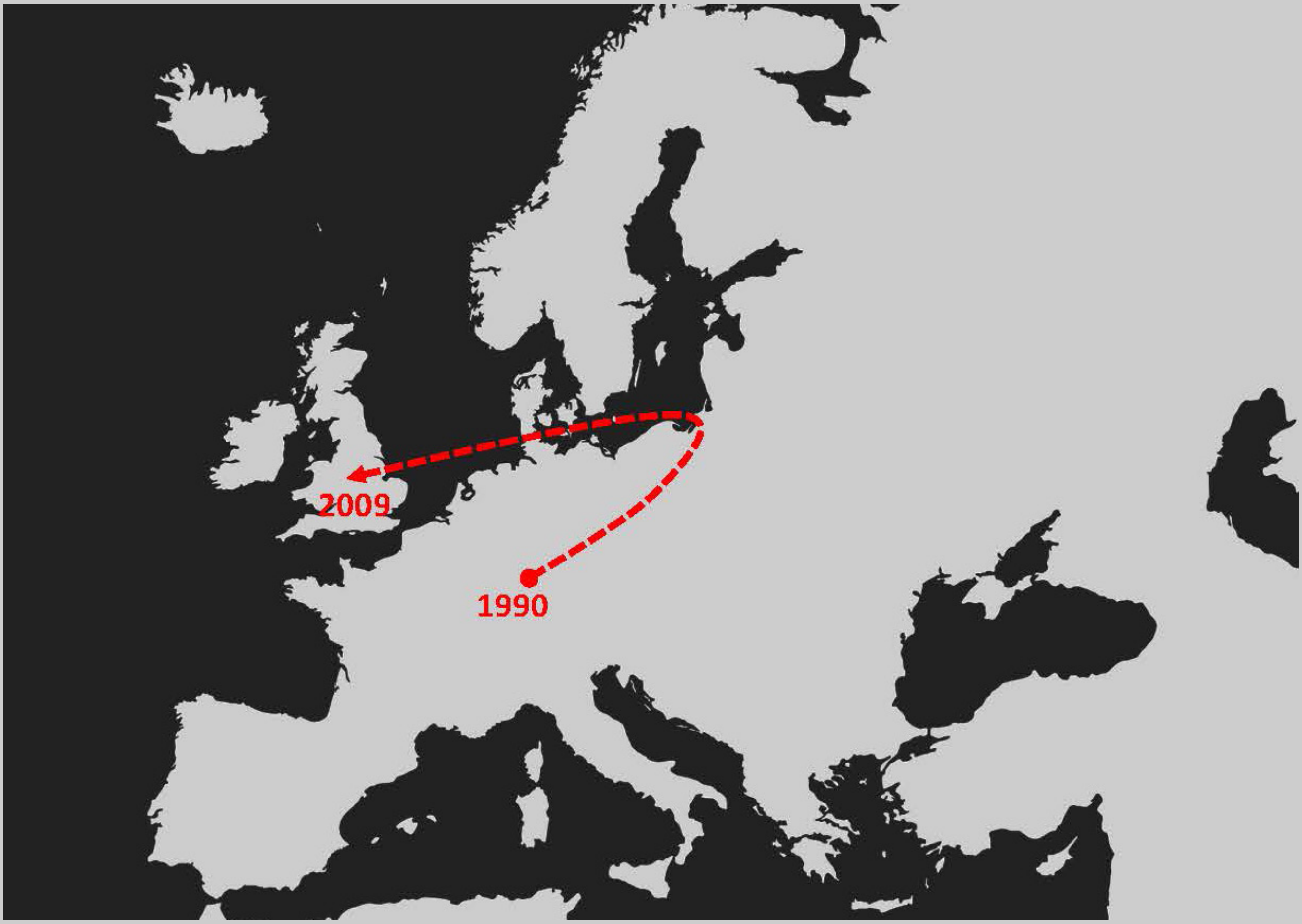
Interrogating the technical, economic and cultural challenges of delivering the PassivHaus standard in the UK



Editor and Project coordinator Dr. Henrik Schoenefeldt

With case studies contributed by students of the Master of Architecture: Adam Nightingale, Jessica Ringrose, Rosie Seaman, Sebastian Willett, Sam Ashdown, Karl Bowers, Natasha Gandhi, Tim Waterson, Katarzyna Kwiatek, Thomas Hayward **and the final year of the BA in Architecture**: Miguel Peluffo-Navarro, Cordelia Hill and Sam Fleming.

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Forword

Dr. Henrik Schoenefeldt
Project coordinator

Since joining the Kent School of Architecture as a lecturer in sustainable architecture I have been developing and piloting news approaches to teaching sustainability in architecture through design-led as well as research-led projects. This was underpinned by new research into how the sustainability agenda is driving architectural practices and schools of architecture to adapt to new forms of practice. This research has also led to the development of the pedagogical concept behind a new collaborative research project, looking into the technical, economic and cultural challenges of delivery the German PassivHaus standard within the context of the UK. The objective was to involve students directly in primary research through a larger collaborative research project. Acting as an alternative to the traditional dissertation, the project offered students to participate in one large study, including twelve in-depth case-studies.

PassivHaus is an energy performance standard for domestic and non-domestic buildings, which was established in Germany in the early 1990s but has only recently been introduced to the UK. As a result experience with designing and delivering PassivHaus standard buildings in the UK is still limited compared to Germany and Austria, where extensive knowledge and experience had been accumulated over the past 25 years. The pioneering buildings completed over the past five years provide critical insights into the process by which the standard is gradually been adapted to the UK context.

In this research project a team of nine students from the MArch (stage 5) and three students of the BArch (stage 3) investigated how architectural practices and the building industry as a whole are adapting to successfully delivery buildings of this standard. Using multi-methodology research, this project investigated the learning process underlying the delivery of twelve buildings completed between 2009 and 2013. Through the study of the original project documents (e.g. drawings, sketches, planning documents and construction photographs) and semi-structured interviews with clients, architects, town planners, contractors and manufacturers, these case studies have illuminated the more immediate technical as well as the broader cultural and educational barriers,. Moreover, the interviews facilitated students in engaging with the various professions that had been directly involved in the design, delivery and post-occupancy evaluation of each building. Through this students not only developed an understanding of the process from point of the architectural profession but also from a broader cross-industry perspective. This was particular critical as all of the cases covered in this studied involved an exceptional level of cross-industry collaboration. As such it yielded close insights into the impact of sustainability on architectural practice and its relationship to the wider industry. The findings of this research are presented in this peer-reviewed eBook.

The pedagogical concept behind this research projects builds on the findings of an earlier research project on sustainable practice and education, which was entitled 'Inquiries into a new model of teaching sustainable design' and funded by the Higher Education Academy (HEA). Interviews with practitioners, which I have conducted as part of the HEA project, highlighted the importance of establishing stronger links between architectural practice, research and education in sustainable development. As such the project engages with issues raised in the Farrell Review of Architecture and the Built Environment and studies(2014) by the Royal Institute of British Architects (2013), Royal Academy of Engineering(2005) and the The UK Architectural Education Review Group(2012). These studies highlight that teaching, research and practice suffer from too much separation.

One of the key objectives of this project was to bridge the gap between academic research, architectural practice (and the construction industry more widely) and university-based teaching. It provides a potential model by fostering collaboration between academic researchers, students and industry partners. Over the course of the project several workshops and research reviews have been held, bringing together students of architecture, university-based researchers and practitioners. These allowed critiques of student work, and group discussions on some of the emerging themes, these events facilitated a dialogue between academia and practice.

The research team at the launch workshop held in Boughton Monchelsea, near Maidstone on 5 June 2013, which involved the architects Doug Smith (left), Richard Hawkes and James Anwyl. (Photo: Doug Smith)

Practioners and academics who contributed to this project in various ways include:

Richard Hawkes (Hawkes)
James Anwyl (Director of Eurobuild)
Doug Smith (Principal Director Tp Bennett)
Patrick Osborne (Lee Evans Partnership)
Bertie Dixon (Maxfordham)
Philipp Proffit (Director of Princedale Homes)
Tanisha Raffiuddin (RDA)
Jon Bootland (PassivHaus Trust)*
Keith Bothwell (Kent)
Derrie O' Sullivan (Huddersfield)

As such the project facilitated the development of a new network of practioners and academics working in the field of low-energy architecture, which is to be developed in future projects. The Higher Education Academy, peer-review panel of this book and the Part II external examiners, highlighted that the project presented innovative pedagogical model, for which it received the 2014 Purcell Prize for Technology at Part II.

Dr. Henrik Schoenefeldt
Project coordinator

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Introduction

Introducing the PassivHaus standard to the UK

In 2010 the architecture magazine Detail announced that PassivHaus had finally become a fully-established energy performance standard within Germany and Austria and therewith ended its pioneering phase. In this year thirteen thousand projects had been completed in Germany alone. This pioneering phase had started in the early 1990s, when a row of terraced houses were erected in Darmstadt-Kranichstein as a first prototype. This prototype was used to test the feasibility of the PassivHaus concept, which had originally been developed by the physicists Wolfgang Feist and Bo Adamson in the late 1980s. A six-year monitoring study demonstrated that these houses had achieved a space heating demand as low as 10 KWh/m2 per annum, which was one sixteenth of the space heating demand of the average German building stock. The results also verified the accuracy of the energy balance model, which formed the basis of the PassivHaus Planning Package(PHPP), an energy modelling tool used in the certification process. As such PHPP performs a similar role to the UK's Standard Assessment Procedure (SAP) used for the Code for Sustainable Home and Part L of the building regulations. In addition, the pilot study involved the development and testing of advanced construction details, window systems and mechanical ventilation and heat recovery systems that are required to achieve this level of energy efficiency. At the PassivHaus Institut(PHI), an independent research organisation established in Darmstadt in 1996, the PassivHaus principle was developed into a formal performance-based energy standard and certification scheme. It was based on a rigorous assessment methodology and set of strict performance criteria. For the formal certification, which is conducted by an independent PHI accredited PassivHaus certifier, project teams need to provide, among others, (1) a detailed energy performance assessment of the building using PHPP, (3) thermal modelling of construction details (4) an airtightness test (3) comprehensive set of plans, including construction details (5) specification of components (6) documentation of the construction, recording any deviation from the original construction details. In Germany and Austria the PassivHaus standard experienced a strong uptake and within twenty years following the completion of the first prototype, an extensive body of experience and technical knowledge was accumulated and a mature supply chain of components meeting the high energy performance criteria was established. An extensive technical grey literature and the proceedings of the Annual International Passivhaus Conference give detailed evidence of the exceptional level of knowledge exchange, collaboration, and R&D that architects, contractors, suppliers and academic departments in Germany and Austria had engaged in over this period to establish the standard. The Institute played a central role in the development of this supply chain through research, setting of performance standards, product certification and the consultation of manufacturers.

In the UK the experience with the design, construction and use of PassivHaus standard buildings, however, is still comparatively limited. In July 2012, the National House Building Council reported that approximately 20,000 PassivHaus buildings were either completed or under construction in Germany, compared to only 165 in the UK. The first house in the UK, Y Foel in Machynlleth, Wales, was certified in 2009 and monitoring data collected after completion verified that it had met the performance benchmarks in real life. It had a measured primary energy demand of only 105kWh/m^2/yr and 14.97kWh/m^2/yr for space heating. This and other pioneering buildings completed in the UK over the past five years provide critical insights into the process by which the PassivHaus standard, which up to this point had been a predominantly Central European standard, is gradually been adapted to UK conditions. This process, however, cannot be understood through the study of technical questions alone but also needs to address the wider economic, educational and cultural contexts. The director of the PassivHaus Institut in Darmstadt, Professor Wolfgang Feist, acknowledges the importance of the wider cultural dimension in his paper W*hat can be a Passive House in Your Region with Your Climate?* He stressing that the adaptation of the standard in different parts of the world cannot be achieved through copying central European technologies, but requires the development of new technical solutions taking into account the specific economic contexts, skills, materials and building traditions. A report of the NHBC Foundation, entitled *Lessons from Germany's Passivhaus experience*, provides a brief overview of some of the broader issues that are specific to the UK, but the aim of this book is to investigate how these manifested themselves in the context of specific projects and the different ways in which project teams had addressed them. For this purpose detail case studies, focusing on thirteen PassivHaus projects realized in England between 2009 and 2013, were conducted as part of the research project *Interrogating the technical, economic and cultural challenges of delivering the PassivHaus standard in the UK*. This was co-ordinated by Dr. Henrik Schoenefeldt at the Kent School of Architecture between May 2013 and June 2014 and involved a team of thirteen architecture students.

