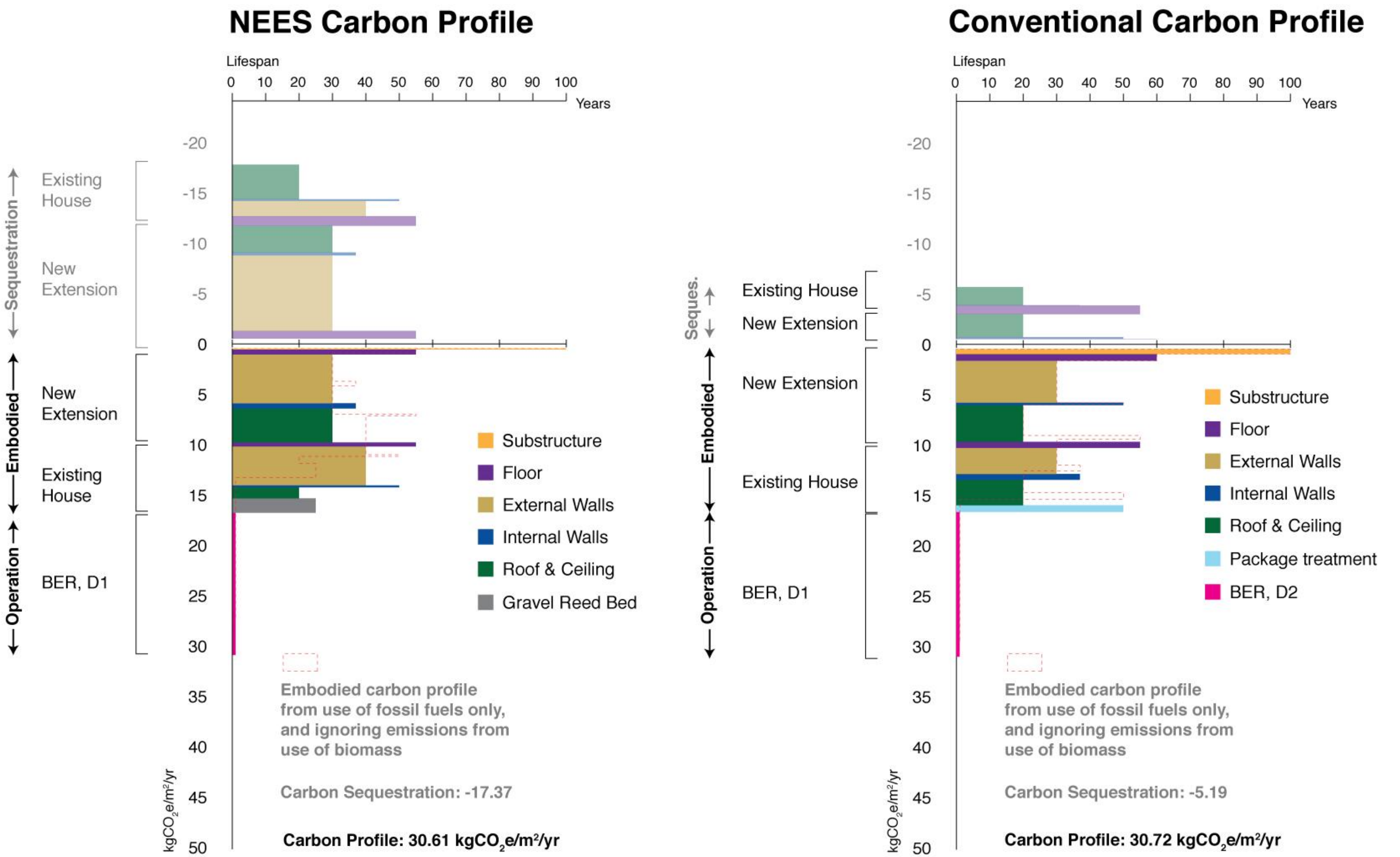

Figure 4-3: Carbon Profiles

4.4 NEES BEST PRACTICE COMPARISONS

Both the 100 year Life Cycle Assessment in section 0 and the profiles above give slightly different interpretations of the environmental impact of the NEES design against a conventional build. Table 4-4-1 below compares each of the six NEES best practices against the materials that would otherwise be needed in the conventional build.

