409: Crossing Tresholds

A Zero Energy Demonstration House in Ireland

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Abstract

This paper presents a case study of the iLEEiD research and demonstration house, which is targeted to be one of Irelands first Zero Energy house. The house is currently under construction and due for completion in October 2008.

The design philosophy behind the project attempts to integrate two often divergent schools within the environmental buildings movement, notably ultra low energy design and environmental impacts of materials.

A particular focus of the study is to explore the threshold where ultra low energy design mandates a shift and transition to low impact materials, including low embodied energy and embodied carbon, with implications for the envelope design, material specification and construction in particular.

This study includes a comparative analysis of embodied energy and embodied carbon for an experimental wall build up, examined against traditional cavity wall construction methods across a range of required U values / energy targets.

In addition to demonstrating the technical possibility of achieving Zero net Energy it is hoped this project will provide useful data and stimulate debate concerning the need to move to an integrated and holistic sustainability paradigm in building design and construction.

Keywords:
Zero Energy, Zero Carbon, Demonstration House, Integrated Design, Low Energy and Environmental Impact, Passive, Renewables, Embodied Energy, Embodied Carbon, Carbon Sequestration, Green Materials, Bio Composite Construction.

1. Introduction

The environmental buildings movement represents a diversity of interests and agendas. One area of greatest divergence seems to be between the schools of low energy (in-use) design and the 'green' materials camp, the latter focused on wider environmental impacts.

National legislation in many European countries and certainly in Ireland and the UK has in general focused primarily on energy in use.

Voluntary standards however have developed in both spheres with some focusing on energy in use exclusively, for example the German Passive Haus Institute (PHI) standard [1] and others, such as the various environmental preference methods have a wider scope including broader environmental aspects.

However recent trends in building regulations in Ireland and the UK indicate that the prioritisation of legislation toward energy in use is now changing, with UK building regulation compliance moving to primarily a carbon emission basis (albeit from energy in use) [2], the Irish one including both energy and carbon, [3], and the UK now setting a strategic target to achieve Zero Carbon homes by 2016. [4]
More recently the UK have integrated an development of the BRE Eco Homes environmental assessment method into their national building regulations, via the UK Code for Sustainable Homes [5], which heralds a major shift in mandatory legislation from energy in use to wider environmental impacts such as toxicity, recycling, water use, transport, etc.

On a European scale we are seeing the impacts of the EPBD (Energy Performance of Building Directive) [6] and there is increasing political support for a European Directive on the German Passiv Haus Institut (PHI) standard becoming mandatory across Europe by 2015. [7]

As EU and National Legislation drives house design to increasingly low energy consumption, via either Passive or Zero Carbon strategies, are we crossing a threshold where embodied energy and material environmental impact should now be integrated into a single design philosophy? Is this feasible?

Is the gap between energy in use and the green materials agenda now closing?

2. Achieving Zero net Energy

2.1 Design Strategy

The strategy for achieving Zero net Energy in the iLEEiD house (Integrated Low Energy and Environmental Impact Design) is based on achieving PHI Passive standards of ultra low space heating demand coupled with specification of integrated technologies, both energy efficiency and renewable.

The overall target is to reduce the total annual demand of the house, (including appliances and cooking) to circa 6500 - 7000 kWh/yr (delivered energy) and to meet this via an all electrical solution provided on site by renewable solar PV and Wind energy.

Figure 1 shows the total annual energy loads and carbon emissions for the Zero net Energy House calculated under the Irish national energy rating calculation method, Dwellings Energy Assessment Procedure (DEAP) [8], benchmarked against various recent revisions to Irish building regulations and the Passive Haus Specification [1] measured in DEAP.

The chart shows the significant reduction in space heating demand from building regulations to PHI passive standard, and the iLEEiD ultra low energy demand, the delivered energy of which can be met by circa 6500 kWh/yr of electrical renewable provision, thus achieving Zero net Energy. Note the DEAP calculation excludes appliances and cooking and so an estimation of these loads has been made.

