# From Targets to Occupied Low Carbon Homes: Assessing the Challenges of Delivering Low Carbon Affordable Housing

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*ABSTRACT: This paper investigates the challenges of achieving affordable low carbon housing in the context of the Scottish, UK, and Passivhaus Standards. It also investigates the potential for bridging the gaps between set targets and what is happening in reality, in order to achieve better performance of low carbon affordable housing at a wide scale. It looks at two case study housing projects – Enkelt Simple Living and Tygh-Na-Cladach, completed in 2008 and 2009 respectively. Both are located in Dunoon, Glasgow, Scotland. The case study design compares the high environmental targets set in the design briefs of the two projects; their delivery processes; and the outcome. The analysis is based on identified common challenges to achieving low carbon homes in the context of a four stage process of the lifetime of dwellings. The two projects demonstrate the need for innovative processes and approaches of delivering housing to meet low carbon targets in the affordable sector of the market.*

*Keywords: low carbon standards, affordable housing, barriers, Code for Sustainable Homes, Passivhaus*

## 1. INTRODUCTION

Many governments have developed and revised building codes to drive local, national and international carbon dioxide reduction targets. In the UK, the “Code for Sustainable Homes (CFH)” is in use. The Code has six levels, with mandatory minimum standards for energy efficiency and water efficiency at each level. The timetable for strengthening standards in the Code requires all new dwellings to have a 44% improvement over the 2006 regulations by 2013; and to be zero carbon (Level 6) by 2016. Its target of ‘zero carbon’ is not clearly defined yet, and a consultation on this is ongoing. Since May 2008, a minimum of Level 3 became mandatory for new dwellings where public sector funding is involved in England; all new dwellings promoted or supported by the Welsh Government or their sponsored bodies; and for all new self-contained social housing in Northern Ireland. Despite the UK’s central government’s ambition that the CFH becomes the single national standard for the design and construction of sustainable homes [1], Scotland has been using Ecohomes, (the predecessor of CFH), and in October 2010 introduced new regulations for dwellings. Scotland’s new regulations are based on ‘The Sullivan Report’ [2], and require staged improvements in carbon reduction compared to 2007 levels. The target is for a 30% reduction in 2010; 60% in 2013, and net zero carbon emissions (for heating, hot water, lighting and ventilation) in 2016/17, if practical.

Several evaluations have looked at the potential for low carbon standards to reduce energy/$CO_2$ emissions in European countries [3, 4, 5, and 6]. Results show that the impact of the standards to raise the environmental performance of UK housing has been limited. This is due to low levels of compliance. In 2007, the top 20 UK home builders achieved an average score of just 8.5 per cent for their commitment to EcoHomes [5]. They only built to the minimum required standards of EcoHomes, and largely only where required to do so by planning or funding agreements. In spite of a review to help increase compliance [7]; and the introduction of mandatory minimum standards; evidence shows wide gaps between the expected performance of many dwellings during the planning stage and the actual performance in use. Achieving the zero carbon level in 100% of dwellings constructed from 2016 onwards is currently one of the biggest challenges in the industry. The need is for solutions to: (a) reduce energy demand through the fabric design, services and occupants; and (b) increase supply from low carbon energy sources. This paper focuses on the former.

To put the challenge in context, it is worth looking at the achievements of the Passivhaus Standard since it is one of the oldest and most demanding standards regarding energy demand reduction. Except for the role of renewable energy sources, it is also closely related to the ‘zero carbon’ level in both the CFH, and the 2010 Scottish regulations, in emissions for heating, lighting and ventilation. Passivhaus requires: excellent insulation with minimal thermal bridges; utilisation of solar and internal gains; air tightness; and indoor air quality provided by highly efficient mechanical ventilation with heat recovery. It requires a total energy demand for space heating and cooling that is less than 15 $kWh/m^2/yr$ treated floor area. It is a complete standard in the sense that achievement is based on certification of the completed building, as opposed to enforcement at the planning stage.

