

DEVELOPING AN ECONOMIC LED APPROACH TO ZERO CARBON HOUSING DESIGN THROUGH INTEGRATION AND SUBSTITUTION OF TRADITIONAL BUILDING MATERIALS

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Abstract

Zero carbon homes have met with mixed reactions from key stakeholders within the housing and energy sectors, with many bespoke zero carbon designs being rejected as commercially unviable. This paper draws on research conducted with The University of Surrey and Zedfactory Architects to outline key factors which should be considered in order to facilitate the adoption of a more commercialised approach to zero carbon design. Key design criteria for zero carbon homes are outlined before presenting a housing model designed to provide the best balance between the financial, technical and social elements involved. The paper then demonstrates the importance of reducing the additional costs associated with zero carbon design through integrating energy efficiency and generation technologies into the building fabric; by substituting the use of traditional building materials with energy generating ones it is possible to create both an energy and economically efficient housing model. The proposed energy system adopts an integrated approach to the selection of space heating, water heating and ventilation technologies in order to create a design that is as user friendly as possible. By adopting this approach it is argued that it is possible to develop a model which does not require major changes in household behaviour patterns to work. The paper also highlights the importance of carefully balancing energy production and exportation to grid connected sources to develop a zero carbon home that can substantially reduce the financial burdens of rising energy costs.

Keywords: Sustainable Building Design, Renewable Technologies

1. Commercial Viability of Zero Carbon Homes: An Introduction to the Design Challenge

Zero carbon homes have been met with mixed reactions by key stakeholders within the housing and energy sectors, with many bespoke zero carbon designs being rejected as commercially unviable. This is characterised by bespoke zero carbon homes failing to progress beyond the boundaries of innovation parks such as those at the 'Building Research Establishment (BRE) Innovation Park' in the UK. This paper develops a methodology for designing zero carbon homes for commercialisation based on incorporating key socio-technical, economic and political factors at the design stage. The design philosophy attempts to address key barriers in order to minimise potential hurdles to commercialisation whilst also utilising key political drivers.

Commercialised zero carbon designs require changes to current housing construction methods and it is essential these factors are taken into account at the design stage. As well as methodological changes to building design there are also fundamental changes required within the political, economic and socio-technical environment that surrounds the housing industry. Changes to areas such as building practices, the relationships with energy supply and consumption, changes to the relationships between consumers and energy supply companies, and an appreciation of how finance and economics affects the buying behaviour of property owners are all important considerations. There are also critical consumer considerations to take into account such as changes to the aesthetics of houses, user practice changes for zero carbon living, cultural habits and social practice changes (Lee 2011; Roy et al 2007). These create distinct design challenges for architects and designers to address if commercialised zero carbon homes are to be successfully developed.

The initial design challenge for those involved with zero carbon housing is what the definition of a zero carbon home should actually be. This is a field open to some debate and in the UK the choice is between the easier to meet regulatory definition or a more holistic definition, with the definition adopted substantially altering the design parameters. The UK regulations will only account for the 'as built' building services loads; these are only the loads covered within the building regulations such as lighting and heating, however, they will exclude the unregulated emissions from appliances such as cookers, televisions and computers (HM Treasury & BIS 2011; The Zero Carbon Hub 2011). By designing under these parameters it calls into question the appropriateness of this regulated definition. Whilst it is arguably easier and more cost effective for commercial actors to design to these standards it is questionable whether this weaker standard will make a significant contribution to UK's 2050 CO₂ reduction targets. This is supported by estimations that unregulated emissions account for approximately a third of total emissions and as such a zero carbon home under regulatory parameters will still be allowed to emit around a tonne of CO₂ per annum (The Zero Carbon Hub 2011). With an estimated 2 million additional homes required in the UK by 2016, this regulatory standard would still create an additional 2 million tonnes of CO₂ annually (The Select Committee on Environmental Audit Twelfth Report; Zero Carbon Hub 2011).