The primary objective of the project was to investigate how project teams and the UK construction industry more generally, have adapted to the German Passivhaus standard. The case studies illustrated, among others, how dependent project teams had been on imported technologies and collaborations with partners in Belgium, Austria or Germany to gain from their extensive experience with the implementation of the standard. They also showed hat the PassivHaus standard acted as a major driver of technical innovation, research, skill development and new forms of practice. It provided the context for new forms of collaboration between architects, consultants, contractors and university departments in research, design, construction and education. Various new technical solutions were developed, some specifically with the aim of accommodating existing skills and building traditions within the UK. Questions of skills and education had also to be re-addressed as part of this process. All of the projects covered in this book involved a level of dedication to the development of advanced construction skills, technical education and to technological innovation through research and development (R&D) that is rare within the UK construction industry. As such the project teams actively engaged with a wide range of broader educational and cultural issues within the UK construction industry that had been highlighted by the Climate Change Committee, Department of Business, Innovation and Skills and the Department for Energy and Climate Change. In various report these Departments have emphasized that insufficient investments into skills, education and research and development (R&D) in the British construction industry are serious barriers to the successful implementation of low-energy buildings. Despite efforts to set new sustainable design standards, such as the Code for Sustainable Homes, and various government programmes, including the Green Deal and Energy Company Obligations, it was found that the main challenge was that the mainstream building industry lacked the necessary skills, innovative power and technical know-how to deliver highly energy buildings in practice. This frequently resulted in a significant gap between the projected and actual energy performance.

Facilities to address these practical issues, however, are critical to meet the UK's ambitious carbon reduction targets. In the Climate Change Act 2008 the UK government has set out to reduce carbon emission by 80% in 2050 and increased energy efficiency of new and existing buildings forms a core part of its current carbon reduction strategy, alongside decarbonising the UK energy supply through a transition towards renewables and nuclear. In various papers, including Carbon Plan 2011, Energy Efficiency Call for Evidence 2011, Energy Efficiency Strategy 2011, the Department of Energy and Climate Change also promotes energy demand reduction measures as potentially more cost effective than supply-side measures. The thirteen case studies included in this research, however, have shown that all of project teams had developed ways of successfully delivering buildings performing to the PassivHaus standard, addressing the immediate technical as well as the wider economic, cultural and educational barriers. The project illuminated, although at a small scale, the nature of the culture shift the government aims to promote.

The questions to be addressed in this book are:

Why and how did the project teams achieve this?

What approaches were taken by different project teams?

Has the PassivHaus standard provided the impetus for the development of a practical working model by which the UK's carbon reduction targets could be met?

The PassivHaus standard

Before further discussing the research aims and objectives, a brief overview of the principles, performance benchmarks and design parameters underlying the PassivHaus standard are provided. The strategy behind the PassivHaus is to increase energy efficiency to a point where (a)direct solar gains, (b) internal heat sources, such as occupants, lighting, showers, appliances and the (c) heat recovered from the extract air through a heat recovery system, can cover the space heating demand with no or very limited active heating.

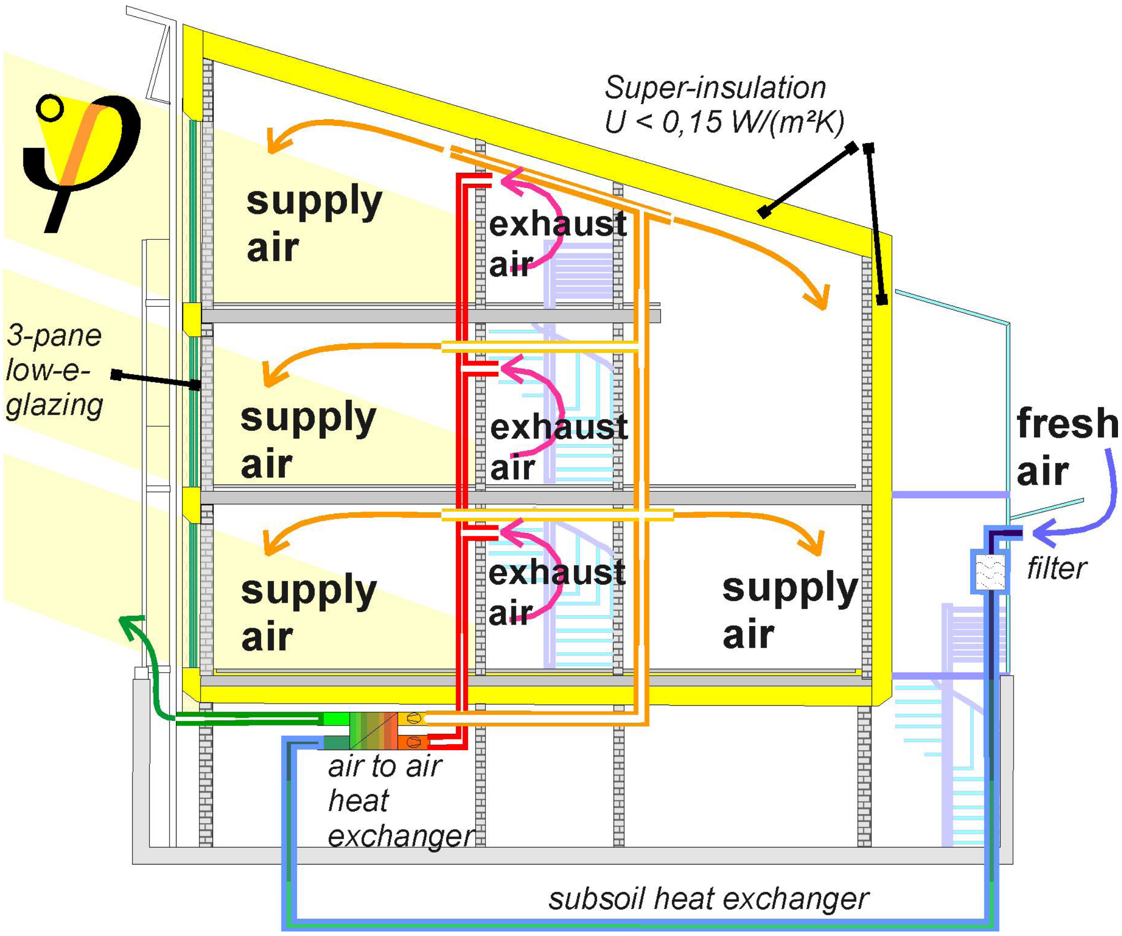

Figure 1: The general principle of PassivHaus is illustrated by the cross-section of the prototype terrace in Darmstadt, showing the key component (a) a super-insulated and airtight building envelope with minimal cold bridges (b) high performance triple glazed window with insulated frames (c) the mechanical ventilation and heat recovery system, connected to a ground-coupled heat exchanger used to pre-warm (winter) or pre-cool (summer) the supply air. (PassivHaus Institut, Darmstadt)

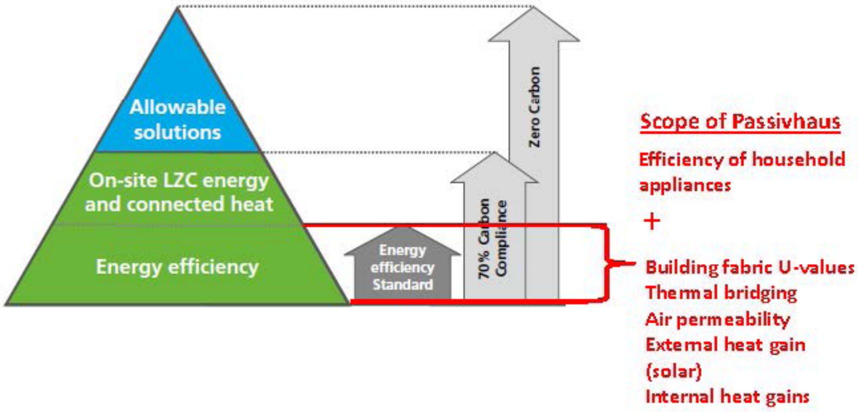

Fig. 2: The PassivHaus approach in the context of the UK's zero-carbon hierachy underlying the Code for Sustainable Home. Passivhaus focus on energy efficiency, combining a fabric first approach and with energy efficient appliances and environmental services. (Sustainable New Homes – The Road to Zero Carbon (Communities and Local Government, 2009)

To gain Passivhaus certification, however, buildings have to achieve a space heating demand not exceeding 15 kWh/m^2 per annum (equates to 25% of the space heating demand of a standard UK new build). In addition the total primary energy demand, which includes the space heating, hot-water and the electricity consumed by the fans of the MVHR unit, lighting and appliances, is limited to 120W/m^{2}yr. To achieve such a low space heating demand, a fabric first approach, which involves minimizing energy demand through the adoption of a high performance building envelope, massing and the exploitation of passive solar design principles, is combined with mechanical ventilation and heat recovery. A high performance fabric is to be achieved through 1) high levels of insulation, 2) elimination of thermal bridges and 3) good air tightness. The Passivhaus standard needs to be distinguished from the prevailing UK certification schemes, such as the Code for Sustainable Homes (CfSH) or BREEAM (Building Research Establishment Environmental Assessment Method). Passivhaus is an energy peformance standard following a fabric first approach, whilst BREEAM and the CfSH are environmental assessement methods, in which energy is only one out of several environmental impact factors considered in the certification process. In the CfSH, for instance, there are nine categories, each given a particular weighting, (1) Energy and carbon emission, 36.4% (2)Water, 8%, (3) Materials, 7.2%, (4) Surface water run-off, 2.2%, (5) Wast, 6.4%, (6) Pollution, 2.8%, (7) Health and well-being, 14%, (8) Management, 10%, (9) Ecology, 12%. BREEAM has eight categories, with energy given 43%. The Passivhaus standard, on the contrary, focuses exclusively on energy efficiency. The PassivHaus Institut has set a series of clear energy efficiency benchmark for the fabric that need to be met to pass certification:

Space heating demand not exceeding 15kW/h per year (25% of standard UK new built)
Primary Energy demand not exceeding 120kW/h per year (includes household applicances)
airtight building envelope with a maximum of 0.6 air changes per hour at 50 pascal (Part L (2013): 10 air changes, Code level three: 3 air changes)
a highly insulated buildings envelope with maximum u-values of 0.15 W/m^{2}K for roofs, floors and walls (Part L (2013): walls: 0.30W/m^{2}K, roofs: 0.20W/m^{2}K)
triple glazed windows with insulated frame achieving overall u-value of 0.80W/m^{2}K (Part L(2013): 2.0W/m^{2}K)
energy efficient mechanical ventilation and heat recovery system (MVHR), with a minimum heat recovery rate of 75% and fan power not exceeding 0.45 Wh/m^3.
Thermal bridge free construction

Fig. 3: Performance benchmarks to be met to gain PassivHaus certification

The PHI's certification criteria ask for a highly insulated building envelope with a heat transfer co-efficient (u-value) not exceeding 0.15W/m2K for walls, floors and roofs. In Part LA1 of the building regulations, to give a comparison, the maximum u-value for walls is 0.30W/m^{2}K and 0.20W/m^{2}K for roofs. In practice, however, the insulation levels required in order to meet the PassivHaus performance benchmarks are much higher, with u-values as low 0.06W/m^{2}K, which is no less than five times more efficient than Part L requirements. This is largely due to the fact that the required u-values are directly affected by other performance significant design factors, such as building form, solar orientation and size of glazed areas. PHHP can be used to determine the insulation levels required for a particular design but also to explore how insulation levels can be reduced by improving the overall building form. Designers are provided with a series of general design guidelines for optimizing the general form and orientation of buildings for energy conservation or solar access, which include a preference for compact building forms (heat loss form factor of 3 or lower), south facing elevations with at least 40% glazing and north elevations with minimal glazing. An outline of these guidelines, which are particular important during the early design stage, are given in the *PassivHaus Handbook* and BRE's *Passivhaus Primer: Designer's Guide*. For windows an overall maximum u-value of 0.85W/m^{2}K has been set, including the glazing and window frames. The Part L requirements for windows is only 2.00 W/m^{2}K. The latter is typically achieved through windows with argon filled triple glazing and insulated frames. In addition air leaks through the building fabric is minimised through a mandatory airtightness standard not exceeding 0.6 air changes per hour (ACH) at a pressure of 50 pascal. In comparison Part LA1 (2013) of the building regulation only requires an airtightness of 10 ACH and 3 ACH for housing at CfSH Level 3. For certification buildings have to pass an air pressure test.