2.2 Beyond passive.

The house design incorporates PHI principles of passive solar gain, super insulation, air-tightness, MVHR (Mechanical Ventilation with Heat Recovery) and is targeted to exceed the PHI space heating target of 15 kWh/m2/yr, which reduces the space heating demand considerably.

However the total primary energy target within the PHI framework of 120kWh/m2/yr was felt to be too generious in terms of renewable energy provision and more challenging targets for reduction of hot water, electrical loads, lighting, appliances and cooking have been set.

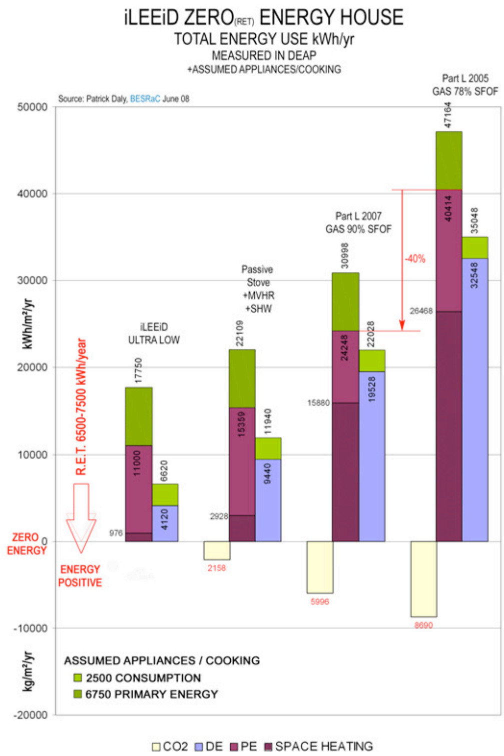

Fig 1 showing total annual energy loads (primary and delivered) and carbon emissions measured in DEAP compared against Passive and National Building Regulations. Note assumed appliance and cooking load.
Source Patrick Daly BESRaC June 2008

2.3 All Electric - Integrated Services

The energy strategy for the house is an all electric solution, which was considered optimal for a zero energy house, considering the ultra low space heat demand, the 100% efficiency of electric integrated systems, the specification of heat pump / MVHR (Mechanical Ventilation systems with Heat Recovery) and the overall compatibility with electrical generating renewables.

Hot water demand is targeted to be met by 50-60% solar hot water system on an annual basis with the balance to be met by ground sourced heat pump (GSHP).

The hot water system is planned to be integrated with the MVHR system in terms of providing a heating coil to the air supply. The MVHR will incorporate a low energy fan and 85% heat recovery. Air pre heat is to be provided by sub soil heat exchanger for winter night use and from PV array in daytime.

Secondary back up heating will be provided by a small wood stove. Lighting will be ultra low energy with intelligent controls and sensors. Appliances will be ultra low rated.

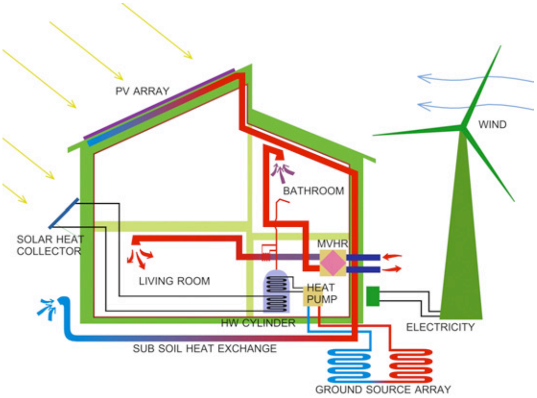

Fig 2 showing integrated energy efficiency and renewable energy all electric solutions. MVHR, SHW, GSHP, PV Wind.
Source Patrick Daly BESRaC June 2008

2.4 Electrical RET Generation
The reduced loads of the house as calculated in DEAP will require circa 6500 to 7000 kWh/yr and it is envisaged to meet this by a combination of on site PV and Wind.