The regulatory responses to such polarised viewpoints seem to be favouring industry based concerns surrounding maintaining housing volume and affordable housing levels, however, to create a new

build housing stock that can effectively decarbonise the sector a harder line is required. A design philosophy that incorporates the offsetting of the total annual carbon emissions associated with total energy consumption from both regulated and unregulated sources should therefore be adopted as the standard for zero carbon design. This paper argues that by adopting an innovative holistic approach to critical socio-technical, economic and political factors it is actually possible to create economically viable zero carbon homes that meet this stricter criteria. At the same time it will also be possible to protect consumers from potential economic crises such as energy price related fuel poverty. As such the approach advocated here is based on offsetting total annual energy consumption with renewable energy generation using grid connected microgeneration technologies (Dunster, Simmons and Gilbert 2007). It is acknowledged that meeting these design parameters requires importing from the grid during times of poor renewable generation and exporting to the grid during times of over production, however, over the course of a year a zero carbon home should be designed to balance its entire energy loads (Dunster, Simmons and Gilbert 2007).

2. The Role of Incorporating Policy Drivers within a Design Philosophy

Innovations commonly face cost based barriers and inhibitive payback periods preventing their successful commercialisation (Keegan et al 2007). In recognition of this and in UK governmental responses to supra-national energy policy such as the 'EU Renewables Directive 2009', key political developments have focused on improving the investment potential of renewables. As such an understanding of how to leverage policy instruments to improve the commercial viability of zero carbon design has been developed. By conducting a policy analysis of subsidies for energy technologies for zero carbon design, a key tool for offsetting the cost of renewable technologies has emerged from this research. Incorporating tariff eligible technologies into the energy system creates the potential to develop price justifications for additional expenditure and address potentially inhibitive payback periods (Jager 2005; Massini and Menicheti 2010). Research has shown that the cost of creating zero carbon homes ranges from £400 to over £800 per m² more than current building regulation homes (Cyril Sweet 2007, Code for Sustainable Homes 2010). If these additional costs can be matched through ongoing returns from tariff payments the potential to stimulate demand for widespread uptake could therefore be greater (Jager 2005; Massini and Menicheti 2010).

2.1 The Role of Addressing Barriers to Commercialisation in Zero Carbon Design

It is critical to develop an understanding of commercial barriers when developing a commercially viable design philosophy. Industry analysts predominantly oppose zero carbon design on the grounds of affordability and consider the decarbonisation of the housing stock as constraining new build construction volumes by increasing cost, risk, and skill based issues (Select Committee on Environmental Audit 2008; Architects journal 2008; Goodier and Pan 2010; Ball 2010). In the UK the commercial house building market represents the largest market segment, at around 75% of the total annual market, and can therefore be considered as the most influential actor group within the house building regime (Calcutt 2007; Welling 2006).

Perhaps the most consistent commercial barriers centre on cost based objections (Goodier and Pan 2010; Ball 2010). As zero carbon homes involve increased material and technology costs this is problematic as zero carbon design is inherently more expensive. As such overcoming key cost based barriers will require innovative solutions and lateral thinking in order to reduce expenditure and justify additional expense. The table below details the results of a cost comparison of zero carbon homes in the UK.

Table 1 UK Build Costs for Zero Carbon Homes

| Project | Costs Per m2 |
|--|--------------|
| Building regulations | £ 1,070 |
| Bere Architects Code 6 | £ 1,700 |
| Miller Zero Aircrete house | £ 1,608 |
| Miller House Merton Rise | £ 1,423 |
| Kingspan Lighthouse | £ 1,938 |
| Source: Cyrill Sweet 2007, Code for Sustainable Homes 2010; Bere Architects 2010, Miller Zero Homes 2010, Kingspan 2009) | |