Another key part of the PassivHaus strategy is the use of a mechanical ventilation and heat recovery (MVHR). This is used to minimise the quantity of heat lost through ventilation whilst maintaining a good indoor air quality. According to Feist, 35kW/h of heat is lost per annum if a ventilation rate of 8 liters per person per second is to be provided through direct natural ventilation. The heat recovery system therfore has to be understood as a means to reconciling energy conservation with indoor air quality. The certification criteria demand a highly efficient MVHR system with a heat recovery rate of at least 75% and a fan electricity consumption not exceeding 0.45 Wh/m3. This means least 75% of the heat from the outgoing exhaust air is reused to heat the fresh supply stream air, using an air-to- air heat exchanger unit. In PassivHaus a fully mechanical or a mixed mode ventilation strategies are deployed. During the heating season the building is sealed and serviced entirely by a central mechanical ventilation and heat recovery system in order to minimise ventilation related heat losses. In summer it can be operated in a natural mode with windows and doors opened for cross-ventilation, but in office buildings the MVHR system is frequently used as part of a passive cooling strategy, in which all of the supply air is cooled through a ground-coupled heat exchanger before entering the building.

Research Methodology and Structure

Using Jeremy Till's model of architectural research as a starting point, the primary objective of this research project is to investigate the learning process underlying the delivery of thirteen PassivHaus schemes in England, completed between 2009 and 2013. The case studies are compiled into three thematic sections:

Educational Buildings:
1. Hadlow College's Rural Regeneration Centre, Tonbridge
2. Montgomery Primary School
3. Centre for Disability Studies, Rocheford

Retrofit:
4. Grove Cottage, Hereford
5. 100 Princedale Road, London

Housing:
5. Hastoe Housing Association Passivhaus Development
6. Howe Park PassivHaus, Milton Keynes
7. Camden PassivHaus, London
8. Denby Dale, near Huddersfield
9. Crossway House, Staplehurst
10. Grey Lyn PassivHaus, Faversham (not certified at the time this book was published)
11. Underhill House, Moreton-in-Marsh

Till uses the archaeological expedition as a metaphor for the role of academia in architectural practice, with the academic research acting as an archaeologist entering into the world of practice as an external observer to uncover the (a) process of designing and delivering buildings, (b) to study the anatomy of completed architectural artefact and (c) to evaluate the real life performance of buildings at post-construction stage. These form the three main areas to be covered in each case study.

Process
The first area is the design, construction and procurements process, which is important to gain a critical understanding of the specific approaches used by architects, contractors and clients to adopting the PassivHaus standard in the design, detailing and construction stages. The focus is on the design and technical objectives, methods and tools deployed during the design and construction stages. This part of the research will be based primarily on interviews with clients, contractors, engineers and the architects involved in the project.

Anatomical analysis
The second area focuses on the anatomical analysis of the final design, with a particular focus on the building form, the construction of the external fabric and the integration of environmental systems, including the MVHR system and the various technologies used to meet the auxiliary electricity and heating energy demand.

Post-occupancy
The third area is the environmental post-occupancy review, which analyses the performance of the selected buildings from the point of energy use, indoor climate and air quality and user satisfaction. It also explores how

user-behaviour affected the performance and the efforts taken by architects and clients to address this through training sessions, consultation and user-manuals.

Mixed methodology research was used, which included a literature review and original primary research. The latter comprised the analysis of the original project documentation (e.g. planning documents, developmental sketches and architectural plans) and semi-structured interviews with clients, architects, town planners, contractors and manufacturers. These provided detailed insights into the project development, illustrating, among others, how the standard has driven technical innovation, closer cross-industry collaboration and significant changes in practice. It provided critical insights into the challenges encountered by the different parties during the design, procurement and construction stages in each project. By studying the experience gained by various parties involved in each case study, not only the architects, the research was able to analyse the process from multiple perspectives. This is particular critical due to the exceptional level of collaboration between designers, technical consultants, contractors and clients that were required to deliver projects of this standard effectively. The interviews were used to unshackle some of the tacit knowledge accumulated by practitioners in the context of real life projects that rarely become subject of deeper retrospective analysis. They permitted gaining deep insights into the immediate technical, economic and organizational challenges as well as some of the broader cultural barriers, such as the implication of the current standard of vocational and technical education in the UK for the successful delivery of the PassivHaus standard.

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Section 01

An investigation into the use of Passivhaus in educational buildings

Introduction: Educational Buildings

Adam Nightingale, Katarzyna Kwiatek, Sam Fleming

In the last 10 years, 834 schools have been built using the £34 billion of Government money through the BSF, Academies' and PCP schemes. In 2011, 25 new and refurbished schools were randomly selected by the Partnerships for Schools group and assessed. With an on growing number of educational buildings currently on the rise, the issue of energy efficiency is an immediate concern in order for the UK to meet future energy targets. Whilst Passivhaus has been previously seen as a niche approach within the residential sector, its influence is now growing rapidly within the public realm. With regard to energy efficiency, the standard creates a potential solution to obtain future energy targets. However, a considerable amount of innovation around design and construction techniques is necessary in order to catch up with European counterparts. In order to identify the key constraints to achieving this standard within the public sector, three recent non- domestic case studies have been analysed to understand the design and construction techniques which are currently being adopted in the UK.

Montgomery Primary School was the first project as part of the Devon County Council's Primary Capital Programme (PCP) 'strategy for change' and therefore was overseen by the Zero Carbon Task Force (ZCTF), enabling them to create an exemplar school that would be easy to reproduce across the country. In 2008 the UK government budget announced its ambition that all schools should be zero-carbon from 2018, therefore the Department for Children, Schools and Families (DCSF) established the Zero Carbon Task Force (ZCTF); to give advice on how England can achieve this ambition and to create a set of guidelines and recommendations for schools to follow in order to achieve 'zero-carbon' in use status (Tatchell, A).

The Centre for Disability Studies, designed by Simmonds.Mills architects, is the first non-domestic, purpose build project certified to the Passivhaus standard in England. 'Disability Essex' is a charity organisation, that were looking for a building which would provide flexibility with minimal running costs. The project's main focus was on energy efficiency and maximising daylight in order to displace the use of gas for space heating as well as increasing comfort to it's users – that it, those with physical, sensory, cognitive and learning disabilities.

The final case study is located in Tonbridge, Kent. The Rural Regeneration Centre (RRC) was the first educational Passivhaus is the UK. Providing seminar based teaching spaces for students at Hadlow Agricultural College, as well as providing for the local community, this was the first Passivhaus project completed by design and build company Eurobuild. Minimising risk from an early stage was critical in this project, providing an insightful case study into the role and importance of BIM (Building Information Modelling) in achieving Passivhaus status.

MONTGOMERY PRIMARY SCHOOL

Sam Fleming

Location Exeter
Building Type Primary School
Construction Type Structural Insulated Concrete Panels
Floor area 2786m^2
Completed March 2012
Year Certified Early 2012
Overall Cost £8.9 million, £3194/sqm

Client Devon County Council
Architects NPS South West
Main contractors BAM Construction
Council Devon County Council
Certifier WARM Low Energy Building Practice
Consultants and Collaborators Centre of Energy and Environment, University of Exeter; Robson Liddle; W.T.Hills; Buchan Concrete Solutions; John Parker Associates; N.G.Bailey Ltd.
Funding sources Devon County Council Primary School Capital Programme (PCP) £7.3 million; Zero Carbon Task Force (ZCTF) £1.2 million; Devon County Council contribution to the acquisition of new knowledge in this field £400,000.

Abstract
A case study on the project Montgomery Primary School that aims to interrogate the technical, economic and cultural challenges that the team faced in order to deliver one of the first Passivhaus standard schools in the UK.

Figure 2: Computer modelled image of the school

Figure 3: Photograph of the PV panels and the neighbouring buildings.

Montgomery Primary School Case Study

As part of Devon County Council's Primary Capital Programme (PCP) 'strategy for change', the decision was made to demolish the existing Montgomery Primary School in Exeter and to replace it with one of the UK's first Passivhaus standard schools. In 2008 the UK government budget announced its ambition that all schools should be zero-carbon from 2018 and the Department for Children, Schools and Families (DCSF) established the Zero Carbon Task Force (ZCTF); to give advice on how England can achieve this ambition and to create a set of guidelines and recommendations for schools to follow in order to achieve 'zero-carbon' in use status (Tatchell, A). Montgomery Primary School was the first project as part of this scheme and therefore was overseen by the Zero Carbon Task Force (ZCTF), enabling them to create an exemplar school that would be easy to reproduce across the country. The £9.2 million project, designed by architects NPS South West and built by the large contractor firm BAM, received a £1.2 million grant by the Zero Carbon Task Force, with the ambition being to create a 'climate change ready school' using innovative sustainable design, construction and renewable energy technologies (Tatchell, A).

At the time of commission there was no agreed definition to the term Zero Carbon, therefore to progress the scheme (and secure grant funding) the designers agreed on a definition of 'Zero Carbon in use over the annual cycle' therefore removing the argument for embodied energy in the materials (Sutton, R).

Development of Brief

The general design philosophy was to use on site renewable energy sources to meet the 'Zero-Carbon in use' target, and the first step was to minimise the building's final energy consumption by pre construction modelling. Passivhaus has a proven capability of achieving low-energy-in-use buildings (Tatchell, A). After consideration, Photovoltaic panels were chosen as the most appropriate solution since the site did not lend itself to wind or water-based power generation (Tatchell, A).

The school, which was completed in October 2011, received a great amount of collaboration from a number of organisations during each stage from the initial design to the final completion, and is now being monitored by the University of Exeter to determine whether the school will achieve its 'zero carbon in use' status after 5 years (University of Exeter). This means that the net energy will be equal to zero over the year. The key element of the design, which helps to achieve the Passivhaus standard, is the highly insulated and airtight building envelope. The principle behind this is to maximise the natural heat sources, such as solar gain and body heat, and trap them in the building, thus reducing the need for conventional heating. The project aimed to be as air tight as possible, with a minimal air leakage of < 0.6 air changes/house volume/hour – which is equivalent to an air permeability value of less than 1 m3/m2/ hr @ 50 Pa (Devon County Council). The team established at an early stage that a U-value of below 0.15 W/ m2/K was required and that glazing should be limited to 0.8 W/ m2/K, which could be achieved by using triple glazed units. (Devon County Council)

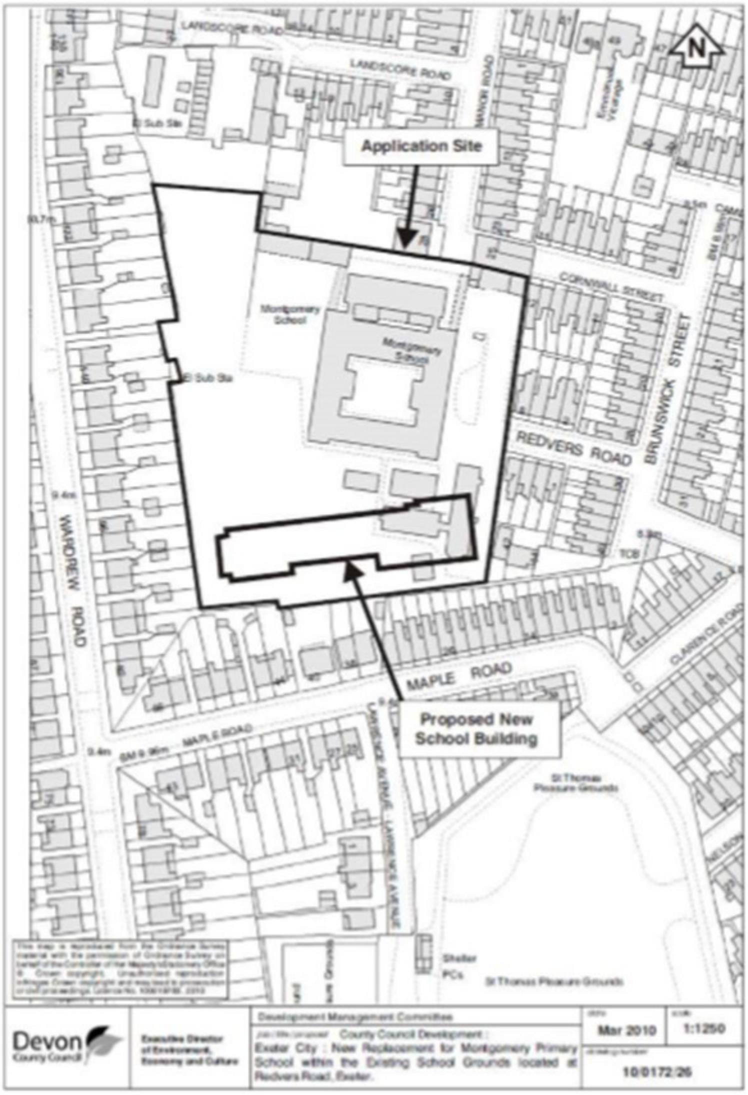

Figure 4: Devon County Council Planning Proposal – note how close the building is to the southern boundary.