1. Timber frame: it is not surprising that the timber frame has a lower mass than an equivalent blockwork and concrete structure. What might surprise some is that the embodied energy is somewhat higher. This is because the embodied energy per unit mass of timber is over 15 times that of 100mm blockwork (see embodied energy factors in Appendix I)
2. Hempcrete: one would expect hempcrete to have more mass, but as so much has been made of the sequestration potential of hemp shiv, why does it have higher mass and higher emissions than cement render, 40mm PIR insulation and plasterboard? The high energy and emission associated with hempcrete result from the high factors in Appendix I which in turn result primarily from the use of binders (lime and cement) and a significant transportation burden. Carbon sequestration and even carbonation of lime has been included in generating these energy and emission factors, but so too has the energy consumption and emissions arising from hemp shiv production (i.e. fertiliser, N_2O fertiliser emissions to atmosphere, farm machinery fuel, fibre processing and transport to processing plant)
3. Cellulose insulation has higher mass than petrochemical based insulations, but it also has significantly lower embodied energy and emissions. Additionally it is locally produced only 30km from the site.
4. The triple glazing comparison is straight from the factors listed in Appendix I and the wooden frames have significantly lower emissions and embodied energy than their PVC equivalents. The lifespan of hardwood window frames is also better (40 years typical lifespan as against 30 years for PVC [4])
5. The green roof is considered an add on, and therefore increases in mass, energy and emissions are expected. As the sedum blanket and soil medium are relatively thin (say 125mm) any possible carbon fixing has been excluded. The benefits of a green roof go beyond the metrics used in this evaluation, e.g. aesthetics, biodiversity, urban cooling and Sustainable Drainage Systems (SuDS) all of which may be more beneficial in an urban environment, etc.
6. The gravel reed bed has a far larger mass burden than conventional wastewater treatment systems, but the comparable embodied energy and emissions are not significant. Again any possible carbon fixing has been excluded from this analysis. Surprisingly, while wetlands do provide for long term storage of carbon dioxide, they are also natural sources of greenhouse gas emissions, especially methane. Some landscape managers might consider wetlands to be sources of climate warming although recent studies have shown wetlands to be net carbon sinks.[25]

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[25] See for example: William J. Mitsch, Blanca Bernal, Amanda M. Nahlik, Ulo Mander, Li Zhang, Christopher J. Anderson , Sven E. Jørgensen, Hans Brix, *Wetlands, Carbon, and Climate change*, Received: 3 December 2011 / Accepted: 7 May 2012 Landscape Ecol DOI 10.1007/s10980-012-9758-8

Table 4-4-1: Comparison of NEES Best Practices against Conventional (100 Year Life Cycle)

	Mass (kg)	EE (MJ)	EC (Fossil) (kgCO2e)	EC (Biomass) (kgCO2e)	EC (Sequestr) (kgCO2e)	Conclusion on NEES Best Practice
1. Timber Frame						
NEES	19,000	168,283	6,896	5,839	- 21,665	Lower mass, higher EE, lower EC, especially if allowing for sequestration and ignoring biomass
Conventional	190,014	133,587	12,976	1,231	- 4,704	
2. Hempcrete						
NEES	24,800	110,861	12,462	-	- 8,111	Higher mass, higher energy, higher emissions even if allowing for carbon sequestration
Conventional	9,335	42,565	3,295	-	-	
3. Cellulose						
NEES	4,355	9,462	24	-	- 7,983	Higher mass, lower energy, lower emissions
Conventional	1,978	198,083	8,233	-	-	
4. Triple glazing with wood frames						
NEES	-	318,952	11,888	-	-	Lower energy, lower emissions
Conventional	-	424,642	27,435	-	-	
5. Green roof						
NEES	9,183	57,080	4,651	-	-	Higher mass, energy & emissions as it is an add on
Conventional	-	-	-	-	-	
6. Reed bed						
NEES	290,049	65,544	5,486	-	-	Higher mass, slightly higher energy, slightly lower emissions
Conventional	126,199	64,600	5,848	-	-	
Totals						
NEES	347,387	730,182	41,406	5,839	- 37,759	Higher mass (because of reed bed), lower energy, lower emission, especially so if sequestration counted and biomass ignored
Conventional	327,525	863,477	57,787	1,231	- 4,704	
% of NEES total	92%	73%	75%	43%	58%	
% of Conv total	98%	81%	83%	30%	29%	
Grand totals*						
NEES	375,618	1,006,528	55,075	13,477	- 65,144	
Conventional	333,054	1,063,948	69,993	4,132	- 16,439	

* includes cradle-to-gate, construction waste, transport to site, end-of-life & maintenance, wastewater operation; excludes installation and building operation as these are regarded to be the same

4.5 A FEW OTHER QUESTIONS

What is the environmental value of retaining the existing cottage walls, despite other reasons for conserving historic fabric?