Although the Standard points to a significant potential for designers and clients to drive low carbon standards, it is interesting to note that only a relatively small number of dwellings have achieved the standard. Since 1991, when the first Passivhaus Standard building was completed, only 1826 dwellings had been documented by May 2009, and an estimated 19,132 buildings across Europe had met the standard [8]. The relatively small number could be partly explained by the voluntary basis on which the Passivhaus Standard is implemented. It could also be linked to barriers to achieving low carbon targets that are experienced in countries across Europe. The common barriers identified [3, 9, 10 & 11] are:

1. A gap in the skills and knowledge base:
   Most developers, builders, and architects are aware of low carbon building issues, but lack in-depth understanding and ability to deliver them. The training of most of them predates current low carbon standards. Inadequate knowledge means they may not adequately promote and/or readily access the necessary technologies.
2. Lack of motivation and interest:
   There is a widespread lack of in-depth interest in low carbon issues by professionals. For developers, low carbon standards may not be attractive, given the limited returns. The stepped strengthening of the standards can encourage developers to aim for the required minimum.
3. Cost and perceived cost:
   Division of labour during construction and lack of local solutions can all result in higher costs. Many developers perceive the costs of low carbon technologies to be high, despite the low marginal cost if solutions are incorporated early in design. Governments may pay higher grants if housing associations exceed minimum targets, but these may not fully cover the extra construction cost.
4. Regulatory bureaucracy:
   It can be hard to get planning consent for some renewable technologies in conservation areas.
5. Lack of technology and standard solutions:
   Low carbon solutions exist, but are not produced and/or available locally in all regions. There is a lack of ready standard solutions on a wide scale.
6. Legislation differences:
   Differences in standards in different codes across local and national governments can be confusing.
7. Uncoordinated efforts:
   Lack of cooperation between industry players; and uncoordinated promotion of low carbon standards by the many bodies doing so may result in inconsistent messages to stakeholders.
8. Split incentives:
   Owners may not invest in energy efficiency when tenants pay the bills. Tenants may not invest in property they don't own. While split incentives are possible for housing associations, for new dwellings, it may be difficult to earn back low carbon investments from rent. For existing dwellings, a decrease of energy costs can make up for increase in rent to cover the investments.
9. Information on benefits and user behaviour:
   Information on low carbon benefits is not widespread and feedback on energy use has been poor in the past. User behaviour is often ignored in target projections.

What measures are UK institutions taking to tackle the existing challenges? To promote low carbon housing, they have put efforts into making advance announcements for future further tightening of standards and minimum requirements for new buildings, including the expected dates for their introduction. This has encouraged the industry to investigate possibilities and develop timely solutions. To meet the education and training requirements of the European Energy Performance of Buildings Directive (EPBD), the UK government set a target of having 2,000 Domestic Energy Assessors, accredited by various UK bodies. A similar scheme has been established to train assessors to use the Code for Sustainable Homes.

Independent training programs for architects, engineers, and craftsmen are run by various institutions, e.g. the Building Research Establishment (BRE); University of Strathclyde course on the Passivhaus standard; and curriculum requirements enforced by the Architects Registration Board. There are growing numbers of professionals and craftsmen with the required knowledge and skills. It is possible they will increase as others interact and share best practice with colleagues at work and across professional bodies. In 2010, the Building Standards Division of Scotland commissioned the Mackintosh School of Architecture and 55 North Architecture to prepare a 'Guidance for Living in a Low Carbon Home' that could be included in building regulations.

Other promotion instruments have included: energy certification; demonstration projects; local planning requirements; and financial schemes. Demonstration projects are a very practical way to learn about low carbon dwellings. Economic and financial incentives (direct funding, taxes, soft loans, and green mortgages) to drive the development towards low carbon dwellings are very efficient [3]. UK governments have set compliance requirements for housing receiving direct public funding as part of the investment. Higher local planning requirements can encourage higher compliance of standards. Another instrument is persuasion on the benefits of low carbon to change opinions and attitudes.

To transform the market to zero carbon by 2016, today's challenge is to close the current gaps between regulatory requirements; implementation by many players in the production of dwellings; and performance in use. To do so in the affordable housing sector is particularly important in the context of the already existing challenge of providing adequate housing in the sector. Although competition amongst market parties is likely to drive widespread uptake of low carbon standards in future, there is no guarantee that this will happen.

## 2. LOW CARBON STANDARDS AND THE LIFE CYCLE OF DWELLINGS

In order to tackle the duo challenges of achieving both 'affordable' and 'low carbon' housing, we must look at them in the context of the four stage process involved in the life-time of dwellings, namely; programming, design, construction, and utilization. During the life-times of housing, changes to demographics, economics, and occupant tastes may lead to a repetition of the cycle through extensions, refurbishments, conversions, or development of new housing. Table 1 analyses the identified challenges to achieving low carbon targets in the context of the four stages in a dwelling's lifetime.

