TOWARDS ZERO-HEATING: AFFORDABLE MODELS FOR ENVIRONMENTALLY FRIENDLY HOUSING IN SCOTLAND

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The 'Zero Heating' home has been designed, built and monitored. The home is the end result of a major research programme aiming to produce radical new designs for more sustainable affordable housing in Scotland's rural areas. The precedents for housing with these kinds of aims have tended to be one-off, high cost designs, which have made environmental improvements at the expense of economic affordability. They are typically not replicable designs, which can be applied to a mass market for affordable housing. The 'Zero Heating' home, despite being a single, prototype house, aimed to deliver replicable improvements at an initial capital cost no greater than that of standard, low cost, 'spec-built' mass housing. The 'Zero Heating' home offers great possibilities for radical energy conservation and other environmental improvements in new housing. The house was monitored and evaluated to establish the building performance and the benefits to the environment of this type of home. The analysis of this home will also establish key recommendations for future evolutions in affordable housing for the mass housing market.

Keywords: affordable housing, passive solar design, sustainability, green design, performance evaluation.

INTRODUCTION

The research involves the culmination of three rural projects in the north east of Scotland, which have resulted in the design of the 'Zero Heating' family home as a means to producing affordable housing for the mass housing market. With the emphasis in current housing construction on density rather than environmental objectives, and a lack of expertise in planning, designing and building environmentally sensitive projects, there is a need for an affordable environmental design, which can be built to achieve short term and long term benefits.

An environmental design aims to have clear long term benefits over conventional designs, but it is generally assumed that there is a cost penalty to be paid during construction. The cost of environmental design for much of the affordable housing produced will fall on the developer, while the benefit will be gained by the home buyer. This has restricted development of affordable housing in much of the UK. This model for affordable housing offers the housing developer an alternative, with low capital costs comparable to conventional construction and with the usual long term benefits of environmental design, situated in a semi-urban environment. This paper describes the home and covers the research involved in its monitoring.

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STRUCTURE OF THE DOCUMENT

Recently there has been an increased awareness of issues affecting the environment and of energy as an issue and its excessive use in buildings as a problem. Numerous attempts have been made to create houses which demand much less energy than their ‘standard’ contemporaries. More recently this concern to produce radical, energy efficient buildings has expanded to incorporate a whole series of other aspects of an increasingly complex environmental agenda in a quest for what has come to be known as ‘sustainability’. There are many showcase developments around Europe that aim to fulfil the objectives of sustainability using various methods and such ‘cutting edge’ developments have followed, at a somewhat more sedate pace, by improvements in building standards demanded by legislation in the UK (Borer & Harris, 1998).

Many of these radical homes are as showcase developments, which employ all manner of state-of-the-art techniques, generally are expensive, prestige homes designed to demonstrate what is possible. The theory is generally that a trickle-down effect will ensure that the benefits ultimately reach a mass housing market. Where such one off, demonstration developments have been transferred, perhaps in a somewhat diluted form, into the more affordable mass housing market, it has generally been accepted by all concerned that there must be a cost penalty. In order to achieve reduced energy use, improved life cycle criteria and/or enhanced sustainability, there is assumed to be an inevitable capital cost increase, however modest.

The research by the authors provides a project which is a practical demonstration that this need not be the case. It has delivered very radical savings in energy use, together with other sustainable features, at an initial capital cost comparable to the most basic specification private sector housing by the volume builders. This has been achieved by adopting sound design principles and taking advantage of the inherent environment properties of a construction system developed to reduce material use and capital cost.

The specific aim of the design and construction project, built for a private client and completed in November 1999, was to reduce the need for dedicated heating plant to be as close as possible to zero in a simple, replicable design which could be applied, perhaps in modified form, to a mass market for affordable housing. The ‘Zero Heating’ home, as it is called, despite being a single, prototypical house, has succeeded in delivering these improvements at an initial capital cost no greater than that of standard, low cost, ‘spec built ’ mass housing.