			Cradle-to-gate		Transport		Avoided	
If replaced, would need:	Volume (m^3)	Mass (kg)	EE (MJ)	EC ($kgCO_2e$)	EE (MJ)	EC ($kgCO_2e$)	EE (MJ)	EC ($kgCO_2e$)
Mass concrete strip foundations (800x600 mass concrete x 30m)	14.4	33,120	25,834	3,743	829	70	26,662	3,813
Blockwork walls (2no. 100mm skins x 77m^2)	15.4	24,943	15,716	1,785	4,492	381	20,208	2,166
Stainless steel wall ties (4/m^2 built in)	-	33	1,851	213	6	0	1,857	213
Total	**29.8**	**58,096**	**43,400**	**5,740**	**5,326**	**452**	**48,727**	**6,192**

What is the carbon footprint of transporting the Western Red Cedar cladding from Vancouver?

Calculation Step	**Qty**	**Source**
Western red cedar (m3)	4.69	Origin, Vancouver
Density (kg/m3)	380	http://www.engineeringtoolbox.com/wood-density-d_40.html
WR cedar (kg)	1,784	
Nautical miles	8,390	via Panama Canal, http://www.sea-distances.org/
Kilometres (km)	15,538	http://www.digitaldutch.com/unitconverter/
tonne.km	27,715	
Conversion factor	0.01315	General cargo ship, average emissions (DEFRA)
Additional kgCO2e	**364.5**	

5 CONCLUSIONS

Savings

Table 5-1 below summarises the building results from section 3 with regard to mass, embodied energy, embodied carbon and cost. The 100 year LCA savings are shown against the cradle-to-gate savings for comparison.

Table 5-1: Summary Mass, Energy, Carbon and Cost Saving Comparison for Building

Building Comparison	Cradle-to-Gate				100yr LCA
	NEES	Conventional	Saving	%	% Saving
Mass (tonnes)	57	157	100	64%	59%
Embodied Energy (GJ)	581.4	630.3	49	8%	1%
Embodied Carbon (tCO_2e)					
Fossil & biomass	36.6	37.1	0.5	1.4%	
Fossil only	27.8	34.3	6.5	19%	8%
Fossil, biomass & sequestration	-6.8	26.1	32.9	126%	
Fossil & sequestration	-15.6	23.4	38.9	167%	
Cost (€)	€ 72,422	€ 80,000	€ 7.5k	9.5%	
Labour (man days)	179.2	224.2	45	20%	

Based on the assumptions detailed in this report, the material cradle-to-gate savings from the NEES specification compared against the conventional specification are:

- 64% in mass
- 8% in embodied energy
- 1.4% in carbon emissions (including biomass emissions as it is not clear that timber is from sustainable sources, and excluding positive effect of carbon sequestration)
- a possible 20% in labour/man days, which is principally due to the greater ease of construction resulting from use of timber frame construction (i.e. less use of teleporter to carry heavy blockwork materials, less excavation for larger foundations, quicker erection of timber frame as against conventional blockwork construction).

LCA versus Carbon Profiling

The Cloyne demonstration project has been evaluated on a life cycle basis (tender requirement) and with a second technique called carbon profiling (not a tender requirement, but provided as it is perhaps a better method for illustrating the relative merits of carbon assets against the typical lifespans of different building elements). Both methodologies give a slightly different perception of the proportion of embodied energy and carbon in the building project.

	LCA		Environmental Profiles	
	NEES	Conventional	NEES	Conventional
Embodied Energy	11.3%	11.9%	21%	24%
Embodied Carbon	30.4%	36.1%	53%	54%

Broad Conclusion

In considering the title of the project – Natural Energy Efficient and Sustainable – the broad conclusion to the demonstrator project as against a conventional build is that:

- Yes, the building is more natural
- No, the building is not energy efficient, as it has a low BER rating
- Yes, the building is arguably more 'sustainable' as:
    - People: it attempts to generate jobs locally
    - Planet: it has lower carbon emissions
    - Profit: the cost analysis seems to indicate that the NEES costs are lower than the conventional. In terms of contributing more to the local economy, further consideration is needed to source materials that are required by the NEES best practices more locally

Perhaps a more appropriate title would have been – Natural Low Carbon and Sustainable.

