The Leechwell Garden House

A passive solar dwelling built from renewable materials

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ABSTRACT: This paper describes the design of the Leechwell Garden House, a proposed low carbon dwelling that addresses both the issues of the energy used in the running of the house, and the embodied energy in the materials used in its construction. This design follows on from the Totnes House, an existing award winning straw bale and timber house that performs as well as buildings built to the most stringent contemporary standards (Passivhaus, Code for Sustainable Homes) despite facing northeast [1]. The Leechwell Garden House will build on the lessons learnt from the design and monitoring of Totnes House to produce a comfortable dwelling that will use less energy in use than any comparable house whilst having a greatly reduced the carbon debt from its construction materials.

Keywords: Eco-house, Straw-bale, Embodied energy, Building design.

1. INTRODUCTION

This planet has a steadily rising population [2] that is currently dependent on the hitherto cheap and abundant energy provided by fossil fuels; coal, gas and most importantly, oil [3, 4].

The increasing use of fossil fuels as a primary energy source has resulted in rising levels of carbon dioxide in the atmosphere [5]. The levels of atmospheric carbon, along with other greenhouse gasses, are contributing to a measurable rise in global atmospheric temperature which in turn is the source of anomalous variations in weather patterns known as 'Climate Change'.

If it is accepted that these changes are based on human behaviour, then by changing our behaviour it may be possible to ameliorate, if not reverse, the worst effects of climate change [6].

The construction industry has an important role to play in the reduction of atmospheric carbon as is clear from the following United Kingdom statistics. The first is the fact that in 2009, 27.5% of final energy consumption in the United Kingdom (UK) came from domestic dwellings [3] and that 10% of the total energy used in this country is embodied in construction materials [7].

It is clear from these statistics that the materials and methods used to build houses in the UK and the rest of the world have a significant effect on the environment.

In the UK, the government has introduced a range of policies to reduce the emissions from buildings with the expressed aim of making all new domestic dwellings 'zero carbon' by 2016. The leading policy is the 'Code for Sustainable Homes', which proposes a system of incremental improvements to move from level one to six where six represents a 'zero carbon' dwelling [8]. There are many problems with this scheme, but one of the main concerns is that the focus is on lowering the energy used during the lifetime of new buildings. Less emphasis is placed on the embodied energy of the materials used in the building envelope and the additional technologies (such as mechanical heat recovery) that are a requirement under the code and can also significantly increase the embodied energy of a house built to the highest level of the code (code level six).

The less energy a building uses during its lifetime, then the higher proportion of its carbon debt will be in the materials used. There is therefore an increasing awareness of an imperative for architects and designers of low energy houses to take into account the embodied energy and the origin of their construction materials [9].

2. EMBODIED ENERGY IN CONSTRUCTION

2.1. Importance of Embodied Energy

The table below explains why the amount of embodied energy that goes into a domestic dwelling is of increasing importance if it is looked at as a percentage of the primary energy use of a building over a sixty-year lifespan.

Table 1: Relationship between the embodied and heating energy in a selection of different dwellings of the same size.

Theoretical 120m^2 House	Housing stock	Current new build	Passivhaus/ CHS 6 house	Straw House
Embodied Energy (MWh)[9]	100	100	120	10
Annual Heat Energy (MWh)	30	13	3	3
Heat Energy used over 60 years	1,800	792	180	180
Total Energy Use (Embodied plus Heat)	1,900	892	300	190
Embodied Energy as percentage of total	5%	11%	40%	5%

(The amount of embodied energy in any building will vary. The figures are representative, and are used to argue the principle, not to demonstrate actual case studies)

There is an argument that an increase in embodied energy is justified if it results in an overall reduction in energy used, and the figures below bear that out. The extra embodied energy involved in building a Code for Sustainable Homes Level Six (CSH 6) house has resulted in a significantly lower total energy use. But looking the embodied energy as a percentage of the total then forty percent of the carbon debt of that building over sixty years is tied up in the fabric. A dwelling built with timber and straw as the principal materials, and avoiding the use of other high energy materials where possible could perform to the same standards as the CSH 6 house [10] but with a further reduction in total energy use, and the percentage of the total taken up in the embodied energy of the fabric is reduced to 5%.