Low carbon opportunities at the programming stage can suffer from traditional expectations of housing. Dwellings continue to be developed in traditional programmes in spite of significant shifts to smaller households; increase in single person households; and changes in the ways in which people occupy dwellings. The programming stage can also experience disparities between how clients communicate development requirements, how designers understand and interpret them; and how project programs are developed and written. The design stage is also partly influenced by building codes and regulations. Other factors that can significantly influence how low carbon ambitions are supported by a project team include cost estimates; and the architectural ambitions of clients and designers.

*Table 1: Challenges (√) to achieving low carbon housing targets in the context of dwelling lifetimes: Programming (A), Design (B), Construction (C), and Utilisation (D).*

| Barriers | Stages | | | |
|---|---|---|---|---|
| | A | B | C | D |
| 1. Skills and knowledge gap | √ | √ | √ | |
| 2. Lack of interest and motivation | √ | √ | √ | √ |
| 3. Cost and perceived cost | √ | √ | √ | |
| 4. Regulatory bureaucracy | √ | √ | | |
| 5. Lack of technology and standard solutions | √ | √ | √ | √ |
| 6. Legislation differences | √ | √ | | |
| 7. Uncoordinated efforts | √ | √ | √ | |
| 8. Split incentives | √ | √ | √ | |
| 9. Information on benefits and user behaviour | √ | √ | √ | √ |

Recent Post Occupancy Evaluations have shown evidence of large disparities between predicted energy and environmental performance during design, and the actual performance after construction of dwellings. This could be partly attributed to the erosion of quality due to: inadequate commitment beyond the programming stage; division of labour during construction; and lack of collaboration between the project team. Low carbon standards in the past have not included mechanisms to ensure that measures approved during the planning stage are effectively implemented during the construction stage. New regulations in England require pressure tests on all new build dwellings [13] but the capacity to test all new builds is inadequate. Pressure testing is currently optional in Scotland. The quality of feedback to householders, and knowledge of householders on their energy use have been poor in the past [10, 11].

How can we bridge the gaps between each stage and across the four stages from dwelling planning to utilisation? How can we develop our capacity to do so in order to tackle the low carbon challenge? The following section looks at two case studies to identify appropriate measures and future directions.

## 3. CASE STUDIES

Making homes more energy efficient by moving towards a standard comparable to Passivhaus standards or higher, in line with Northern Europe would make a major contribution to the Scottish government aims to cut carbon dioxide emissions by 42%, more than a third of 1990 levels by 2020. Passivhaus meets many of the energy requirements of the zero carbon targets by the Scottish and UK standards for heating, lighting and ventilation. It has been suggested as a possible standard for European Building Regulations by 2015. There is a need for a deeper understanding of the application of such high standards in Scotland. The following sections look at two case study projects in Dunoon, Scotland, that aimed to achieve the Passivhaus standards at the outset. The methodology analyses the case studies in the context of: the codes for low energy homes; the challenges and measures promoting realisation of low carbon housing that were identified in the Introduction section of this paper; and the four stage process involved in the life-times of dwellings.

### 3.1. Enkelt Simple Living

The Enkelt Simple Living project consists of four Scandinavian inspired semi-detached low energy houses. Each is two stories with three bedrooms. They are constructed on a brown-field site at Queen Street, Dunoon, Scotland. The following sections discuss the strengths and challenges to achieving low carbon targets experienced in the project.

*Figure 1: Front elevation – Queen Street, Dunoon.*

Ballyconnelly Construction Ltd. was the developer-cum-contractor. The director in charge of the Enkelt project had transferable skills gained from experience in shipbuilding; and as a contractor of building refurbishments and conversions. Ballyconnelly used guidelines from the UK's Building Research Establishment for the construction of the Passivhaus standards. They combined them with Scandinavian design principles of respect for nature and appreciation of the intrinsic qualities of natural materials. They had clear ambition, interest, and motivation to develop low carbon homes from the onset. Although an architect was involved, the contractor pushed the agenda for low carbon principles. This included an extensive search to meet the demands of sustainable eco-friendly homes, and to make full use of local employment opportunities. They proactively sought materials based on recycled products or sources from managed forests. Such materials constitute the majority of the materials used in the project.