It is important to acknowledge that these are demonstration projects and as such have not benefited from the cost benefits that scale production can bring, however, the reasons why the properties have not broken into the commercial market significantly contribute to this. One such issue is the current lack of established sales values for zero carbon homes and the effect this has on whether or not a sufficient market premium can be commanded. In the UK this is compounded firstly by the way modern methods of construction are poorly understood by the banking sectors and secondly due to the lack of appreciation given to the economic benefits a zero carbon home can bring (Zero Carbon Hub 2009). As such housing valuations have resulted in lower mortgage offers made for higher capital cost zero carbon homes. This is created by the valuation system not fully accounting for the financial benefits of low carbon technologies and unjustly penalising innovative designs for perceived maintenance issues and technological unknowns (Zero Carbon Hub 2009). Whilst education in the sector will be key to addressing this it is also implicit that for zero carbon homes to diffuse into current market practices, the amount of technologies employed to decarbonise the home must be minimised and standardised in order to give financial actors greater confidence in the reliability and usability.

A second key issue is that energy efficiency and low carbon living are just two factors that encompass a range of purchase decisions for housing (CABE 2005; RICs 2010). Whilst these factors are moving up the list of decision factors there is an inherent limit to the impact they can have on demand for a higher priced home (CABE 2005; RICs 2010). Without a premium for a zero carbon home, commercial roll-outs will be unlikely as zero carbon designs will be the least profitable option. This firmly emphasises the need for cost reduction to be a priority design element incorporated at the design stage.

A third issue stems from perceptions of consumer willingness to adopt designs which require user practice changes to energy service provision. Before embarking on large scale zero carbon housing projects it is essential for commercial actors to take into account the level of consumer demand within

the marketplace, however, there are significant commercial concerns regarding demand side variables. Unfortunately, in the UK the resistance to technologies that require significant user practice change is considered high (Castell 2010). If the market is thus limited the investment required to instigate a commercial roll-out of zero carbon homes is unlikely. To widen the market potential beyond green motivated consumers the impact that technological innovations have on established user practices need to be minimised.

The combination of these commercial barriers also has the effect of increasing risk factors for commercial actors. It creates a situation where higher construction cost homes potentially offer lower profitability, whilst the market demand is un-established. This creates such a significant risk factor that commercial viability will continue to be questioned until the first projects are completed to prove otherwise. Unfortunately, in a risk adverse market in an economic downturn this is unlikely to occur. As such it is up to the designers to attempt to reduce the impacts of these barriers though considered and intelligent design and thus attempt to establish more commercially viable options.

2.2 An Integrated Design Philosophy for Zero Carbon Homes

Based on this research it was identified that there are 4 key requirements when developing a design philosophy for a zero carbon home. Firstly, a zero carbon home should offset the entire annual energy load of the building via grid connected microgeneration technologies to make maximum impact and investment return. Secondly, cost reduction should take priority when designing to achieve this. The methodology for assessing cost reduction is based on offsetting the additional 'over and above costs' of creating a zero carbon home when compared against a benchmark cost of a building regulations home. This is based on the methodology used in the Sir Cyril Sweet Report (2007). Thirdly tariff eligible technologies should be utilised where possible in order to generate an income and thus offset the additional costs of zero carbon design. Finally, technologies required to create the zero carbon home should be minimised in order to reduce both costs and the requirement for user practice change.

Whilst it is acknowledged that decarbonisation can be achieved using community led energy systems, a microgeneration led approach was adopted in the design philosophy for this study. This was in order to develop properties that did not rely on community based infrastructure projects and thus remove the associated complex legal, financial and managerial arrangements required for community led energy service companies. A microgeneration led approach was also preferred in order to develop zero carbon homes that could function on a single unit basis and that generated investment returns for individual property owners. A detached 4 bedroom home with a gross internal area of 150 m² was chosen as the basis for comparison. Detached properties constitute 22% of the UK housing market (Housing and Planning Statistics 2009). A market analysis of the best available microgeneration technologies was conducted in order to identify the costs involved with different market leading technologies.