Yet as well as resulting from a research commission (Edge & Pearson, 2000) the ‘Zero Heating’ home also encompasses a research project in itself. The Team is aware of the frequent criticism that supposed design innovations are very often not subjected to rigorous, quantitative testing. Even where assessments are made, they are too often restricted to measurements of theoretical performance at the design stage. In the case of the ‘Zero Heating’ home a comprehensive study, financed by Aberdeen City Council, G. Deveci Architects and the Robert Gordon University, delivered a life cycle analysis, a post occupancy evaluation and, crucially, a comprehensive, longitudinal environmental monitoring exercise of the building in use over two years.

THE DESIGN

Passive solar design

Passive solar design, a broad term for designing buildings that are orientated towards the equator to benefit from solar heat gains (at high latitudes), requiring to face approximately south in the northern hemisphere, is a holistic design method for *reducing* the need for non-renewable fuel (Kachadorian, 1997; Balcomb, 1992). It is unlikely that a solar heated home will make the heating system redundant, however, the aim of passive solar in this case is to reduce the energy dependency from non-renewable sources while promoting more reliance on renewable energies (DTI, 2000; DTI, 1999).

Beyond the issue of solar gain, passive solar design encompasses concepts such as thermal mass, air-tightness, super-insulation, green building construction, waste reduction, recyclable material, fuel and low embodied energy. Few other design approaches making full use of all these features. Where *all* these strategies are used the greatest savings in terms of heating and emissions are possible and an appropriately designed passive solar home can reduce heating costs by up to 70% and reduce emissions by similar proportions, thus benefiting both occupier and environment. The main advantage for affordable housing is that it is a free source of energy, with no direct cost for installation.

Low Impact Design

To be sustainable, some may claim that you should not build at all (Dunster & Williams, 2000). To be fully sustainable in building, careful selection of systems, technology and materials are required. In this design the aim is to be more sustainable, and to build a home that has low impact. With this in mind, the building incorporates a small footprint, open plan space and a habitable roof-space, which limits materials used when compared to a typical two-storey home.

In previous research projects, it was also an aim to offset the cost (to the environment) of building in some manner. For example, consideration of alternative methods of waste water management through the adoption of a reed bed is one option used in a previous project and considered for the zero-heating project. A number of problems, typical of the urban environment, restricted this philosophy. The site was restrictive in that it was small, a common problem in urban environments, and the soil type was not suitable for many environmental ideas put forward. It was imperative, therefore, to adopt an environmental design that restricted emissions as much as possible from non-renewable sources and that could, in future, adopt, for example, photovoltaics.

Affordable design

The authors have long been working to achieve affordable designs and the ‘Zero Heating’ home is the latest in a series of built designs, which are the result of an iterative research and design process. The ‘Zero Heating’ home is a timber framed, timber clad, detached house, using standardised components and incorporating a number of relatively simple technological innovations, used holistically. The principal aim of this design was to ensure that, as far as possible, all the heating needs of the house can be derived from passive solar and internal gains such as lighting, cooking, human body heat etc, thus eliminating the need for a central heating system.

The energy conserving specification therefore includes;

- Resource efficient, modular construction system restricted by grid and length of structural timber beams
- Super-insulation within the depth of structural timber “I” beams using recycled, newspaper insulation
- Passive solar design employing some thermal mass to smooth out diurnal temperature fluctuations
- Low-E triple glazing to optimise heat loss to heat gain ratio
- Closely controlled mechanical ventilation with heat recovery through extractor units
- Quality control of the construction process to guarantee optimum air-tightness
- Solar water heating through roof-mounted panels
- The use of sustainable materials, including locally produced, recycled and ‘waste’ materials.

Most aspects of the design are not conceptually new. Rather its originality lies in the conjunction of different innovations and the fact that they have not hitherto been used in the construction of housing in the UK. The main thrust of the idea for this building was the elimination of dedicated heating plant through the use of insulation 400mm thick in the roof, 300mm thick in the walls and 200mm thick in the concrete floor as the thermal mass. The ‘Zero Heating’ family home is built using timber ‘I’ beams, which are simultaneously quick to install and designed to be less expensive than traditional construction by spanning clear lengths without the secondary supports needed in trusses. Cutting and openings were carefully managed on-site to ensure as little waste from construction was possible. Glue used by the timber ‘I ’beams was also environmentally friendly and the construction uses a third less timber than its solid timber alternative. The crucial advantage of these ‘I’ beams, however, lies in their increased depth, which allows extremely deep insulation to be incorporated into the structure without any cost penalty in terms of additional structure. In a highly insulated building, ventilation and/or draughts become the most important source of heat loss and the design therefore incorporates an air-tight envelope and heat recovery in a mechanical ventilation system.