2.2. Use of Straw Bales in Construction

For the Architect or designer/builder looking to reduce the energy impact of their constructions a group of materials of increasing prominence with low embodied energy is that of renewable materials or “Non-Food Crops”, such as straw, hemp-shiv, flax, reed, jute and sisal [11]. Of these, it is straw in the form of straw bales that will be discussed as part of a low energy build strategy in this paper.

The use of straw bales in construction started in the wheat producing states of America at the end of the nineteenth century after the mechanical baling machine was introduced in the 1890’s [12]. First used to make temporary structures as protection from the weather in places where timber was scarce, the idea of using straw bales to build more permanent houses became popular as more people appreciated the combination of low cost, quick construction and high insulation [13]. The popularity of straw bales as a building material started to decline after the nineteen twenties, until the energy crisis of the 1970’s produced a desire to create more energy efficient housing, which has become more focused with current environmental concerns.

The use of straw bales in construction can reduce the embodied carbon of a building, as well as reducing primary energy needs, and therefore operational carbon emissions. The low embodied carbon stems from the fact that the straw bales are a co-product of the growing of food crops and despite increases in the uses found for the 9.5 million tonnes produced annually in the UK [14], there is normally a surplus. The crop from which the straw is derived will have absorbed carbon dioxide through photosynthesis [15]. This makes straw bales not just carbon neutral, but carbon negative. The low U-value achieved by a straw bale wall (typically 0.17 W/m^2K from a thickness of 450-500 mm) [16] contributes to a low primary heat energy needed by providing a high level of insulation.

A straw bale wall is conventionally finished on both sides with a 30 mm layer of render, and this tradition has the effect of producing a self supporting structure that combines high levels of insulation with a quantity of thermal mass that has the ability to ameliorate the peaks and troughs of the heat load.

A straw bale wall both reduces and smoothes the heat energy needed by the building.

The Leechwell garden house will demonstrate that by combining straw bale walls with a design that maximises passive solar gains, a building can comfortably exceed the UK governments definition of ‘zero carbon’ without the additional technologies that can add to the embodied energy of the building.

3. THE TOTNES HOUSE

3.1. Principles of Design

The design and structure of the Leechwell Garden House are based on an existing house built by the author in 2005 in the south west of the UK, known as the Totnes House (Fig. 1).

Figure 1: The Totnes House

The Totnes House was designed to avoid the use of construction materials with a high embodied energy content, such as cement. This decision also influenced the sourcing of the chosen construction materials, attempting to obtain them as close as possible to the site in order to cut down on transport energy and potentially to support the local economy. It was therefore decided to use timber for the building’s structural frame, straw bales for the external walls, loose sheep’s wool for insulation and lime based renders for exterior and internal wall coverings.

The structure of the Totnes House was built around a traditional large section post and beam frame supported on minimal foundations, with an insulating wall of straw bales wrapped around the outside.

In terms of the primary energy use of the house, one of the main drawbacks was the orientation of the site. The house sits on the side of a hill and has a significant amount of glazing facing northeast to make best use of the outlook.

The inevitable losses through this northeast glazing are counteracted by using clerestory lights between the roof pitches facing southeast, and a fully glazed south facing sun space.

3.2. Monitoring of the Totnes House

Despite the less than optimal orientation the Totnes House performs very well in terms of its primary energy use.

In March 2006 a full Standard Assessment Procedure (SAP) was performed on the house using software called SuperHeat 5.1 (no longer available).

The calculations gave a SAP rating of 108 and a carbon index of 9.0 with a calculated space heating requirement of 6,758 kWh.

The energy use of the house has been monitored since completion, and in a typical year the actual space-heating requirement is just 3,975 kWh (2008/2009), equivalent to 19.48 kWh/m^2. This is a significant reduction on the designed value despite maintaining average internal winter temperatures of 20.19ºC (day and night).

There are two possible reasons for this

1. The SAP calculation software couldn't account for the gains through the sun space
2. The combination of the high heat capacity of the render, with the low thermal transmittance of the straw in the walls, performs better than the U value alone would suggest.

The Primary energy use of the Totnes House can be compared to average figures from existing building stock and the energy use allowed under the two current standards mentioned, CSH 6 and Passivhaus (Fig. 2).