The south elevation of the house has capacity and planning to install a 70 sq m array and planning permission is currently being sought for a 2.5 – 3 kWe wind turbine and mast.

3. A low Embodied Energy / Carbon Wall

3.1 In Use Versus Embodied
Studies have in general indicated that embodied energy (EE) is a relatively small fraction of the total lifetime building energy, which is dominated by energy in use. However such studies have tended to be conducted on conventional buildings.

A study undertaken by the BRE in 1991 indicated that for a typical UK building regulation compliant 3 bedroom semi detatched house the EE over a 60 year life span would account to circa 10% of the Energy in Use (EIU), however for a low energy house this could rise to 50%. [9]

The indication is that as we move toward Passive, Zero Carbon and ultra low energy in use buildings, the issue of embodied energy becomes a more significant proportion of the total life time energy load and may need to be given greater priority in design strategies.

Importantly as we move to zero energy in use, the sphere of embodied energy could become the primary area of remaining energy reduction.

3.2 The iLEEiD experimental wall
The design of the iLEEiD house includes an experimental research wall, which amongst a range of issues includes the prioritisation of low embodied energy and low embodied carbon materials.

An analysis was made of the embodied energy (EE) and embodied carbon (EC) for the following range of wall constructions based on traditional masonry cavity wall constructions for different energy in use standards and compared with the iLEEiD carbon based wall for the Zero Energy house.

a) Part L 2005: Wall U Value 0.27 [W/m^2 K]
A traditional double leaf masonry block wall with the cavity partially filled with 80 mm PIR insulation.

b) Part L 2007 Wall U Value 0.18 [W/m^2 K]
A traditional double leaf masonry block wall with a wider cavity partially filled with 120mm PIR insulation

c) PHI Passive Wall U Value 0.15 [W/m^2 K]
A traditional double leaf masonry wide cavity with expanded polystyrene insulation and an inner leaf of aerated block.

d) iLEEiD Ultra Low Wall U Value 0.1 [W/m^2 K]

i) A traditional double leaf masonry with wide cavity fully filled with expanded polystyrene insulation beads with 200mm inner leaf of aerated block.

ii) iLEEiD Low Carbon / Embodied Energy Wall
Timber frame wall construction dominated by carbon based renewable materials.
Lime rendered wood wool slab cladding board, on battens, on breathable boarding on structural studs with hemp quilt insulation with inner stud and 200mm of lime hemp bio-composite mix to inner face.

There is no national data based for embodied energy / carbon of construction materials in Ireland and data was drawn in general from the UK (ICE) Inventory of Carbon & Energy [10] with reference to Bjorn Berge Ecology of Building Materials [11] and the CAT Whole House Book publication [12].

Figure 3 indicates the embodied energy (EE) and embodied carbon (EC) output of each of these constructions for a range of U Values and total energy targets compared against the iLEEiD wall for the Ultra Low energy target. (Note wall tie variations were ignored in the EE and EC study)

The graph show increasing EE and EC output due to increasing insulation levels for different U Value and energy reductions. Notably the iLEEiD wall has significantly lower EE and EC the most advanced U Values for Ultra low energy targets.

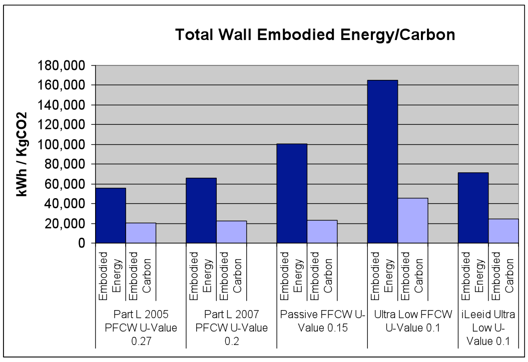

Fig 3 showing total WALL embodied energy for range of U Value / Wall Constructions / energy targets . Note: EE and EC for Ultra Low House with Low Carbon Wall is significantly less than traditional equivalent for the same U Value and Ultra low energy target. Source Patrick Daly BESRaC June 2008

3.3 EE EC Comparative Analysis

The study shows a significant increase in both embodied energy and carbon for the conventional constructions to achieve the ultra low energy demand, equating to a near twofold increase in EE from a u value of 0.27 [W/m^2 K] to achieve a u value of 0.1 [W/m^2 K] or a 196% increase, with a 127% increase in embodied carbon emissions.