Figure 5: Photograph showing PV roof mounted panels

One of the requirements was to have a predominately concrete structure, thus to provide thermal mass and to help regulate/control the temperature. It was intended to act as a heat store and therefore reduce the risks of temperature extremes (Tatchell, A). This concept works in conjunction with the next design philosophy, which was to incorporate controlled mechanical ventilation and heat recovery (MVHR) into the design of the building. The MVHR system delivers fresh air into the building's habitable spaces (i.e. the classrooms and offices) and extracts air from the wetter areas (i.e. the kitchens and toilets) all at relatively low air speeds (Dadeby 2012). This would be used during colder months and works by warming the supplied air using a counter-flow heat exchanger, the major part of the warmth from the exhaust air is fed again to the fresh air supply – with heat being transferred from high occupancy spaces to low occupancy ones if needed. In addition, the idea was for supplementary heat to be supplied via simple electrical heating elements inside the ducting (Devon County Council). During summer months, natural ventilation via open-able windows would be used.

Another one of the team's design focusses was to ensure that the users of the building (i.e. the pupils and staff) use the building correctly and fully understand the main principles in order to gain maximum benefits from a Passivhaus building. The education of the occupants is an important aspect of making it successful, particularly in a public building, as the balance of thermal mass and heating/ventilation could be easily disrupted by users leaving doors and windows open. Energy consumption is also an area where the co-operation of the users is necessary to achieve the design aspirations, with the incentive being income potential from Feed in Tariffs and potentially no energy bill in the future (Devon County Council).

Form Factor and Orientation

A key aspect that the team had to take into consideration when designing, was the location of the building on the site. The existing Montgomery Primary School was required to be in use throughout the entire construction, therefore this will have impacted certain elements of the design. The adjacent image shows the planning proposal of where the building was to be situated on the site. The new building is located 8 metres away from the southern boundary of the site, which avoided the potential impact of the properties on Maple Road. Initially, the building design was extremely tight against the southern boundary of the site which is why the east/west and the interior layout had to be repeatedly reworked and honed to reduce the overall floor size and ,as a result, the cost. One of the proposals was to be a part 3 storey building, which would have solved the problem of how large the building is on the site. However, in order to achieve the most economic PV output from the minimum square meters of panels, the building was reduced to just 2 storeys, which obviously had more of an impact in terms of space on the site and its constraints, nevertheless, this was a compromise that the team thought was worth taking as it improved the efficiency of the PV panels. Although the use of renewables is not a specific requirement of the Passivhaus standard, the team and the client opted to implement Photo-Voltaic panels in order to achieve their 'zero carbon in-use' aspirations. With the south facing roof sloping down at 35º, the Photo-Voltaic (PV) roof mounted panels are at the optimum angle for the best energy performance. The PV panels are supported by the building structure and attached to the roof by special thermally broken brackets and steel beams (NPS). The PV panels also extend beyond the building and over the roof to maximise solar exposure.

In terms of form factor, a compact design is generally required to achieve Passivhaus standard as the ratio of external surface area to internal floor area (i.e. treated floor area TFA) is generally lower (Dadeby 2012). This building has a simple rectangular plan, with the long facades facing north and south to optimise solar gain. In addition, the shape and orientation follow the site boundary, thus maximising the external space on the rest of the site.

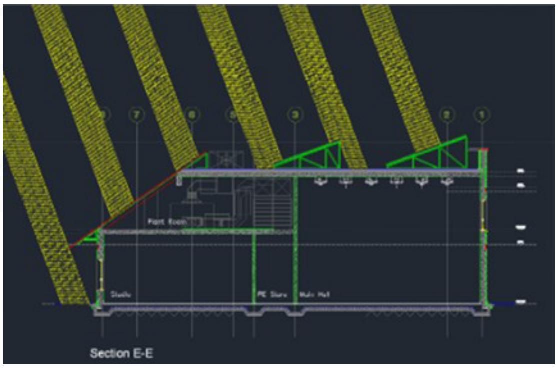

Figure 6: Environmental section showing PV panels and sun angles (summer)

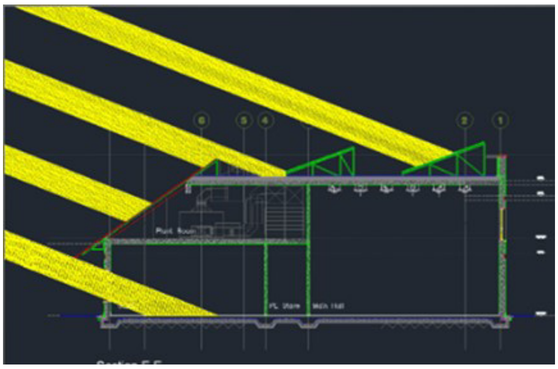

Figure 7: Environmental section showing PV panels and sun angles (winter)

Figure 8: Analytical author's sketch showing floor plan arrangements: Ground floor and First floor

However, certain restrictions were imposed due to the width of the site and the area around the existing school, the classroom sizes are slightly deeper than a standard classroom, meaning the area for glazing is reduced. Therefore, the team introduced high central skylights and light wells to compensate for this. Additionally, this provides routes for air flow to the central corridor, adding to the natural cross ventilation (Tatchell, A).

Typically in Passivhaus design, the most habited rooms are positioned on the south elevation with plenty of glazing for solar gain. However, interestingly all the major rooms (such as classrooms) are orientated North to avoid overheating and glare. Overheating is a common problem within school buildings due to the fact that there are often up to 35 pupils in a classroom at a time, this creating a large amount of body heat which can be too hot on summer days. Had the classrooms been orientated on the south façade, there would have been a high possibility of overheating during warmer months and times of high occupancy. Therefore the south is predominately used for circulation and overflow spaces as these will generally not have as much use.

Before the brief for a 'Zero Carbon in-use' School was issued, possible forms and technical demands had already been considered and pre-conceptions on the form and external appearance had already been assumed by some of the design team. Generally in Primary Schools, the norm is to promote many free flow opportunities in and out of the building to aid independence for earlier years. However, in the case of Montgomery Primary School, the team wanted to minimise the number of external doors and the periods that they are open, by incorporating automatic opening doors via push pads, in order to minimise heat loss in winter. This technique did have implications though, as limiting the classroom window areas to the minimum necessary also impacted on the natural daylight levels which the team enhanced by the use of internal windows which lead onto the highly glazed central corridor. The classrooms are benefiting from a mixture of natural light via the north facing windows (so no glare) and 'borrowed light from the heavily glazed south facing corridor, the result provides suitable light for learning which is not too bright and overpowering.

Layout and Function

Typically in Passivhaus design, the key principles remain the same, such as: getting the fabric right, form factor, ensuring there is sufficient solar gain and shading, making sure the insulation is overall and avoids thermal bridges etc. This therefore, has had some impact on the general design areas of a school and has forced some compromises. In particular, with the location of open able doors, standard primary school classrooms may have an exterior door/ fire exit from either the back of the room, or in the cloak room/ sink area. However, at Montgomery the rooms have been designed in a more flexible way, making use of partition walls. The main access routes are contained in stairwells and circulation areas or via lobbied doors, in order to maintain the heat in the building (Devon County Council). Therefore, creating buffer zones between the internal and exterior spaces, thus reducing the amount of heat loss. In addition to this, the doors have been fitted with opening mechanisms, this is one of the techniques that the design team used to help control the users' behaviour in the building and prevent doors being kept open unnecessarily, which can often be the case in public buildings. Caution is generally needed with the use of these doors during the winter as the central core of the building is at risk of cooling down significantly, requiring large amounts of energy to re-stabilise temperatures (Devon County Council).

Figure 9: Photograph showing construction of the new school, it is clear to see how the concrete panels start to show the building form.

Figure 10: Photograph showing the construction process.

Figure 11: Interior photograph of the plant room - where all the mechanical ventilation and services are kept.

Certain restrictions have been imposed on the planning/ layout of the building due to the size of the site and also due to the strong ambitions that the team had in achieving Passivhaus standard. For instance the classrooms are slightly deeper than typical UK classrooms (Devon County Council), and therefore spatial arrangements and lighting were quite important factors to consider in order to compensate for the unconventional shaped classrooms. One problem due to the narrower classrooms is the reduced amount of exterior glazing, one of the ways that the architects addressed this was by including high central skylights and light wells. These served dual functions, not only did they provide a better daylight uniformity factor than would otherwise be the case, but also, they allow for natural ventilation during summer by providing an air flow route through to the central corridor/ circulation space (Devon County Council). The classrooms also make use of borrowed light from other spaces within the building by having glazed openings, reducing the need for sunlight and therefore solving issues with glare and overheating. In terms of the sizing of the classrooms, the design team have maximised the useable space by locating sinks in central resource areas.

Materials

The fact that the concrete panels were quick and easy to put up and that no scaffolding was needed also means that fewer people were needed on site, making this a much more economical option than a more traditional approach. “We could have gone for a precast concrete frame but that would have meant a separate cladding system and more interfaces and workmanship issues,” explains James Turner, BAM’s senior site manager (Lane, T). One key decision was the use of insulated precast concrete panels for the structure, as opposed to conventional timber or masonry. These insulated precast concrete panels were chosen to give the building a large amount of thermal mass and therefore to help control the temperature, also the idea was that these insulated concrete panels would reduce energy use as heat would be stored in the thermal mass and less energy would be needed to heat the building up.

The panels consist of a 150mm structural inner slab which is joined to a 75mm outer skin. Sandwiched in the middle is 150mm of PIR insulation, which gives a Passivhaus-compliant U-value of 0.15W/m2K (Buchan). In addition, there is around 200mm extruded polystyrene (XPS) insulation above the precast roof deck and 150mm of high-performing dense expanded polystyrene (EPS) insulation under both the raft foundations and floor slab. (Tatchell, A). Externally, the high quality finished concrete was left untouched and kept exposed, the interior slabs were literally painted, keeping costs down and maximising heat transfer between the concrete and the interior. The panels are joined by steel rods which link together the wire hoops at the end of each panel, grout is then poured the gap to lock everything together, making them structurally sound and airtight. The Precast concrete panels comprise 104 external ‘sandwich panel’ walls and 84 internal walls, along with 217 floor and roof slab units of plain reinforced concrete, pre-stressed solid and pre-stressed hollow core. The sandwich panel thickness varies from 370 to 410mm and comes with high performing rigid foam insulation already installed and protected behind thick concrete (Tatchell, A).