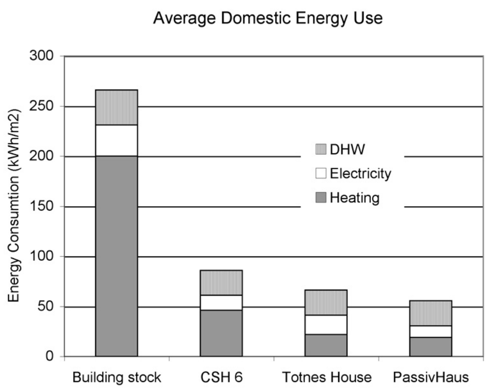

Figure 2: Primary energy use of Totnes House compared to current standards. (Figures for CSH and PassivHaus are from published standard, Totnes house is recorded data)

As can be seen in the chart above, The Totnes House uses less energy than the CSH 6 house, and only slightly more than the Passivhaus.

In addition to the theoretical comparisons shown in Fig. 2, the total primary energy use of the Totnes House for 2008/2009 can be compared to two existing high profile low energy developments: The BedZED housing project in Surrey, UK, and the Kingspan Lighthouse at the BRE innovations park, Watford UK [17]:

Totnes House	83 kWh/m^2
BedZED*	82 kWh/m^2
Kingspan Lighthouse**	87 kWh/m^2

*The result from BedZED is an average of the actual use from 56 dwellings in the project

**The result from the Lighthouse is from the design data for energy consumption.

The conclusion that can be drawn from the results shown above is that despite facing northeast, the Totnes House compares favourably with current low energy designs, both in terms of design data and actual use, but with significantly lower embodied energy and build cost.

The Leechwell Garden House, with the additional passive gains from its south facing orientation, should comfortably exceed all the current standards.

3.3. Differences between the two houses

The single most important difference between the proposed Leechwell Garden House (Fig. 3) and the Totnes House is the orientation, as has already been discussed.

There are other differences; In the Totnes House the beams that support the first floor cantilever out of the frame to support the walls. This creates a thermal bridge through the insulation, the effects of which have been recorded using thermographic imaging. In the Leechwell Garden House the straw bale walls will run continuously from the ground to the roof.

In addition to the sun space, the new house will have more direct glazing on the ground floor of the south elevation. This glazing is shaded from the high summer sun by an external matrix of parallel timbers, but the lower winter sun will be able to shine in and provide additional heat energy during the heating season.

4. LEECHWELL GARDEN HOUSE

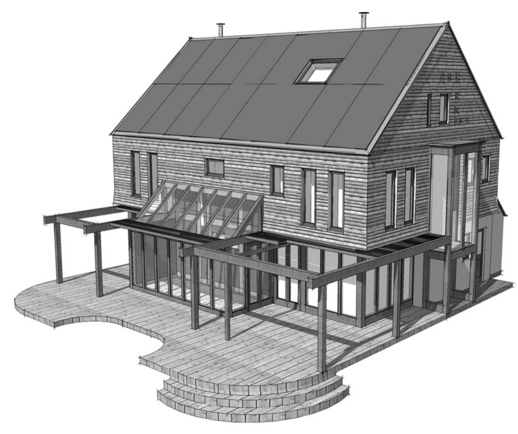

Figure 3: 3D model of Leechwell Garden House

4.1. Design Principles

The Leechwell Garden House is designed to be straightforward and affordable to build. The building has a gable ended, rectilinear form with a projecting sun space and timber gazebo on the south elevation. The ground floor of the south elevation consists of a direct glazed timber frame, with the gazebo carrying the summer shading elements for the glazing.

The south facing roof slope will be made up of building-integrated, combined photo-voltaic and solar thermal panels (BIPV-T) [18]. The area of this roof (70 m^2) is more than enough to accommodate sufficient BIPV-T panels to supply all the annual electricity and DHW needs of the house [19].

4.2. Role of the sun space

The double glazed, south facing, sun space is critical to the best use of passive solar gains in this house, and in doing so it serves two functions:

1. To preserve the energy from the sun in a high mass wall acting as a diurnal heat store.
2. To pre heat the ventilation air for the building.

Because the double glazing preserves the heat energy of the sun by trapping longer wavelength radiation behind the glass, this energy can be stored in a object that has a high mass (greater heat storage capacity) [20]. This stored heat energy will be re-radiated as the surrounding temperature drops. In the case of this house the high mass element is a wall made from recycled bricks that divides the sun space from the rest of the house.