Critically the iLEEiD carbon based wall has a significantly lower embodied energy and carbon value while achieving the same u Value and overall energy target.

The traditional construction values for the ultra low demand being 164,750 kWh of EE and 45,750 kg Co2 (45 Tonnes) of EC compared to 71,250 kWh and 24,200 kg Co2 (24 Tonnes), respectively for the iLEEiD low carbon wall, being effectively a 50% reduction.

While similar reductions may not be translatable to the roof or ground constructions, the study indicates that total material embodied energy / carbon reductions of 30% to 40%, for wall, floor, roof, could be achievable.

3.4 EIU and EE 50 year Life Time Study

Fig 4 i) and ii) show the total energy in use over 50 years compared to wall embodied energy for each of the constructions / energy targets.

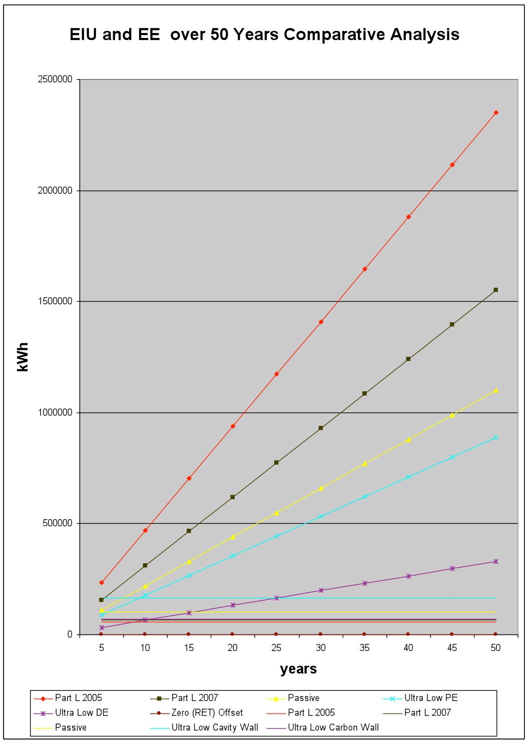

Fig 4 i) showing total energy in use and WALL embodied energy over 50 years (primary) for range of energy targets as presented in Fig 4ii). Note: EE for Ultra Low House with Low Carbon Wall is 50% less than traditional equivalent. Source Patrick Daly BESRaC June 2008

For traditional constructions at 2005 and 2007 building regulations standards the wall embodied energy is a minor proportion at 2% and 4 % respectively. Even for Passive standard the wall embodied energy proportion is only 9%, however for the ultra low demand house it increases to 18% and in proportion to its delivered energy the wall embodied energy would be to 50%.

If total wall roof and floor embodied energy were considered, it most likely will match or surpass the total 50 year delivered energy consumption of the Ultra Low energy iLEEiD house.

For Ultra Low energy houses this would indicate that the principle area of remaining energy saving could be in the materials.