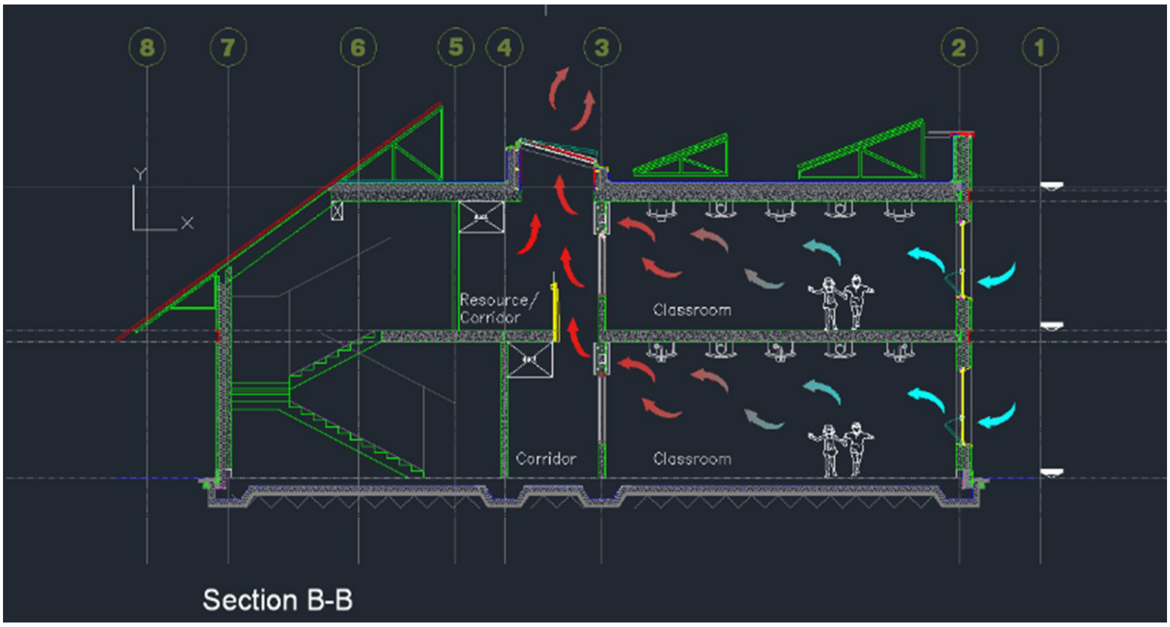

Figure 12: Section showing the natural ventilation during the summer – note how the cold air comes in through the open-able windows on the north façade and flow through the classrooms into the central corridor space where the warm air leaves the building via the roof windows. The body heat from the classrooms is fed into the central corridor creating a reservoir of warm heat, thus removing the need for a conventional heating system. This corridor also benefits from solar gain on the south façade.

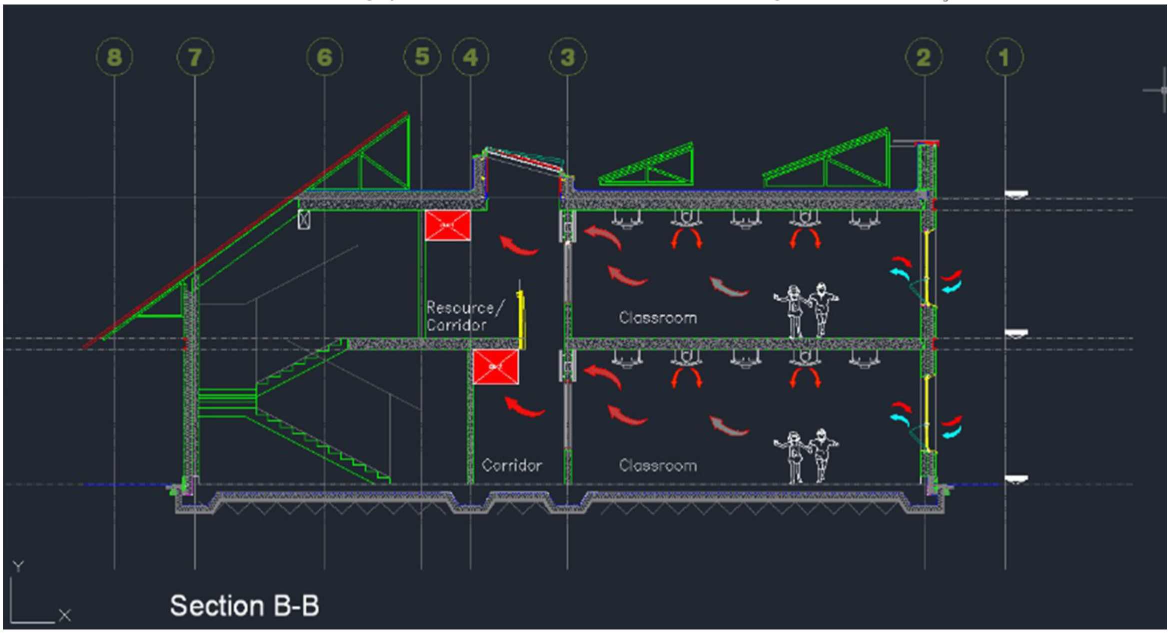

Figure 13: Section showing the mechanical ventilation during the winter – the classrooms benefit from trace heaters which release warm air during colder periods. The school has a 60% reduction plant space requirement compared with a normal school (JPA).

The design and construction teams encountered problems with providing a continuous layer of insulation around, under and on top of the whole building, particularly where structural junctions and the joining of different building elements occur. A certain level of experimentation was used to determine the best solution, which is why a "sample, try, test and dismantle" method was used (Tatchell, A). This proved to be very useful during the early stages of design and construction as it was often apparent that the team's original ideas were unsuccessful, and have suggested that a revised detail or slightly different approach would be necessary for a better result (Tatchell, A). To ensure as much air tightness as possible and to prevent cold bridges, the team sealed any gaps with tape and filled with a low expanding rate foam. Although a great amount of effort was put into designing the correct method of insulation, ultimately it came down to quality control and workmanship during the construction stage to ensure that the insulation works as intended. The panels therefore had to be tightly butted and joined to minimise the gaps that needed sealing. Junctions at tops and bottom of insulation are also sealed on a thin bead thereby eliminating thermal bypass (Tatchell, A). In addition, reducing the need to breach the insulation layer had to be a prime consideration as even modern products struggle to compete thermally with the insulation they are bridging.

Heating and Ventilation

The general strategy for heating the building relies on the body heat of the occupants, along with the high thermal mass, insulation and air tightness of the building envelope to help control the temperature. During the summer months, the building is mechanically ventilated using an ultra-high efficiency heat recovery air handing unit (where the heat recovery rate is over 82%) (Tatchell, A). Trace heaters are also provided in individual classrooms for extreme cold conditions. Interestingly, the strategy for cooling most of the classrooms is by passive cross ventilation, cold air is brought in through the north facing windows which is passed through the classrooms and into the central corridor, where the warm air rises and leaves the building through open able roof windows, thus cooling the building. See diagram. The ventilation strategy was partly devised from further computer modelling by NPS, which helped determine some of the lighting levels, which is dependent on the placement of windows and rooflights.

Collaboration and Prototyping

As the project was very much the result of a collaboration between different parties, (i.e. NPS, BAM, Exeter University etc.) there were many opportunities to review any issues with the initial designs or concepts. One major advantage that this project had, was the international contacts from BAM's sister company in the Netherlands, where they had significant experience with Passivhaus design. This therefore provided the project with crucial advice and feedback to solve any problems that they encountered.

Academic colleagues from the Centre for Energy and the Environment at the University of Exeter played an important role in the design stage and developing the design philosophy in the Client Brief, they modelled the design of the school using weather files from one of their previous projects (Exeter University). As the building uses exposed concrete in the classrooms and corridors, it was important that the team considered options to improve the acoustic qualities of the interior rooms. The Centre for Energy and the Environment helped to design 'acoustic rafts' on the ceiling so that the reverberation in the room was kept low, whilst allowing air to flow over the exposed concrete so that access to the thermal mass is maintained. In addition to this, the team essentially created a classroom prototype with the first set of concrete panels in order to conduct some acoustic tests within it (Exeter University). From this experimentation, it was found that the acoustic conditions exceeded expectations and also the Centre's specially designed acoustic air-transfer baffles worked extremely well. The Centre of Energy and the Environment had to come up with a solution to allow air to flow naturally throughout the building without making compromising the sound conditions (which could disturb lessons) therefore, they designed a solution that used acoustic tiles to construct a bespoke air-transfer baffle (Exeter University).

Figure 14: Photograph showing the German Passivhaus School using a concrete panelled method of construction.

Figure 15: Photograph of flat roof and sky lights

Prototyping and experimentation also played a crucial role in the development of this project as the team were able to test whether an idea would be successful or not. An issue arose with heat loss and thermal bypass where convection currents within insulated cavities reduce the effectiveness of the insulation, this can be due to gaps in the insulation as little as 2mm (Lane, T). Therefore it was important that the quality control was high and the correct sealant was used. The team made various prototypes and decided that expanding foam was the best solution to seal any gaps in the insulation. Modelling and prototyping was also used greatly in determining how the windows would be attached to the panels, as it was important for the junctions to be airtight. A mock-up panel and window was used to investigate different techniques for fixing them together, the team had to decide whether positioning the windows on the same plane as the insulation would be airtight enough. Eventually, the team decided to fit the window into the aperture between the insulations. A special adhesive paste is used to fix the cloak to the panel's inner leaf, ensuring an airtight seal. This is covered with a decorative wooden strip. The integrity of the seal was locally tested with smoke pencils. (Lane, T) This technique of prototyping and modelling enabled the team to come up with an effective solution to the problem of making the window fittings airtight, allowing it to be an easy and consistent strategy that can be replicated in schools across the country.

Some members of the team from Devon County Council and BAM visited some exemplar Passivhaus school projects in Germany to gain crucial knowledge and understanding of the principles used in Passivhaus design (Critchlow, L). One of the schools they visited was a 260 pupil school, so slightly smaller than Montgomery Primary School. However, the key principles remained the same. One of the main things that came from this experience was the idea of using high thermal mass in order to control the temperature effectively. This is where the team came up with the precast insulated concrete panel solution as it was also adopted by the German schools and proved to be successful. It became clear to the team from this experience, that a balance between high thermal mass on the north, west and east facades (with minimal glazing) along with low thermal mass (and large amounts of glazing) on the south façade was required (Coley, D). Note the adjacent image shows how the German Passivhaus School was constructed using concrete panels, it is clear to see how this influenced the design of Montgomery Primary School.

Leo Critchlow of Devon County Council was the project officer for the Montgomery Primary School build and incidentally was one of only three members of the team who were involved in the project through its entirety. Leo Critchlow, worked alongside Malcom Hopkins and David Coley throughout the whole project. David Coley, at the time worked with the Centre for Energy and the Environment at the University of Exeter, and was one of the principle drivers for the zero-carbon Passivhaus project. David Coley, had been working on the design of a low carbon building for over twenty years and had researched thoroughly into the Passivhaus principles and technologies, in order to come up with his own school design. David Coley, who is currently a Professor of Low Carbon Design at the University of Bath, said: "I have been carrying out research into Passivhaus technology for over twenty years, and in that time I have seen the technique grow in use outside the UK, especially in Germany where over 20,000 buildings have been realised. I worked closely with Devon County Council and the Department for Education, and the result is a zero-carbon purpose-designed building that will require almost no heating and is fit for purpose until at least 2080."

Figure 16: Interior construction photograph

Figure 17: Interior photograph of naturally lit central corridor

Figure 18: North façade photograph showing external play area and classroom entrances.