The sunspace has a sloping roof that is open at each end. This allows the outside air to move by convection up under the glass roof absorbing heat as it rises. This air passes into the interior of the house to provide pre warmed fresh air to replace exhaust air that has been extracted from the kitchen and bathrooms through a passive stack ventilation system [21].

This is an example of where an entirely passive system designed into the structure of the house can fulfil the same role as the additional technology specified under CSH 6 and Passivhaus. In this case, the sun space replicates the role of the mechanical heat recovery (MHRV) system specified as part of the Passivhaus standard. An MHRV system relies on a perfectly airtight construction and consumes energy in use, as well as having embodied energy in its fabrication. It is arguable that a MHRV system could be more reliable than the heat from the sun for a proportion of days in winter.

4.3. Wall construction

The simplified wall section (Fig. 4) shows the main components and principles behind the structural elements of the house.

In order to minimise the use of cement and concrete, the load bearing components of the house will be supported on dense foamed glass blocks [22]. These blocks take the place of concrete footings and reduce the thermal bridging that is difficult to avoid at the perimeter of the foundation.

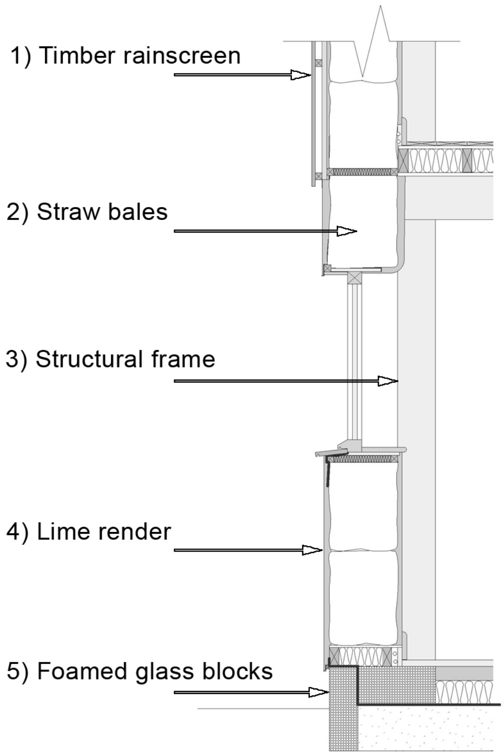

Figure 4: Typical wall section for Leechwell Garden House

The straw bale walls are largely independent of the structural frame in order to increase the thermal separation, but they are connected to the frame by a small section timber ‘ladder’ laid horizontally in the wall on every second course of bales (Fig. 5). One of the drawbacks with a rendered straw bale wall is the difficulty of finding fixing points once the structure is finished. This ladder provides a consistent fixing point at a known height from the floor both inside and outside.

Figure 5: Timber ladder laid on every second course of bales

4.4. Reducing the volume of materials

The main structure of the Totnes house was a large section post and beam frame. This is a beautiful, traditional method, but the frame is made up of a number of single pieces of timber (up to 200 x 250 mm in section), and is not the most efficient use of this resource.

There is an argument that says that locally sourced timber is essentially carbon negative, in that it has sequestered more carbon through photosynthesis than is used during the processing and transport of it [23]. It follows then that the greater mass of timber that you use in a building then the lower the carbon footprint of the building will be. This is an erroneous argument as all resources are limited and although timber is renewable there is an increasing demand for it as a structural material.

In the design of the Leechwell Garden House it was decided to use engineered timber elements in the structural frame and floors. The use of smaller sections of lower grade softwood in engineered timber elements such as the Lignatur floor cassettes and glulam beams specified in the frame, combined with the increased strength of these elements will result in a far lower number of trees being felled than were for the Totnes House. The Lignatur floor cassettes (Fig. 6) will span up to 7m between the bays of the frame, allowing for a reduction in the number of frame sections from 6 to 4.

Figure 6. Lignatur floor cassette [24]

5. CONCLUSION

The experience of designing and monitoring the Totnes House has informed the design of the new house. The Leechwell Garden House has the advantage of a southerly orientation and will demonstrate that a well designed south facing building can have a minimal space heating requirement without the complexity of complete air tightness and mechanical heat recovery ventilation systems.

It has been demonstrated that it is essential for Architects and Designers of low energy houses to take account the embodied energy and the origin of their construction materials. The Leechwell Garden House has the potential to outperform existing low energy designs whilst still having a minimal constructional carbon debt.

6. ACKNOWLEDGEMENTS

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