Economic modelling was conducted using various combinations of best available technologies in order to develop a valid technical base for comparison. By establishing what was technologically possible and then developing a housing design based on it, it was possible to work out the cost and economic parameters, such as implementation costs, build costs, running costs and cash flows for a

variety of technically viable options. Input-output modelling was conducted based on energy losses, energy usage, energy production from key microgenerating technologies and energy reduction from key energy efficiency technologies. This was used to verify that the designs developed were technically viable based on commercially available niche technologies. These technologies were then combined to create holistic energy platforms for the zero carbon design. Once a selection of technically viable solutions were identified and a range of integrated options developed, a full cost based analysis was conducted into each potential option. Options included technology platforms based on varying combinations of PV, biomass boilers, wood burning stoves with back boilers, air and ground source heat pumps, passive and mechanical heat recovery ventilation systems and thermal stores.

3. Developing the Design Model

3.1 Reducing Cost Barriers: An Integrated Approach to Energy Generation and Material Substitution

When the design philosophy is applied to the building fabric of the property it must balance the need to reduce base heating loads with the need to reduce costs. To achieve this the property was designed with a timber balloon frame using a wall build up of 15mm cement board, 75 x 200mm C16 studs at 600mm centres with 200mm mineral wool in between, 15mm oriented strand board, 50x 100mm C16 battens at 450mm centres with 100mm mineral wool insulation in between, breather paper and 25 x 38mm battens at 400mm centres with 15mm cement board and render. The combined 300mm of insulation enabled low wall U-values to be created at low cost. Combined U-values of $0.13\text{W}/\text{m}^2/\text{k}$ were achieved at 300mm insulation thickness. In combination to reducing thermal demand via insulation, terracotta thermally massive blocks were included in the building design. The thermal mass was integrated into the exposed ceiling soffits in the ground floor ceiling. To reduce over and above costs, the thermal mass was used to substitute traditional flooring/ceiling materials and finishes with the thermally massive solution. The combination of timber frame design, thermal mass integration and insulation choice and interior fit out had a build cost of $\text{£}921/\text{m}^2$.

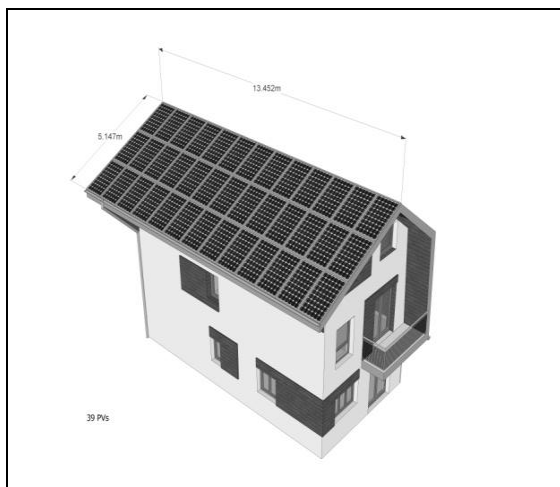


Image 1.1: Render of Building Design



Image 1.2: Elevations of Building design

The renewable energy technology analysis highlighted that photovoltaics were a cost effective choice for electricity generation. PV panels were chosen due to the ability to provide a solid return on investment via the FIT's scheme as well as having negligible user input requirements. However, it was identified that roof mounted PV and standard BIPV were not the most economical way to incorporate PV panels. This was due to the need to install a roofing build-up and then include PV panelling as an additional cost on top. Whilst the tariff income could provide a return on roof mounted PV it was not maximised for an over and above cost methodology. If a roof mounted PV solution was pursued, RHI eligible biomass and ground source heating technologies would have to be incorporated into the energy system design to further offset costs via tariffs. This reduces the integration of the system and increases the impact on user practice change by requiring both biomass and solar thermal technologies. Through conducting the technical-economic modelling for PV it showed that if the roofing substrate was replaced by PV it could be more cost effective. As such the PV panel was re-engineered to create an integrated electricity generating roofing tile that eliminated the need for a sub-roof. Internal and external images are detailed below.