Regulatory bureaucracy was not a barrier, and challenges related to information on which Code to use were not applicable since the Ballyconnelly Construction Ltd. made a decision from the outset not to go for minimum requirements. They had a clear aim to achieve the Passivhaus Standard, which exceeded all Scotland and UK requirements for low carbon. They set out to establish a model of low carbon homes that would suit the mass market and social housing. The aim was to build low carbon homes that looked like, and cost the same as conventional homes i.e. less than £900/m$^2$. The final cost was £829/m$^2$. However, the contractor did not meet the set targets for the envelope aspects of the project. This could be partly attributed to lack of prior experience of using SIPS. An infrared thermographic survey, air tightness test and air leakage audit on one of the dwellings (the one to the far right of Figure 1) was conducted by the British Research Establishment. This was to assess whether it has achieved the continuity of insulation and air tightness performance target set by the Passivhaus Standard.

The following descriptions and figures provide the results of these tests and audits carried out on 17$^{th}$ & 18$^{th}$ Jan. 2010. Two air tightness tests were carried out: a depressurisation test and pressurisation test. Before the start of the pressure tests, the local wind speed was measured at a standard height of 1.5 metres. To provide reliable results, the wind speed should ideally be below 3 ms$^{-1}$ and should not exceed 6 ms$^{-1}$, which is the upper limit specified [14]. The results revealed a need for improvements of the air tightness.

*Table 2: Results of air tightness test. The target test result required for each dwelling was set at 0.6 ach at 50 Pascals.*

| | Depressurisation | Pressurisation | Average |
|---|---|---|---|
| Ach at 50 Pascals (target 0.6) | 4.94 | 5.37 | 5.16 |
| m3/hour/m2 at 50 Pascals. | 4.92 | 5.37 | 5.14 |

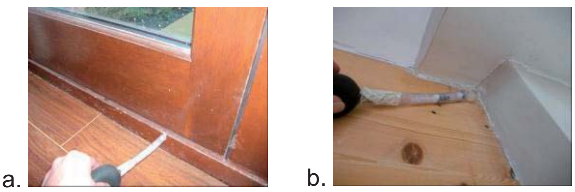

*Figure 2: Air tightness test results: (a) Large gap along bottom of patio windows in living room allowing air leakage; (b) Small amounts of air leakage into gaps between plaster and timber frame in upstairs bedroom's sloping ceilings*

Infrared thermography using an "infrared camera" was used to detect thermal radiation from surfaces and display the results as thermal images in graduated colour. The survey was carried out in the evening on Sunday 17.01.2010. The external temperature measured was 7.5$^0$C. The internal temperature in the ground floor was 18.3$^0$C and 19.4$^0$C in the first floor. The sky was overcast, and it was slightly windy. The results showed heat loss and cold air infiltration through gaps around wall and floor junctions & fenestrations, and services networks. Figure 3 shows sample thermal images.

The supplier (Hemsec SIPS) of the construction Structural Insulated Panels is based in Manchester. This resulted in additional transportation cost. Timber framed windows with argon filled double glazing were available in Scotland, but the budget could only afford U-Values of 1.1 W/m2/K, compared with the Passivhaus maximum of 0.80 W/m²/K. The fitted mechanical ventilation with heat recovery (MVHR) has 70% efficiency – less than the Passivhaus rate of over 80%. A key challenge in deciding on the installation was the lack of sufficient knowledge on payback periods of MVHR systems. Public funds as an incentive to meet low carbon standards were not relevant since the developer was a private company.