Externally, the building is clad in locally purchased Scottish larch cladding with clay tiles, both of which have expected life spans of around 60 years (Component Life Manual, 1992). Consideration of life cycle cost also included ultimate demolition and disposal and the cladding materials have some residual value.

The glazing is mostly south facing, with most of the north east and west glazing restricted. This allows daylight to enter on the south facade while reducing heat loss on the remaining facades. The windows are triple glazed, krypton filled units, roof lights are double glazed and low-E glass is used throughout. Research has found that glazing, in terms of total area, on a passive solar housing is similar to conventional homes being built in Scotland, therefore the cost of glazing between passive solar and conventional homes are remarkably similar. The main difference between passive solar and modern housing in Scotland is mainly through the orientation, where a passive solar home requires 60-70% of the total glazing to be orientated south.

The ventilation is highly controlled using mechanical units with heat recovery, which were tested in laboratory conditions.

The interior of the building is more open than conventional, cellular homes, which allows heat to circulate more effectively, employing the concept of ‘buffer zones’ or ‘comfort zones’ (Borer & Harris, 1998; Swann & Batty, 2000). Another innovation is the near elimination of dedicated circulation space by allowing all rooms to open off the central living space and balcony. As a consequence most of the interior space is two-storey, which allows light to flood in for long periods of the day.

In addition to the added insulation, passive solar design, thermal mass, mechanical heat recovery fans and triple glazing, solar panels were installed to aid the water heating of the house. A wood stove is also included in the central living space as a back-up during winter, though preliminary studies suggested that internal temperatures inside the house over the year should not fall below 14^{o}C, without the use of dedicated heating plant.

The specification also included environmentally friendly materials wherever possible. The environmental credentials include the fact that materials were locally sourced whenever possible, leading to lower embodied energy as well as, arguably, greater economic sustainability.

The ‘Zero Heating’ home is an affordable, replicable model for housing which can deliver very large environmental improvements at costs consistent with, or lower than, the cheapest housing currently on offer by our builders of mass housing. These results are achieved even for the one-off prototypical development carried out so far. Moving to greater standardisation and volume production offers potentially much higher savings and greater environmental benefits. Far from compromising architectural integrity, such standardisation can, it is argued, help to improve many aspects of our built environment. ‘Affordable’ ‘Mass’ housing need not result in the further proliferation of urban sprawl.

PERFORMANCE EVALUATION

Methodology

It has been a long established practice of research, by the team, to monitor closely each evolution of the concept of affordable environmental designs, in order to improve in future evolutions. There are three main strategies employed throughout each project and these were essential in providing short and long term affordability in future housing. The ‘Zero Heating’ home was the latest home to undergo this methodology, which covers the following three areas:

- Life Cycle Cost Analysis
- Energy audit
- Post Occupancy Evaluation

The Life Cycle Analysis

Whilst the design of the ‘Zero Heating’ home applied a series of generally accepted principles of good, environmentally sensitive design it would have been inappropriate merely to assume the levels of benefits arising from this design. Indeed the building design professions and the construction industry generally have often been criticised for a lack of measurement and 'benchmarking' of achievements (DETR, 1999). A key factor in producing innovative affordable housing in particular is ensuring that capital savings are not secured at the expense of higher life cycle costs. There are obvious life cycle advantages to the 'Zero Heating' home in terms of energy use, but these need to be set against the maintenance profile. The Research Team therefore carried out a desk study of the life cycle costs of the design, using computer based techniques developed by a team of researchers at Robert Gordon and Salford Universities (Kishk, 2000).