One of the problems that have become apparent from interviewing the project officer at Devon County Council was the miscommunication between the various members of the design team and the council. Although, David Coley had devised much of the design on paper over the last 20 years, the design was completed by NPS South West Ltd. According to Leo Critchlow, the design of the school was predominantly divided up between various designers/ architects at NPS South West, meaning that the project lacked continuity. Additionally the majority of the team working on this project had little or no experience in Passivhaus design, for public or indeed residential buildings. Therefore, this was a learning experience for everyone involved and created many problems/ issues along the way. One issue which was brought up throughout the course of the project was how to deal with heat loss within the building from the constant opening of external doors. The team resolved this by incorporating lobbied entrances into the classrooms, which act as buffer zones and therefore help reduce heat loss. However, interestingly, the main entrance on the north façade of the school does not have any kind of lobbied space. Since these doors are used throughout the whole day and is the main way of entering the building for visitors, it makes little sense as to why the team did not include some kind of buffer zone at the main entrance, which is probably used most frequently. Heat loss is a regular problem throughout busy times of the day and caution is generally needed with the use of these doors during the winter as the central core of the building is at risk of cooling down significantly, requiring large amounts of energy to re-stabilise temperatures. After speaking with Leo Critchlow at Devon County Council, she said that this idea was proposed to the design team on numerous occasions by the council and client, however it was eventually disregarded for a number of factors. Looking back at the project, and evaluating the faults within the building, this is an aspect which could dramatically improve the comfort of the interior and help stabilise the temperatures. In fact, Leo Critchlow even said that in the future the council may decide to introduce a lobby or some kind of buffer zone to the main entrance as it would be extremely beneficial and would far outweigh the costs.

After speaking to Devon County Council, it is clear to see that the move from a traditional 1930's building to a modern Passivhaus build was quite a challenge, and turned out to be a steep learning curve for everyone involved. However, the learning process continued post-construction and involved all the users of the building. This is why it was important for the team to ensure pupils and staff were sufficiently educated in how to use the building to achieve its full potential. A series of training days were arranged for the staff to teach them specific methods and techniques of using the building and the equipment within it. From the outset, it was clear that some of the teachers and staff were unaware of how to use the mechanical ventilation system and when best to open windows.

Originally, the build was scheduled to be completed in September 2011 ready for the start of the new school year, however, the completion shifted to October half term due to a number of issues taking its toll on the time scale, such as weather conditions and construction delays. Unavoidably the balancing and commissioning the M&E was quite rushed, which caused problems later down the line. The mild autumn 2011 did not immediately reveal any problems, however, after the Christmas break, when the school was closed and unused for two weeks, complaints and concerns began to arise, particularly during the much colder variable weather (Leo Critchlow, Devon County Council). After completion, the project was reviewed by some of the technical design team members, where it was said that the design is satisfactory but did not meet the end users expectations. This was apparently down to how the occupants were initially using the building, constant comments were made about windows and doors being left open unnecessarily and the occupants not interacting with the building and the design intent (Leo Critchlow, Devon County Council).

According to the computer monitored room temperatures, the main area which was flagged as a concern was the reception and main lobby area which had the main entrance doors constantly opening. However, when members of the team sat in a room which was supposedly meeting and surpassing the minimum temperature requirements and found themselves getting chilled in the process the team realised further action was needed and a number of adjustments were made (Leo Critchlow, Devon County Council). The resolution came with the whole team together at the school where it became clear it was not the occupants but shortcomings in the commissioning and balancing that was contributing, together with local detectors for CO2 not being calibrated at the same level as the MVHR system, so teachers were opening windows unnecessarily. Added to this, window closing bars needed to be adjusted to an even snug fit to eliminate the 'whistling' building syndrome that was evident (Devon County Council).

Conclusion

Overall, to summarise the key design aspects and the general approach that was taken, this 420 pupil school was built using Passivhaus principles and adopted high thermal mass, air tightness and thermal insulation from the insulated precast concrete panels in order to eliminate the requirement of a traditional boiler for heating. With the primary heat gain being from the occupants, a mechanical ventilation system was in place to prevent overheating in winter, furthermore all the classrooms were positioned on the north facade with the provision of a south facing draught lobby to maintain air temperature and control air leakage whilst providing direct access to outside. In order to increase the cost-effectiveness and buildability of precast prefabrication, the team developed a modular approach where all the classrooms were designed as identical units incorporating toilets, cloakrooms and stores between (NPS). This leads onto the theme of modularity and how this school was intended to be an exemplar project to determine a standardised design for future schools in the UK.

Additionally, this case study has explored the problems and challenges that the team faced when trying to implement the Passivhaus standard in a public building. Generally, Passivhaus has predominantly been used for residential buildings in the UK so far, therefore this project can be seen as a pioneering effort to apply it to public buildings. One thing that is clear after speaking to the project officer and various other members of the team is that a lack of communication between the various companies that collaborated was a key problem throughout the design and construction process. As the project lacked continuity in terms of the people working on it, certain mistakes were made which could have been avoided, such as the misunderstanding with the collaboration of the mechanical ventilation system and also the main entrance doors not having enough lobby space to help prevent heat loss. Another significant aspect that this case study has explored is the process of knowledge transfer between the UK and Europe – how certain members from BAM and Devon County Council actually visited existing school projects in Germany to gain expert knowledge and expertise on the Passivhaus standard. This helped the Montgomery project a great amount as the team were able to use and draw upon some of the key methods and techniques that were adopted in the German Passivhaus schools.

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Architectural Appraisal
Planning Consultation Minutes
Planning Permission Decision Notice
Devon County Council Design and Access Statement
Montgomery Primary School Exeter Awards
Briefing Note on Montgomery Primary School Devon County Council
Presentation and Script courtesy of Leo Critchlow
Chris Rea's Passivhaus Conference Presentation
Dr David Coley's German Passivhaus Presentation
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Robson Liddle Foul and Surface Water Drainage Proposals
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Image References

Figure 1 - Courtesy of Devon County Council
Figure 2 - http://content.yudu.com/A1squ6/edbmagazine20110601/resources/61.htm
Figure 3 - http://www.building.co.uk/top-of-the-class-passivhaus-school-design/5022372.article
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Figure 5 - http://www.sceme.org/wp-content/uploads/2012/04/JPA-Passivhaus-2012.pdf
Figure 6 - http://www.sceme.org/wp-content/uploads/2012/04/JPA-Passivhaus-2012.pdf
Figure 7 - http://www.sceme.org/wp-content/uploads/2012/04/JPA-Passivhaus-2012.pdf
Figure 8 - Overlay sketch done by Sam Fleming (author)
Figure 9 - http://tinyurl.com/pl9w33f
Figure 10 - http://www.sceme.org/wp-content/uploads/2012/04/JPA-Passivhaus-2012.pdf
Figure 11 - http://www.sceme.org/wp-content/uploads/2012/04/JPA-Passivhaus-2012.pdf
Figure 12 - http://www.sceme.org/wp-content/uploads/2012/04/JPA-Passivhaus-2012.pdf
Figure 13 - http://www.sceme.org/wp-content/uploads/2012/04/JPA-Passivhaus-2012.pdf
Figure 14 - David Coley Presentation
Figure 15 - http://content.yudu.com/A1squ6/edbmagazine20110601/resources/61.htm
Figure 16 - http://content.yudu.com/A1squ6/edbmagazine20110601/resources/61.htm
Figure 17 - http://www.buchanconcrete.com/casestudies/bcs_education_montgomeryps.pdf
Figure 18 - http://www.bath.ac.uk/news/2012/03/01/passivhaus/

Author Information

My name is Sam Fleming, I am 21 years old and a thrid year Architecture Student at the University of Kent. Originally from West Yorkshire.

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In terms of the primary source research that I have undertaken, I would especially like to thank Leo Critchlow from Devon County Council, who has been extremely helpful with providing her first-hand knowledge of the Montgomery project in addition with the various planning documentation that has been crucial to understanding this project. I would like to David Coley at the University of Bath, and the various members of staff at NPS South West, BAM Construction and the Centre of Energy and Environment at the University of Exeter for their help with this project.

Centre for Disability Studies

Katarzyna Kwiatek

Location Rochford, Essex
Building Type New Build
Construction Type Floor area 307 m^2
Completed March 2010
Year Certified 2010
Overall Cost £2,039,795

Client Disability Essex
Architects Simmonds.Mills
Main contractors DCH Construction
Council Rochford District Council
Certifier Passivhaus Institute
Consultants and Collaborators (M&E- Alan Clarke, Energy- David Olivier
Funding sources contribution of £815,918 from ERDF, Public Funds: £800,000, Disability Essex: £423,877

Abstract

The uptake of the Passivhaus principals in the UK is far less than in Germany where 138 of non-domestic buildings are currently certified. Although, criterion for Passivhaus certification are very challenging the concept is being seen as a huge potential and gathers its momentum within the UK with 15 non-domestic buildings currently certified Passivhaus (NHBC Foundation, 2012). Notably, the first non-domestic structure in England designed to German Passivhaus standards is The Centre for Disability Studies located in Rochford in Essex. Designed by Simmond.Mills Architects in 2010, the case study creates a perfect base to analyse the technical, economic and cultural challenges which architects, contractors and clients had to face when delivering Passivhaus standards to a public sector in the UK.

Interrogating the technical, economic and cultural challenges of delivering the Passivhaus standard to the public sector in the UK.

Background Information

The Centre for Disability Studies is a collaboration between Simmonds.Mills Architects, the client Disability Essex, M&E consultant Alan Clarke and the main contractor DCH Construction Ltd. The submission for the project called for a new Passivhaus certified non-domestic building, targeting the BREEAM excellent rating. While Passivhaus addresses mainly the external envelope of the building, BREEAM assessment uses recognised measures of performance to evaluate a building's specification, design, construction and use which include: aspects related to energy and water use, the internal environment (health and well-being), pollution, transport, materials, waste, ecology and management processes (The BRE Group , 2014). The brief called for a building which will provide head-quarters and training facilities for Disability Essex and meeting spaces for the charity's staff, clients and visitors as well as a combination of high levels of thermal comfort, low running costs and CO2 emissions. 'This cutting edge building has been designed to use robust, 'conventional' construction, but derives its very low energy performance and high comfort levels from a mixture of advanced design and modelling, innovative construction detailing and advanced, yet simple building products' (Simmonds.Mills, 2010). Additionally, the charity wanted to generate energy on site by installing a PV system not only to reduce CO2 emissions but also to generate additional income.

'The idea for the new eco-building came as a result of the charity identifying the urgent need for new facilities to meet an increasing demand for specialist disability services. By choosing to design and construct the entirety of the building with sustainable theory and methodology, the charity is looking to minimise its impact on the environment as well as creating a bespoke and flexible building with minimal running cost[s]' (East of England Development Agency, 2010). The building, which is 553 sq.m., emphasises the use of cost effective 'passive' techniques; ensuring high levels of air tightness, superinsulation and passive solar gain. It also aims to achieve a 90% CO2 emissions reduction compared to current operational energy use. Its main focus is on maximising daylighting and passive solar gains in order to increase well-being and displace the use of electric lighting and gas for space heating. Subsequent sections will provide an in depth analysis of how building's design and construction contributed in achieving this exceptionally high standard of thermal performance and energy efficiency providing low running costs and internal comfort for its users.

Dedign Anatomy

In order to fully understand the Passivhaus concept it is important to not only follow the mandatory technical requirements but to recognise its fundamentals as an energy performance standard and also as a coherent design process. Therefore, studying design anatomy step by step is vital to understand how Passivhaus was being achieved

from the early stages of the development of the Centre for Disability Studies. In case of this project, similarly as for any other, the client usually has an initial vision for the development. 'The client wanted us [Simmonds. Mills Architects] to design so-called eco-building. Eco is anything and everything. At the time they [Disability Essex] had this idea of eco-building using a lot of eco materials, wind turbines and PV panels' (Simmonds, 2014). Nevertheless, the client's utopian vision of the energy efficient design was not convincing enough for the architects who knew that the project needed to be more about reducing the amount of the energy used and trying to make it a comfortable building to work in. 'We told them [Disability Essex] that we want to design something with a very low running cost and that their vision of the eco-building wouldn't necessarily do that – it's going to be cold, draftee and expensive to run. So we said can we try you out on the Passivhaus'(Simmonds, 2014).
As a result, it was necessary for the architect to introduce the client to the main concept of Passivhaus - 'getting the fabric right' which consequently became the main design focus in order to achieve an energy efficient building.

The architect Andrew Simmonds and his team approached the project by drawing from previous experience. While progressively learning about the Passivhaus construction the team was working on the refurbishment of Grove Cottage (Andrew's own house) to the Passivhaus EnerPHit standard. For this purpose, the architects implemented German construction details from the *Passivhaus-Bauteilkatalog: Details for Passive Houses* book, yet adjusted them to fit with well-known English construction methods which will be discussed further within the study.