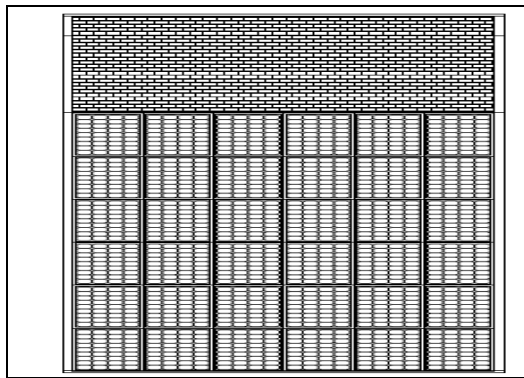


Image 1.3 External Plan of Integrated Roof

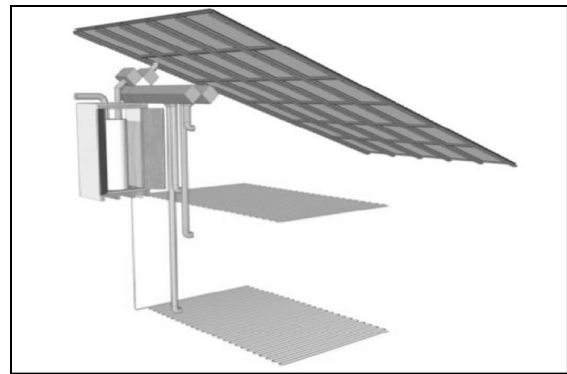


Image 1.4 Internal Image of Integrated PV Roof

According to calculations based on Langdon (2012) figures for roofing systems a roof occupying a similar space to that required for the energy generating roof would cost between £4,500 -£5,500 depending on roof type. This equates to around £83 per m². The cost of the PV roofing system equated to £170 per m² and thus the over and above cost to be justified was only £87 per m². For comparison a roof mounted system would add £100-£300 per m² on top of the build cost.

To integrate the PV panel into the roof involved engineering modifications to enable the conversion of a PV panel into a roofing substrate. The edge extrusions were reengineered to utilise an overlapping flashing cap to create a weather proof seal to the PV tiling system. EPDM seals and gaskets were used in the panel joints to increase the resistance to weather conditions, especially wind driven rain. A condensate drainage channel was also developed to allow the panels to be securely fastened to the rafters to protect against wind uplift. The roof has been tested to meet appropriate British standards.

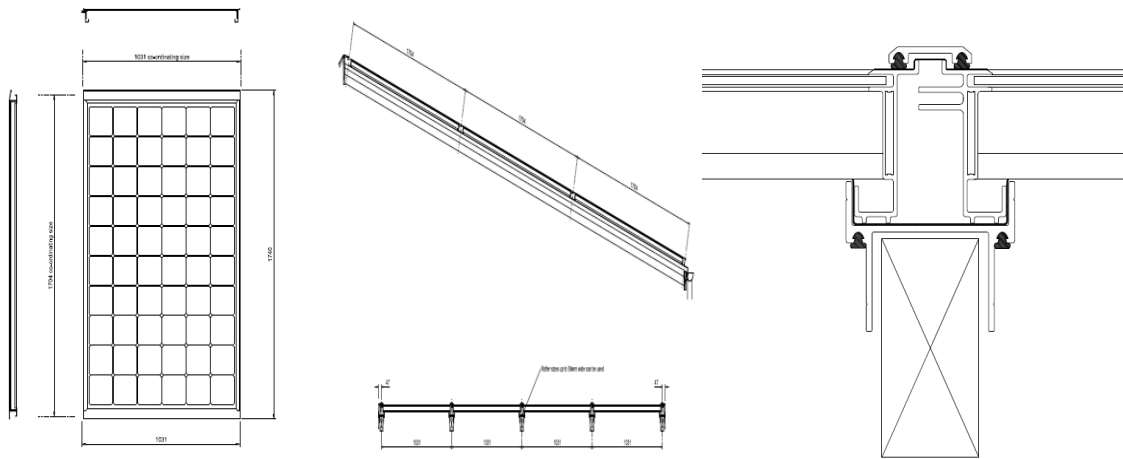


Figure 1.3: Integrated Roofing Panel and System Installation Details

The size of the PV system was 9kW. This was designed to offset the unregulated energy demand for in use building demands such as cooking and entertainment as well as for regulated space heating and hot water loads.