The life cycle cost study assessed the capital, maintenance, running, operation and eventual disposal costs of the house through its life cycle, as well as modelling theoretical energy running costs. The study was carried out using the best available, industry standard information. A sensitivity analysis was carried out to ensure its robustness in the face of a wide range of possible future scenarios (Kirk & Dell'Isola, 1995, Bull, 1993). Life cycle costing was used for two separate purposes, these were:

- Life cycle costing was used as a tool for the selection and specification of building elements and materials prior and during construction. Importantly, the study was carried out iteratively with the design process with, for example, conclusions about the maintenance profile of materials informing design decisions. Life cycle is a key element in establishing long term as well as short term affordability.
- Life cycle costing was also used as a tool to ascertain recommendations for future evolutions of the design concept. After completion, a further life cycle study was used to analyse three alternatives: the 'Zero Heating' home; a design of the same form as the 'Zero Heating' home but with conventional materials for Aberdeenshire and insulation to building regulation standards; an 'off the shelf' standard design of approximately the same size by a local developer.

The Team was anxious to ensure that the life-cycle study helped to optimise the design. For example, the optimum reduction in cost over the life cycle for fabric insulation occurs between 300-450mm. Consequently the 'Zero Heating' family home has 300mm of insulation in the walls and 400mm of insulation in the roof. Life-cycle information is thereby used intelligently in the design process, rather than merely in a post-facto justification process.

The building life cycle was assumed to be sixty years, a conventional assumption for this kind of study (Ashworth, 1997, Ashworth, 1996). A variety of cladding materials, including Scottish larch, softwood, concrete block and render, brick and metal cladding were assessed over the stipulated life cycle. These results challenge conventional thinking about the 'temporary' nature of timber as a cladding material and are confirmed by many examples in the north of Scotland. Environmentally friendliness, local sourcing, affordability and LCC analysis were the key components in the selection of these materials to ensure short and long term benefits.

In its primary aim of reducing heating costs the 'Zero Heating' home succeeds in reducing annual heating costs by 74% over current 'standard' housing designed in accordance with modern building regulations. The most striking feature of the design is its ability to save on heating bills, with a SAP (standard assessment procedure) rating of +120.

The level of embodied energy in building materials is found by calculating all the resources used throughout the building material's life. This includes the provision of raw material, processing and manufacture into building products, provision of recycled materials, transport and packaging, construction and maintenance, and demolition. It may also include the calculation of heat loss, provision of fuel and electricity generation where appropriate.

Over the life cycle of a building, the CO_2 emissions are also an important consideration for any design. The 'Zero Heating' home exhausts considerably less CO_2 emissions every year than its nearest alternative through the use of no fossil fuel heating. The use of a wood burning stove was also chosen for the renewable nature of the biomass fuel, thus reducing CO_2 emissions almost to zero. Notably, the achievement of lower emissions is not at the cost of additional CO_2 in the construction. All the building materials for the project were previously risk assessed for their embodied energy during the building materials life, though it should be noted that the quality of the available information on this is relatively poor. With the lack of a central heating system the theoretical CO_2 emissions were drastically reduced down less than one tonne per year. The comparable figures for the standard housing in the north east of Scotland were 4 to 6 tonnes per year, the 'Zero Heating' home therefore performs several times better.

Environmental Monitoring and Evaluation

A crucial aspect of the research project was the confirmation, as far as possible, of theoretical performance with the reality of the building's use. This is important for the three following reasons

- To confirm the quality of the design
- To compare with the validity of the desk study assessment methods
- To provide recommendations for future evolutions of the design concept

The environmental monitoring took place over a period of 24 months and included both the coldest part of an Aberdeen winter and some of the warmest periods in the summer. Temperature and humidity sensors were placed in various locations throughout the home and external temperature readings were also taken. Sensors were linked to 'Squirrel' data loggers and the longitudinal data downloaded periodically. Energy use was also monitored over the period. An initial assessment of the quality of insulation was also carried out using a thermal imaging camera.