Although architects had experience as well as the knowledge of different construction methods, the development of the plan and form of a building, especially of a large, public development, was challenging.
Throughout the design process, architects were trying to discard the common misconception about the Passivhaus building representing 'compact, boxy and unimaginative architecture' (Cotterell, 2012, p. 27). Andrew Simmonds believes that the Passivhaus standard encourages more efficient building form. On this particular project architects tried to maximise passive solar gain and were balancing the form of the building against a very good natural daylighting. 'The balance between passive solar gain, daylighting and making an efficient form was a very valuable set of constrains. As architects it is in our blood to play with the form'(Simmonds, 2013). Nevertheless, although the requirements of Passivhaus do influence appearance, this 'can be handled sensitively or clumsily, depending on the skills and imagination applied' (Cotterell, 2012, p. 29).
In this case study the matter was handled with care and concern. When developing design, the architects had to bear in mind users of the building – people with physical, sensory, cognitive, mental and learning disabilities. As a result, most of the building's features were dictated by its users and incorporated into design. For instance, floor textures were given special consideration for those in wheelchairs or with sight issues. Additionally, the entrance pergola (Figure 01) was carefully designed to give wheelchair users the impression of the slope minimising on entry.

The building has been designed as two linked buildings – a North Wing: Jean Strutt House and a South Wing: The Peter Broughton Wing connected by the intermediate buffer zone (Figure 02). While Wing A was designed to accommodate a foyer reception, training room, offices, kitchen, toilets and utility rooms, Wing B creates an open plan activities room. The link between the buildings, which acts as the entrance hallway, consist of a single skin and was designed to allow for the settlement between the building elements. This area is neither cooled nor heated so it can become quite uncomfortable, but it was designed this way in order to avoid people congregating in the entrance (Figure 03).
The way in which spaces were divided inevitably allowed the charity for the flexible use of the rooms according to different activities as well as to rent them (Wing B in particular) for additional income.

Figure 01 : Centre of Disability Studies - The entrance pergola with PV panels installation.

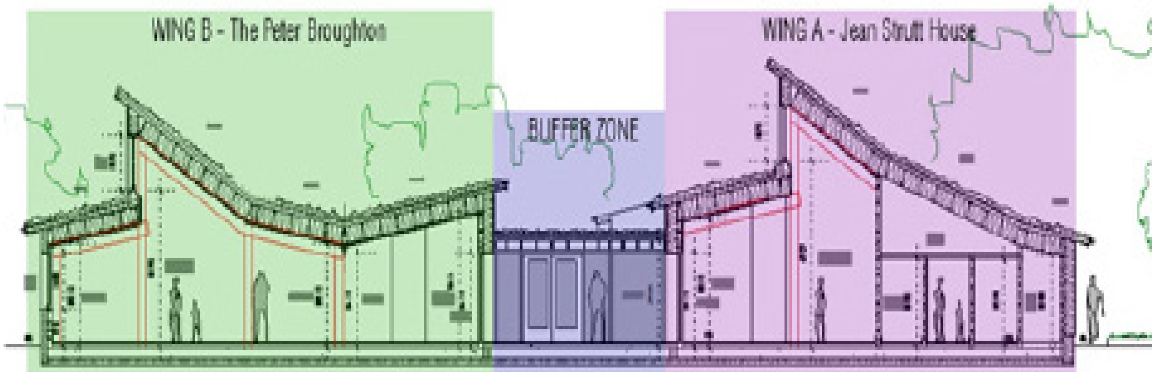

Figure 02 : Long section showing division into three seperate zones.

Figure 03 : Intermidiate buffer zone between Wing A and B.

Separating the design into three distinct parts had a huge impact on achieving the Passivhaus standards.
A good form factor (compact, simple design) means it is simpler to attain the required energy target, which then can be translated into more modest insulation values or, for example, slightly cheaper windows or other components. At first look, the plan for the Centre for Disability Studies may seem complex, implying that the form factor ratio is high and consequently better U-values are needed in order to reach the energy efficiency targets. However, by studying the plan closely it can be noticed that two wings function as two completely separate thermal envelopes which were separately certified to the Passivhaus standard. (Figure 04). This way of designing two compact forms joined together allowed the architects to achieve the low form factor needed for the Passivhaus certification, yet obtaining an architecturally interesting form.

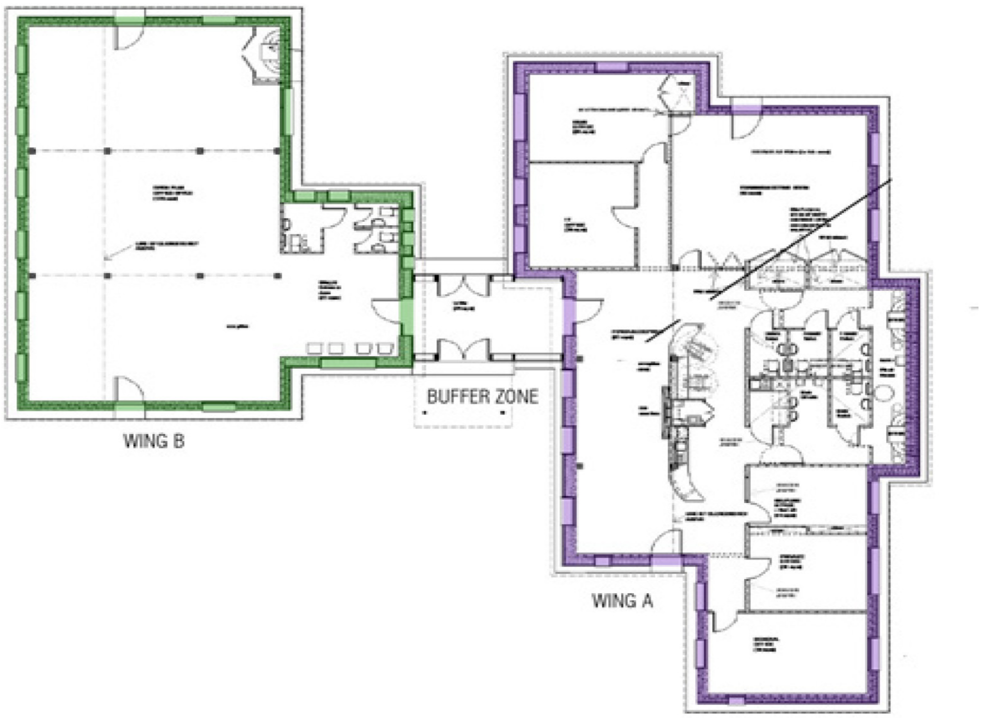

Figure 02 : Long section showing division into three seperate zones.

As already mentioned, the architects focus was on maximising passive solar gain; therefore they were balancing the form of the building against the need for natural daylighting. To achieve this goal, apart from introducing standard height openings, architects decided to introduce high level windows installed within pitched, sedum roofs (Figure 05). This combination of high and low level windows was not only used for the purely practical reasons of achieving good levels of natural daylighting, ventilation and sunlight but also for adding to its spatial qualities.

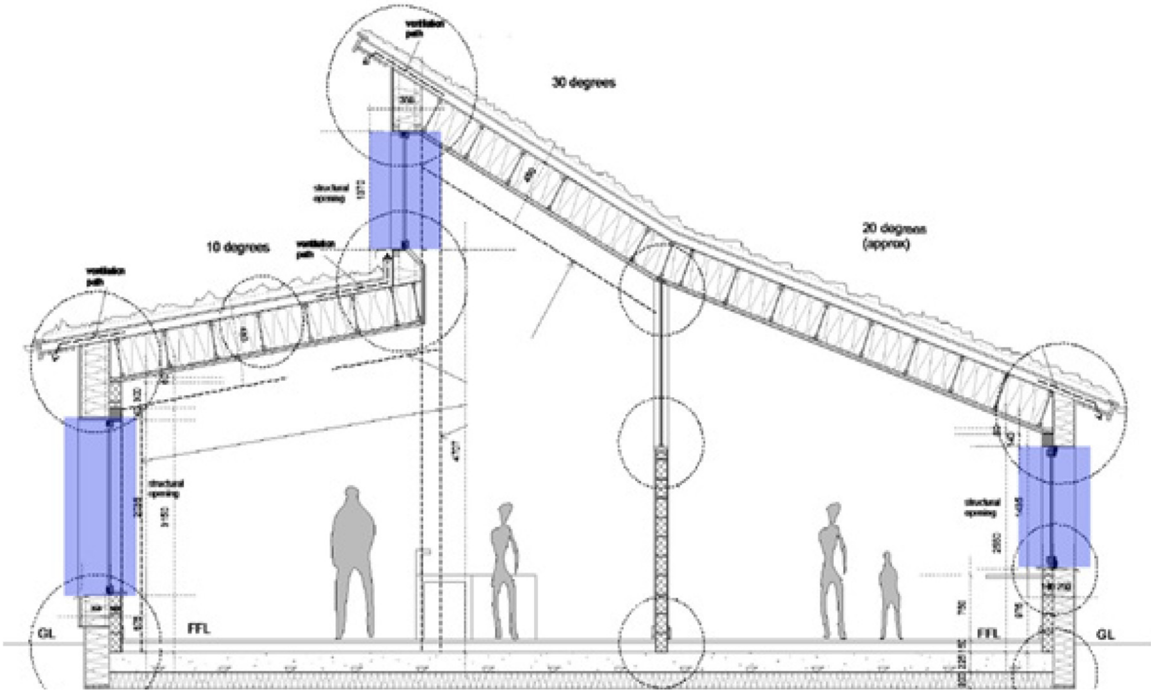

Figure 05 : Section through Wing A showing low and high positions of windows.

Cross-Disciplinary Team

Working on the design and developing its form is one thing, but in order for all pieces to come together into an organised, coherent project an experienced team with an extensive knowledge of sustainable design is needed. ‘Being able to achieve an effective, trusting and cooperative working relationship between architect, builder and client is critical to the success of a Passivhaus build. In the same way that a Passivhaus build demands much attention to technical details, this ‘human’ detail is one that must also be addressed’ (Cotterell, 2012, p. 23) In case of the Centre for Disability Studies, the architects had an extra person involved in the project. Energy consultant David Olivier, who has worked on the series of projects across the UK, advised architects on the daylighting, passive solar gain and the impact of equipment on heating. Moreover, David wrote the guide for the client so that they can understand how to use appliances (energy efficiency and heating). His exceptional and professional knowledge of energy related matters turned out to be very valuable for the architects when working on for example positioning of windows for maximal daylighting.

Additionally, M&E engineer Alan Clark worked on all services, artificial lighting as well as heating and ventilation design; aspects which are extremely important when successfully delivering Passivhaus project. Finally, structural engineer Bob Jonson, who specialises in efficient engineering, advised on minimal use of materials. He also worked with the architects on detailing structural elements of walls, roofs and windows with the use of specialist software to evaluate details. His knowledge of thermal bridge free design proved vital when attempting to achieve Passivhaus standard performance.
To ensure good cooperation between the professional team and the client architects encouraged the charity to employ their local representative. ‘They [Disability Essex] employed a local architect to be their representative which was crucial for communication purposes. The charity was very busy at the time and it would be impossible to pursue this project without that one person with a dedicated role’(Simmonds, 2014).
This was beneficial both for the architects, client and other parties involved as they could agree on decisions with one person working on behalf of the charity which made decision-making process faster and more organised.
Moreover, the architects spent a lot of time working with the client to produce a building that worked for

them and ensuring that the client understood the building and the way it uses energy from the outset, a critical missing link in so many projects.
As a result of a well organised, professional team, and good cooperation with the client, the project could steadily progress into the construction phase. 'The stages were not overlapping. We made sure that it was all in order no last minute stuff. The design was clearly defined before it went to the contractor'(Simmonds, 2014). That was very significant for the project of this nature. As of big, public development, people on construction site change and construction of Passivhaus is more complex, therefore understanding all elements before moving into construction stages was vital.