5.1 CONSIDERATION OF THE GREEN PRINCIPLES OF BUILDING

While the terms of the evaluation of the Cloyne NEES project do not include examination of the application of the green building principles outlined in section 1.3 in equal depth, it does focus closely on the impacts of design and specification decisions on energy efficiency, embodied carbon and energy, and biohazard sufficiently to allow a tentative response relating to the adherence of principles *a* to *h* below:

a) *To make the buildings as energy efficient as possible to minimise the use of fossil fuel;*
Response: although attention has been paid to make the U-values of the building fabric low, the NEES demonstration project cannot be considered to be energy efficient as it has a low BER rating. The heating system can, however, be considered low-carbon. DEAP bases its energy value calculations on primary energy consumed, regardless of the fuel type being biomass or fossil fuels.

b) *To design the building to act passively, absorbing energy from the sun, ventilating naturally and allowing the insulated fabric and thermal mass to work effectively;*
Response: NEES specification is well considered in this respect.

c) *To put the building on the site in a way that acts in harmony with the landscape and setting and minimizes disruption to the ecosystem;*
Response: NEES specification is well considered in this respect.

d) *To take responsibility for all the upstream and downstream impacts of the decisions*
Response: The NEES specification needs more work in this respect, for example, by requesting chain of custody certificates for timber products, and specifying Irish grown hardwoods instead of Iroko for window frames.

e) *To minimise water usage and waste*
Response: No data provided on water usage, but the wastewater has been considered with respect to gravel reed beds. Most of the demolition waste is being retained on site for landscaping and to reduce export to landfill.

f) *To select building materials and methods that are low energy and minimise resource depletion*
Response: This NEES demonstration project generally achieves lower energy and lower resource depletion (mass) generally. However, some areas need more careful consideration, e.g. the hempcrete mix has a higher mass, embodied energy and embodied emissions than the conventional equivalent. Perhaps, a lower energy hempcrete mix could be specified with more careful consideration.

g) *To avoid the use of materials and methods that cause pollution*
Response: This NEES demonstration project appears to have considered this aspect somewhat, with some strong input from the client.

h) *To select materials that do not damage the health of manufacturing workers, building workers, building occupants and wildlife.*
Response: This NEES demonstration project appears to have considered this aspect somewhat, with some strong input from the client.

5.2 PUTTING NUMBERS INTO PERSPECTIVE

Mass

The NEES building (57 tonnes) is three times lighter than the conventional (157 tonnes), saving 100 tonnes. The gravel reed bed, however, was double or some 71 tonnes heavier than a conventional wastewater treatment system.

Figure 5-1: Suzuki Swift GL, kerb weight = 1,005 kg or 1 tonne

Embodied Energy Saving

The NEES building made an energy saving of 49 GJ or 13.6 MWh which equates to 1,452 litres of petrol. 1,452 litres of petrol would fill the above car's 42 litre tank over 34 times, and based on a fuel economy of 5.5 litres/100km would travel 26,400km – about two years of motoring.

Embodied Carbon Saving

The NEES building saved 6.52 tCO_2e as against the conventional build (fossil fuel emissions only). This is equivalent to combusting 2,770 litres of petrol / 66 Suzuki Swift fills / 50,363 km of motoring.

5.3 RECOMMENDATIONS FOR FURTHER STUDY

This study has raised a number of areas that could be considered further:

1) **Hempcrete mixes:** there are no doubt many different ways to mix hempcrete, but can materials be sourced more locally to reduce the transport burden (transport represent 27% embodied energy and 18% embodied emissions, Appendix IV)? Can alternative lower energy and lower carbon binders be used to reduce the burden placed by lime and OPC? It has been assumed that the hemp is grown as a monoculture from where it is sourced in France – Appendix X illustrates the dramatic differences of how hemp is cultivated will impact on embodied energy and emissions – can hemp be cultivated in such a way to reduce its environmental impact?
2) **Thermal mass and thermal inertia (diffusivity):** it has been pointed out, particularly in relation to hempcrete, that U-values which are the thermal metric used in a BER analysis may be an unfair metric for which to compare against petrochemical based insulation products.
3) **FSC/PEFC chain of custody certificates:** the focus on specification should be as a leveraging tool for positive change. It is also possible to get project chain of custody certification that might put less pressure on local suppliers.
4) **Environmental Product Declarations (EPD):** Likewise, making it standard practice to ask all suppliers for EPDs and to collate them is good practice. Most suppliers will not have these, but they are the most transparent method of communicating the environmental impacts of products. If the NEES partners wish to assist manufacturers, they might consider helping produce studies for which to better market lower carbon building products.

KEY REFERENCES

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   [KBOB – Coordinating Group of Building and Property elements executed by awarding authority
   eco bau – organisation for sustainable building in public sector
   IPB – Aggregation of interest in private professional Contractors]

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