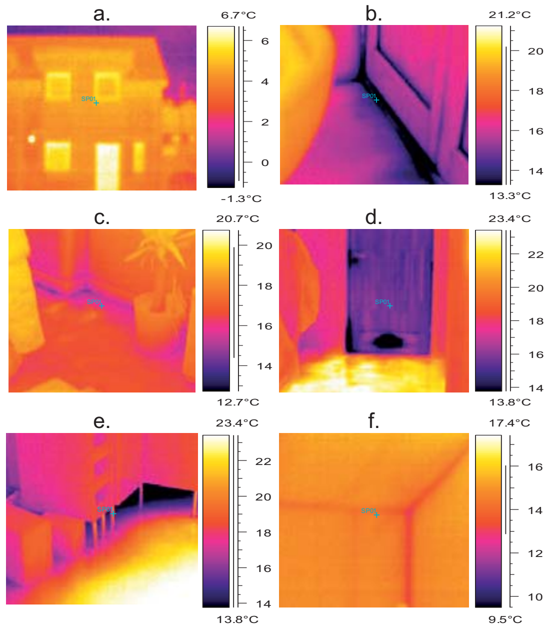


*Figure 3: Thermal images showing: (a) Heat loss through small gaps around windows, boiler flue and recently opened front door; (b) Coldness due to air infiltration through gap under patio window; (c) Coldness on floor of Living room party wall to adjacent house; (d) Warm floor (under floor heating), cool front door and coldness through letter box; (e) Coldness of floor under kitchen base units (where under floor heating is not fitted). (f) Small rear bedroom – external walls and sloping ceilings appear warm – no cold patches.*

The key barriers in the project realisation were therefore the lack of local availability of suitable Structural Insulated Panels; the contractor's lack of prior experience in using them; and the erosion of quality control during construction. One of the houses is currently owner occupied and the other three are rented out. User manuals on the energy saving features of the houses have not been provided to occupants. A planned POE during the coming winter (2011/12) will investigate the role of occupants in achieving low carbon targets in the dwellings. This will compare their performance in the context of the number of people living in each unit and occupancy rates; user behaviour on the operation of windows and other openings versus the MVHR system; and the owner occupied unit versus the rented units to monitor possible split incentives.

### 3.2. Tygh-Na-Cladach

The Tygh-Na-Cladach Passivhaus is the first in Scotland to be officially awarded full Passivhaus certification by the German Passivhaus Institute. It was also the first social 'affordable' home in the UK to be Passivhaus certified. It was unveiled in April 2010 and is part of a development of 14 new low energy homes developed by Fyne Initiatives Ltd. The following sections discuss the strengths and challenges to achieving low carbon targets experienced in the project.

In the context of skills and knowledge, the architect of the project, Gokay Deveci, had long standing experience in low carbon housing gained from practice-based research and design of low carbon houses. The contractor, John Brown (Strone) Ltd, was local and well established in building public sector social housing projects. The Scottish Passive House Centre played a key role of supporting the architect with energy efficiency consultancy and supplying vital Passivehaus components.

*Figure 4: Tygh-Na-Cladach PassivHaus and Low energy houses, Dunoon, Scotland*

From the outset, there was an ambition to provide low energy homes and there were no barriers related to the lack of motivation for very low carbon dwellings. Regarding cost and perceived cost, the challenge was to provide quality, affordable homes that would meet the needs of the local community of Dunoon and remain in the affordable sector of the housing market. Provision of affordable housing was a condition set by the Argyll and Bute Council when they sold the site to Fyne Initiatives Ltd. There was an aim to showcase that highly energy efficient dwellings can also be built for affordable housing. Affordable housing meant there was less money to be spent compared to a standard house. Achieving a Passivhaus in the project was therefore unique in the sense of being in the affordable sector. There were marginal additional costs compared with the adjacent Low Carbon homes, and public funding was not available as an incentive to cover the extra costs.

There were no regulatory barriers except that the Argyll and Bute Council required the developer to lease the woodland and provide a small workshop to accommodate activities of a local group which provides education for local people as part of managing the woodland. Some of the chosen technologies and products were available in Scotland, and others had to be imported. The chosen Prefabricated Closed Panel Timber Frame System (RTC PassivWall) with prefabricated floor, wall, and roof cassettes was from 'RTC Timber' in Elgin, Scotland. It was highly pre-insulated with 80% recycled content glasswool and was specifically developed to Passivhaus levels. The aim to achieve a very airtight building with an air tightness below n50=1/h was a challenge for a timber frame building. A distributor based in Fife, Scotland, supplied both the triple glazed and insulated framed 'Internorm' windows from Austria; and the Passivhaus certified highly efficient 'Paul thermos 200DC' MVHR from Germany. A specialised electrical and mechanical engineer, Dynamight Passive Solutions, was involved in the installation. There was no mains gas on the site, and electric heating and DHW had to be put in.

Barriers related to confusion on which Code to use, and which enforcement body to consult, were not applicable. The developers aimed to achieve the Passivhaus standard, and sought support from the Scottish Passive House Centre. The heating demand for the whole house is 1600 kWh/year. To cope with the Passivhaus primary energy limit of 120 kWh/($m^2$a), a solar thermal system supports the production of DHW – further reducing the energy bill for hot water by over 50%. Thorough planning and detailing by the architect, and careful workmanship by John Brown (Strone) Ltd. led to excellent pressure test results at just n50=0.38/h (q50=0.4$m^3$/($m^2$h).