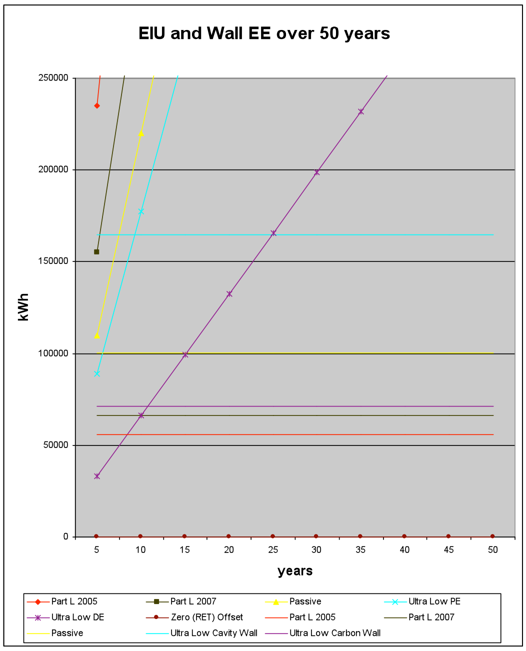

Fig 4 ii) showing large scale of EE results from Fig 4i) highlighting variation and comparison in Wall embodied energy in relation to U Values achieved.
Note the Ultra Low Carbon Wall (purple) has less EE than the passive wall (yellow) with poorer U Values and also than its equivalent conventional construction wall (blue) at same U Value.
Source Authour June 08

3.5 Renewable Offset.

To assess the potential for renewables to offset the embodied energy a study was made to compare the time and loads required to offset the wall embodied energy loads for both the traditional construction and the iLEEiD low carbon construction within the ultra low energy target.

This indicated that if the house were to manufacture an energy surplus of 1000 kWh/yr it would take 164 years to offset the wall embodied energy of the traditional construction or an annual surplus of 3295 kWh would need to be generated to offset it within 50 years.

For the low carbon wall construction a renewable surplus of 1000 kWh/yr would offset the wall embodied energy in 74 years or an annual surplus of 1425 kWh/yr would be required to offset within 50 years.

Given that the total possible embodied energy of construction materials and indeed the systems would be significantly greater, the limitation of renewable offset is clearly evident.

4. Environmental Impacts

4.1 Broader design influences

In addition to the low carbon and low embodied energy strategy in material and construction solutions the design strategy has favoured materials of lower environmental impact and these tend to co-relate with renewable organic materials and a low carbon and embodied energy consideration. Environmental considerations included:

Resource Availability and Reserve
Pollution indices
Process resource consumption e.g. Water Use

4.2 Carbon Sequestration

Embodied carbon figures are primarily derived from the energy in use in processing the material from cradle to site and ignore carbon sequestered in the material.

It may be that carbon sequestered in the construction will significantly further offset the reduced embodied carbon in the iLEEiD wall and roof construction. It is intended to undertaken an assessment of the carbon sequestration of the above ground construction in the future, to assess if the design can achieve carbon positive.

5 Conclusion

As legislative, market, and social / environmental forces drive house design toward passive and ultra low energy solutions, increasing amounts of material are required to effect that strategy and oftentimes the embodied energy is increased.

This study has shown that there are thresholds where the relative importance of embodied energy and embodied carbon increases as we achieve lower in use energy consumption. Indeed the sphere of embodied energy can be significant or even the primary area of energy reduction, as in the case of ultra low and zero energy housing over a 50 year life span.

In such cases strategies to reduce EE and EC can have significant carbon and energy reductions. The probability of further carbon displacement via the sequestration capability of the material needs further exploration, and could be an area of further environmental impact reduction.

6. Limitation and Further Research

The study was limited in its scope in focusing on the wall component and in selecting a 50 year life span. A 75 or 100 year life span would reduce the relative importance, however the principle would remain the same for an ultra low and Zero net energy house.

In addition a more holistic assessment including the increasing embodied energy of the entire construction and also the increasing systems could alter the balance and relationship between EE and EIU over building lifetimes.

While there is some data in relation to EE and EC and lifecycle assessment of Renewable Systems, there are few studies examining these in an overall holistic building EE and EC study. Such a study is envisaged.

Data in relation to Lime Hemp materials was limited and had to be complied from a range of sources and embodied carbon had to be assessed from nearest equivalent materials. However the value ranges were not critical to the overall indication of the results.

Further research is envisaged to be carried out in the area of carbon sequestration, values of which are currently limited.

In addition to materials analysis the project has already provided comparative analysis of the Irish national DEAP energy rating software with the voluntary PHI PHPP Software.

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