By and large the results confirm the desk studies and the precepts of the design. The internal climate during the period of analysis fulfils the entire requirements for creating a healthy home. Areas where the 'Zero Heating' family home succeeds are as follows;

- Provide good daylight and sunlight
- Insulate well to provide thermal comfort
- Air-tight construction which avoids draughts
- Uses well-insulated, air-tight construction to avoid condensation
- Vents pollutants & excess moisture at source
- Has plenty of open-able windows

- Easily understood secondary heating element, which is radiant, and uses bio-mass fuel

For external daily temperatures averaging above 5^{o}C, the secondary heating element (wood stove) is not required to heat the building. The 'Zero Heating' family home maintains temperatures for each day at an average of between 17 to 18^{o}C through passive solar design, internal gains and a well-insulated structure. When the external daily temperature averages below 5^{o}C the secondary heating element is required to burn for 2-3 hours which will then heat the house for around 24 hours before requiring heating again. During the period the desk studies were confirmed as accurate in predicting the potential savings of around 70% over standard housing in Scotland. This is for space heating only.

The average temperature at night is 16.5^{o}C and the average temperature during the day is 17.75^{o}C for the living areas. In the evenings, when the building is fully occupied, the average temperature (until midnight) was between 18.5^{o}C and 20^{o}C.

Internal humidity falls within the recommended comfort zones. All rooms range between 41 to 49%. It is hypothesised that humidity is controlled by the highly hygroscopic materials specified (such as timber, cellulose insulation, etc) and by removing excess moisture at source in the bathroom and kitchen.

With two fans operating, the mechanical ventilation could achieve an air change rate of 0.15/hr. For four occupants a minimum, baseline fresh air requirement for this house would be 0.49 air changes. If the system was balanced with natural ventilation forces, the two fans alone could supply 30% of the total, even in very still conditions when the risk of overheating is greatest. The ventilation system is capable of recovering 70% of the exhaust air heat content. In full operational mode each unit extracted 0.017kg/s of tale air replacing it with 0.013kg/s of fresh air.

Thermographic scanning was used to establish the performance of the construction of the 'Zero Heating' project. Thermographic scanning enables analysis of the building to assess the detailing and variables such as the quality of the installation of insulation and in this case established the temperature of the internal and external surfaces. With the information this provided it is possible to establish which areas require improvement or slightly better detailing to provide more air tight or better insulated joints and construction.

By and large the thermographic scans confirm that the building has been well built in that it is correctly insulated, the windows and doors are air tight and that there is little evidence of cold bridging.

Post Occupancy Evaluation

The measurement of physical criteria was complemented by a Post-Occupancy Evaluation and periodic interviews with the occupants to establish both their satisfaction with the finished product and their patterns of use of the building (Preiser, et al 1988).

Other than some minor physical problems with the home, the POE established that the home is both healthy and provides comfortable spaces for a large family.

CONCLUSIONS

As the design for the '*Zero Heating* 'home currently stands, were the ostensible savings to be replicated for the 4.4 million new homes projected by the government to be needed in the United Kingdom by 2016 (DETR, 1996), annual, undiscounted fuel bill savings would amount to some £921 million. Whilst the total savings made by these houses over a sixty year life would be in the order of £65 billion in comparison with the nearest modern, new housing alternative. Basic housing cost data was obtained from DETR (1996) and BMCIS (1999) sources.

Whilst it is clearly unlikely that this will be the case, it is important to explore how the lessons of experimental developments like the 'Zero Heating' home can be extrapolated to the wider market for affordable housing.

This house provides an exceptionally useful model for such expansion, since it is highly affordable and consistent with Egan targets for improvement in the economic performance of the construction industry.

The 'Zero Heating' home has been highly successful in generating interest in more sustainable housing design. With the current resurgence of interest in timber standardisation and prefabrication in England, a market which has been resistant to timber frame for nearly two decades (Birkbeck, 1999) several of the country's largest house builders have shown an interest in using variants of the design to develop their new products.

It is inevitable both that standardisation of housing designs will increase and that legislated insulation and other environmental performance standards will greatly increase in the future. In that context concerned designers can stand aside and watch, engaging in the increasingly occasional prestigious, one-off architectural expression, whilst the mass house builders decide on the future of our built environment. Alternatively they can engage in the rational development of improved sustainable affordable designs which retain high architectural standards. The Research Team believes that the 'Zero Heating' home is one such design and will continue to work to improve it.

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