The reduction in costs for using an integrated PV roof allowed for a larger PV array to be incorporated more cost effectively. This meant that all energy systems could be electrified with the combined load offset. As such space heating and hot water requirements were satisfied using an integrated hot water cylinder with an exhaust air heat pump and under floor heating coils, illustrated in image 1.4. An engineering modification was made to the heat pump to allow a 'Mechanical Ventilation Heat Recovery (MVHR)' unit to be added to the heat pump. This system was designed to only use the parasitic load from the heat pumps fan and thus require no additional electrical load. As such the entire building heating and ventilation system was integrated into one unit. The design was also adapted to gain a passive energy gain for the heat pump by drawing air in from under the PV roof, using passive solar gain to preheat the fresh air supply to the exhaust air heat pump. The ventilation system was designed to provide 0.3-0.5 air changes per hour to meet building regulations and was 70% efficient at heat recovery. The modelled heat pump efficiency produced an average coefficient of performance of 3.5 due to the use of the preheated air and protection from negative external temperatures in the winter.

An additional benefit from the integration of these systems was that it reduced the amount of user controls and user practice changes required. The controls could be locked to provide water at 37 degrees to the heating circuit and 42 degrees to the taps to maintain maximum efficiency. This system provided the households total energy demand and effectively substituted all traditional heating systems from the property. As such the entire energy demand of the building was satisfied via the heat pump and PV platform without a requirement for natural gas or biomass. The table below shows the housing data inputs and the resulting energy balances.

Table 2: Housing Data and Energy Balances

| Housing Data and Energy Balances | | |
|--|--------|----------------|
| Gross Internal Floor Area (GIFA) | 150 | m ² |
| Area of Insulated Wall | 185 | m ² |
| Area of Glazing | 36 | m ² |
| Total Electrical Consumption | 7,444 | kWh |
| Ventilation Heat Loss (70% efficiency) | 463 | kWh |
| Total Heat Demand (Space and Hot Water for occupancy) | 12,289 | kWh |
| Annual Heat Surplus | - | kWh |
| Annual Electrical Surplus | 656 | kWh |

The total costs of the combined energy system for the zero carbon design was £19,187 however the over above costs, once allowances for the substitution of traditional materials was conducted was £10,187.

3.2 The Economic Viability of the Integrated Approach: A Net Benefits Model

To establish the economic net benefit of the design, energy balances were linked to tariff incomes derived from either FITS and/or predicted RHI returns where appropriate (accounting for inflation and predicted fuel price escalation). A compound annual growth rate of 3% was used for inflation and a compound annual growth rate of 6% was used for fuel price escalation. Fuel price escalation is predictive and subject to significant uncertainty but the mean average of Ofgem's (2011) 'Project Discovery' and DUKes (2010) was used. The model was projected forwards over 25 years to bound investment potential to the tariff period for the Solar FITS. This was due to the FITS period being the longest tariff period.