An Owner's Handbook to the householders outlines the operation of key aspects including services, fixtures and fittings, and manufacturer's information on the components of the heating and ventilation systems. There is no other information on heating and ventilation, and no information on the heating controls, nor energy saving potential through specific aspects of the house. A Post Occupancy Evaluation comparing the Passivhaus home and one of the adjacent Low Energy homes is ongoing.

## 4. COMPARATIVE ANALYSIS

Both of the case studies are located in Dunoon, Scotland, and both had unfavourable sites for south facing orientations. Both are semi-detached and were driven at the outset with an ambition to achieve very low carbon standards in affordable housing. Table 3 compares the challenges to achieving this goal; and Table 4 compares the technical aspects.

*Table 3: Challenges (√) to achieving low carbon in the Tygh-Na-Cladach and Enkelt projects during: Programming (A), Design (B), Construction (C), and Utilisation (D).*

| Barriers | Stages | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Tygh-Na-Cladach | | | | Enkelt | | | |
| | A | B | C | D | A | B | C | D |
| 1. Skills & knowledge gap | | | | | √ | | √ | |
| 2. Lack of interest and motivation | | | | | | | | |
| 3. Cost & perceived cost | √ | | | | √ | | | |
| 4. Regulatory bureaucracy | √ | | | | | | | |
| 5. Lack of technology and standard solutions | √ | √ | √ | | √ | √ | √ | |
| 6. Legislation differences | | | | | | | | |
| 7. Uncoordinated efforts | | | | | | √ | √ | |
| 8. Split incentives | | | | | | | | |
| 9. Information on benefits and user behaviour | | | | √ | | | | √ |

*Table 4: Comparisons of the Tygh-Na-Cladach and Enkelt Simple Living dwelling projects: 1.Treated floor area; 2.Construction method/U-values in W/ (m²K); 3.Ventilation; 4.Heating; 5.Domestic Hot Water; and 6. Air tightness*

| | Tygh-Na-Cladach | Enkelt |
|---|---|---|
| 1 | 88m² | 86m² |
| 2 | External walls: 0.095; Floor slab: 0.15; Roof: 0.094; Windows: 0.8; Doors: 1.16 | Walls: 0.15; Roof: 0.15; Windows: 1.1 |
| 3 | MVHR with 92% efficiency. | MVHR with 70% efficiency. |
| 4 | No mains gas. An air-to-air heat pump heats kitchen. Heat distributed via MVHR. | Under floor heating |
| 5 | Solar thermal collectors, 300-l-buffer with elektrical immersion heater. | |
| 6 | n50 = 0.38/h q50 = 0.40m3/(m2h) | Ach at 50 Pa (target 0.6) = 5.16; & m3/hr/m2 at 50 Pa = 5.14 |

## 5. CONCLUSIONS

The two case studies demonstrate the need for innovative processes and strategic approaches of delivering housing to meet low carbon targets in the affordable sector. They are also evidence of a high potential for professionals and clients to drive higher compliance to low carbon standards. That majority of developers tend to comply with the minimum set targets, suggests a need to discontinue minimum targets and advocate for the highest possible standard. There is an urgent need to emphasize space programming as a key aspect of achieving energy and $CO_2$ reduction targets. If we are going to ensure higher compliance to low carbon standards, we really need to change strategy so that standards are also significantly driven by consumer demand, in place of the current drivers, which are in large part, led by the producers of housing. It is vitally important to develop better communication to householders on low carbon designs, how they work, and how to efficiently operate energy systems.

The Tygh-Na-Cladach case study provides vital lessons on how Passivhaus strategies can be progressed for adoption in affordable housing. Both projects are evidence that very low carbon dwellings do not necessarily have to cost significantly more to build than conventional homes. Although they prove that sustainable and energy efficient design is possible on affordable housing budgets, they had to import some low energy components, and this calls for an urgent need to develop local products. They also demonstrate that affordability can be achieved without being at the expense of architectural design and construction quality. Most significantly, they demonstrate the importance of following quality assurance procedures throughout the planning, design and construction stages of dwellings.

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