The economic model developed assumed that the extra capital costs for zero carbon design would be passed to the consumer. As the initial capital outlay is significant for the combined microgeneration platform, extended mortgage payments were assumed to be the finance method. As such the over and above mortgage costs were incorporated into the calculations for deriving an economic benefit. A mortgage rate of 5% was used over a typical 25 year mortgage period. The technical model was used to calculate the energy loss of the zero carbon design against energy losses of building regulations homes. This positive energy balance was capitalised based on the energy savings from the higher performing insulation and air tightness. Energy savings were calculated on 2012 energy costs for gas and electricity in the UK and termed avoided costs. The reduced energy demand for both regulated and unregulated energy loads were capitalised and an allowance made for the bought in energy requirement during times of low PV production as well as a cost saving for the PV produced electricity. The energy generated was then capitalised using the appropriate FITS rate. The totals were then summed and the over and above mortgage costs for the additional insulation and energy system components was then deducted. The annual net benefit was thus arrived at by capitalising energy flows, comparing energy costs, expenditures and tariff incomes of a Building regulations home to the Zero Carbon design. A further calculation was also made in order to see if removing avoided costs from equation could create a model that was effectively net of energy costs and self-funding. The table below shows the predicted cash flows for buildings commissioned in 2013.

Table 3: Cash flows Year 1(2013)

| Year 1 Figures(2013) | Photovoltaic system | Mineral Wool Insulation | Passive Heat Exchange Ventilation saving | ASHP | Summary Totals |
|--|---------------------|-------------------------|--|--------|----------------|
| Generated power (kWh) | 8,100 | N/A | N/A | 12,389 | |
| Energy Saved over Building Regulations | N/A | 1,135 | 1,081 | 3,540 | |
| Avoided cost | £ 43 | £ 6 | £ 6 | £ 29 | £ 84 |
| Income | £ 94 | £ - | £ - | £ - | £ 94 |
| Bought in Energy | -£ 20 | £ - | £ - | £ - | -£ 20 |
| Monthly Net Benefit | £ 118 | £ 6 | £ 6 | £ 29 | £ 158 |
| Monthly Income (excluding avoided cost) | £ 74 | £ - | £ - | £ - | £ 74 |
| Monthly Repayment | -£ 44 | -£ 9 | -£ 6 | -£ 6 | -£ 64 |
| Monthly Cash Flow | £ 30 | -£ 9 | -£ 6 | -£ 6 | £ 10 |
| Notes | | | | | |
| Electricity | 0.12 p/kWh | | | | |
| Tariff Information | 0.053 p/kWh | | | | |
| Delivered heat price at boiler efficiency(85%) | 0.062 p/kWh | | | | |
| FITS linked RPI increase | 3% | | | | |
| Price increase over inflation | 6% | | | | |

The outcomes of the economic model confirm that by substituting traditional building materials with energy generating ones and utilising tariff technologies in a cost effective manner it is possible to create an economically efficient zero carbon housing model. The outcome of the modelling demonstrated that the tariff incomes could offset the entire cost of developing a home to the most stringent zero carbon standard. The monthly profit of £10 excluding avoided cost benefits also confirmed that the over and above costs could be funded from the FITS income effectively making the energy production and efficiency package cost neutral. This is a key outcome as it could potentially facilitate an increase in sales price whilst not adversely impacting profitability as the over and above costs could be passed on to the consumer without negatively impacting them. Additionally the property owner would also benefit by being protected from energy price rises as the property would effectively be net of energy costs. The zero carbon housing model proposed here offers the potential for zero carbon homes to be the most economically viable homes to live in, however, the model does not account for affordability or the ability to obtain a higher mortgage.

4 Conclusion

Whilst it is possible to create technically viable zero carbon homes using a variety of different techniques creating homes with a potential to move beyond the bespoke level requires a broader set of design parameters. An appreciation of wide reaching commercial, socio-technical, political and economic issues is required in order to address key barriers to the widespread adoption early on in the design process. It has been demonstrated that zero carbon homes can be a more economical alternative to traditional builds, however, communications of the net benefits approach to potential consumers will be required in order to explain how a property with a higher build cost is actually cheaper to run in the long term. What this paper attempts to demonstrate is the importance of reducing the additional costs associated with zero carbon design through integrating energy efficiency and generation technologies into the building fabric and also by integrating technologies together; by doing so a more economic and user friendly housing design can be developed. It is acknowledged that the model may not fully address all the barriers to commercialisation but it does provide a solid basis for future research in this field.

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