Construction Detailing

The most significant component of a building, when looking at the heat gains and losses, is the envelope as it represents the interface of the building with its environment. Therefore, it is important to study the construction of foundations, walls and the roof in order to analyse and evaluate how the Passivhaus standards were achieved through a focus on the building's skin.
When working on detailed design for the Centre of Disability Studies, the architects were highly influenced by the pioneering German's construction details handbook (Passivhaus-Bauteilkatalog: Details for Passive Houses). 'We took some of their details, took them apart and designed them back into the British way of building. We were also thinking about the local builders in Essex, so we were trying to design them [details] to their standards e.g. concrete blockwork, wet plaster etc. - simple, basic skills that they already have been familiar with'(Simmonds, 2014) (Figure 06).
Although the Centre for Disability Studies is a new-build development of a much bigger scale than Grove Cottage the experience gained turned out to be extremely valuable. Andrew Simmonds had building construction details in his head and he was trying them out on a retrofit situation. 'It was very useful, I was actually building details at the same time as developing the CarbonLite guidance for designing Disability Essex'(Simmonds, 2014). While the architects could implement similar detail principles to the Centre for Disability Studies as for the Grove Cottage some changes had to be made and that proved challenging. There were some specific details which were harder to design because of disability purposes and the Passivhaus. For example, the bottom of doors. The height of the threshold of doors has a certain maximum and the architects could not achieve that with the Passivhaus available certified doors. At the time, architects could not find an appropriate replacement product; therefore they had to get a slight relaxation of the Building Regulations. Moreover, the client expressed their need for automatically opening doors, in order to allow for the easier access for people with disabilities, which created a challenge when attempting to keep the building fully airtight. 'We needed to make sure that the building will stay airtight. I have seen it on the other Passivhaus projects when electric door doesn't shut properly so we had to spend quite a bit of time making sure that it won't happen in Disability Essex' (Simmonds, 2014).

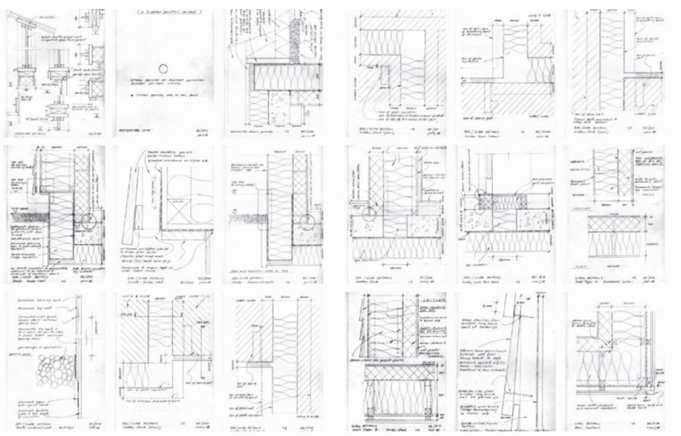

Figure 06 : Construction details sketches based on the German construction handbook.

Foundations and ground floor

The design and construction details of the foundations to ground floor were crucial for the Centre of Disability Studies to perform to the Passivhaus standard. What can usually be discovered in traditional foundation systems is the thermal bridging in the structure; where heat will be lost (Figure 07). Although the architect Andrew Simmonds claims that the construction strategy for the Centre for Disability Studies was just an evolution of what they have been doing already, there was one significant change within the foundation system used. 'It is an evolution of what we have been doing already but we made a dramatic change within the foundations'(Simmonds, 2013). The insulated raft for the foundation was first used in the Grove Cottage. It was the first time architects proposed an insulated reinforced concrete raft as a foundation strategy for the public building (Figure 08). According to Andrew, it was quite exciting as to most people it looked like there was no foundation to a building at all. 'It looked as if the building was floating. That was a big change for us and now we do all our buildings like that. It was a specific method to a Passivhaus'(Simmonds, 2014).

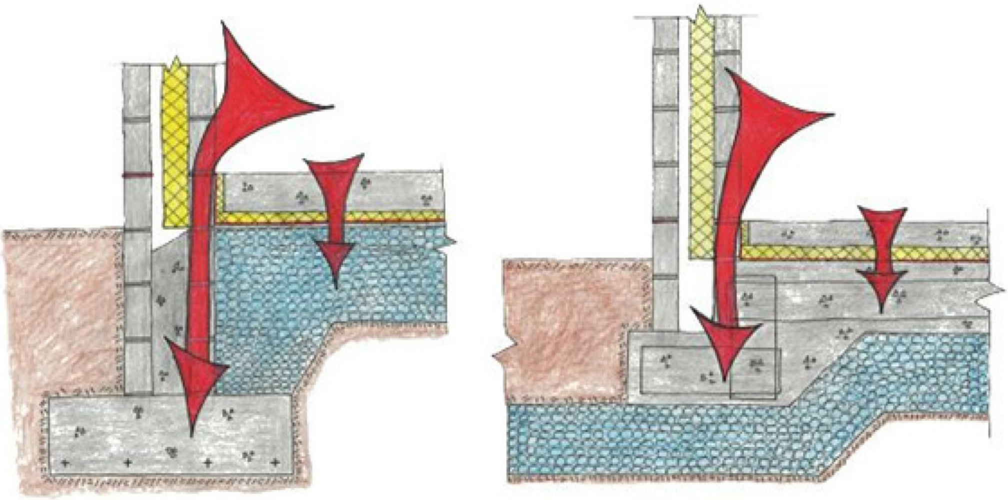

Figure 07 : Typical foundation details.

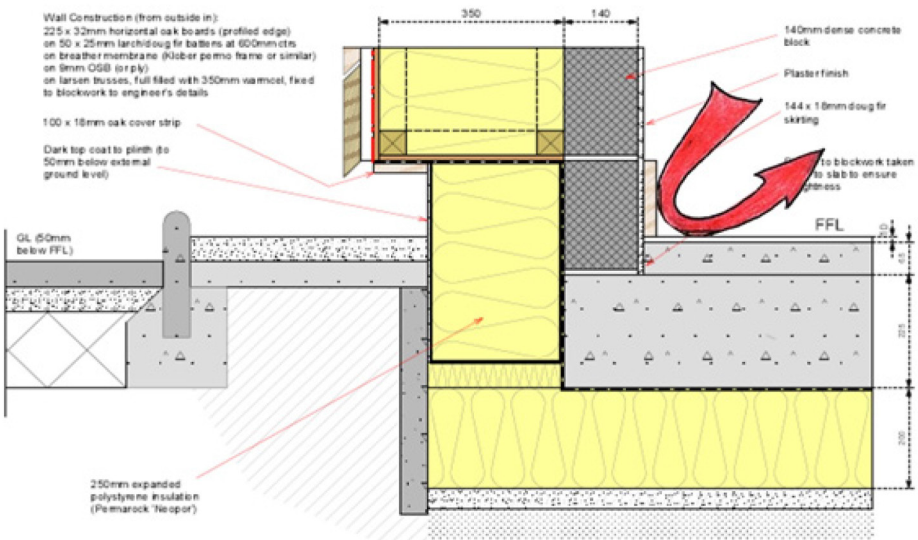

Figure 08 : Centre for Disability Studies - Foundation detail.

A Passivhaus foundation detail differs in the sense that it has no thermal bridges and is very well insulated to minimise heat loss. The design uses an uninterrupted expanded polystyrene insulation (200 and 250mm) to enclose the foundation. By locating the insulation layer underneath the concrete slab any heat loss through the structure are eliminated. Moreover, careful measures were taken in order to provide suitable level for airtight detailing. The plastered blockwork was taken all the way down to concrete raft to ensure airtightness (Figure 09).

Figure 09 : Floating foundation stsrem under construction.

Walls and Roof

When detailing walls and roof the emphasis was again placed on the thermal bridge free and airtight construction. In the building, there are two distinct wall types used for the external envelope. The first wall type uses 250mm of neopor type EPS insulation (expanded polystyrene) glued and mechanically fixed to the blockwork and then externally rendered (Figure 10). This high-performance, light-weight system incorporates microscopic particles of graphite located within insulation layer for improved thermal performance and to dissipate heat, which makes it unique in achieving required Passivhaus standards.

The second wall type is oak clad Larsen trusses (timber frame fixed to external face of 140mm blockwork) filled with blown mineral fibre (resin free) (Figure 11). Originally, instead of blown mineral fibre, the architects intended to insulate walls with cellulose. However, the alteration had to be made, as the architects were caught out with an industry change in the conductivity value of cellulose and it was impossible to change the thickness of the walls. Therefore, they required a blown material with lower conductivity than cellulose and blown mineral fibre turned out to have required value. Without this change it would have been impossible to achieve the Passivhaus target for heat demand. As a result of the change made, the overall U-value of the wall was 0.12 W/m2K.

A similar change to insulation had to be made within the roof construction which features (from outside in): sedum roof, single ply membrane, 100x50mm larch battens within which ventilation zone is created, breather membrane and 10mm ply. Further support consists of 450 mm I-beams which were filled with mineral fibre insulation, followed by airtightness membrane, battens to form a service void and external 15mm fermocell, skim finish (Figure 12). This way of detailing the roof structure allowed the architects to achieve the overall U-value of 0.08/0.09 W/m2K which, similarly as walls structure, much better than the minimum 0.15 W/m2K.

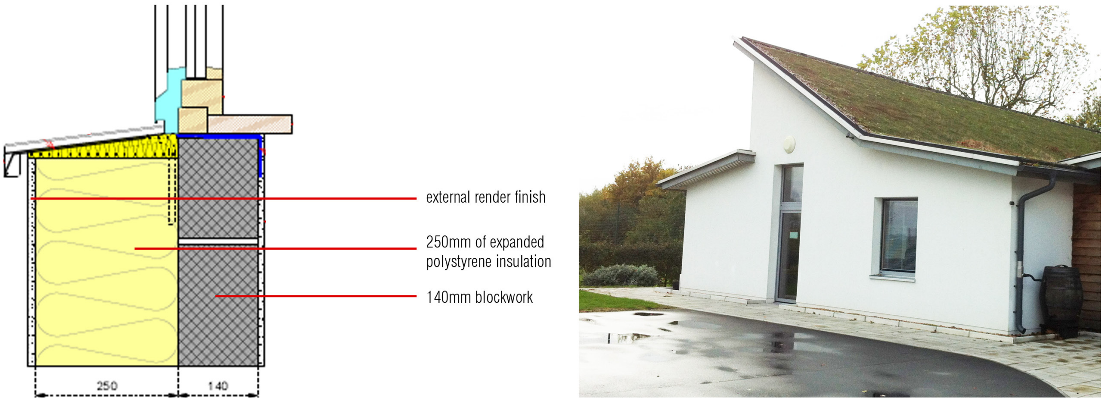

Figure 10 : Centre for Disability Studies - Wall detail.

Figure 11 : Centre for Disability Studies - Wall detail.

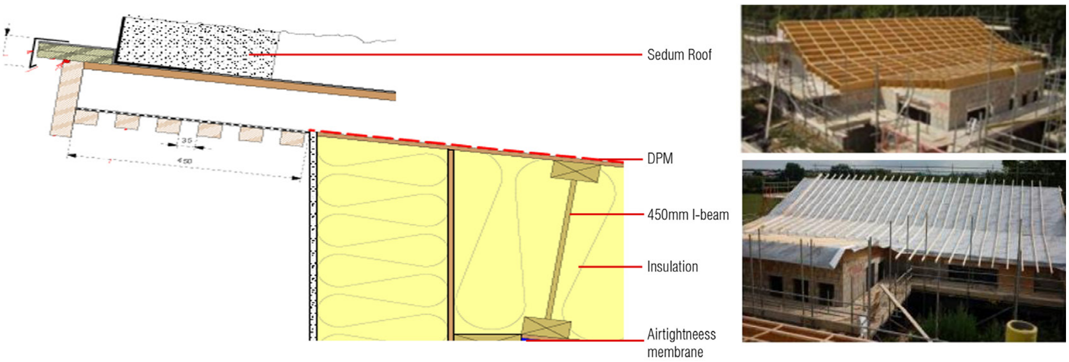

Figure 12 : Centre for Disability Studies - Roof detail.

Windows

Choosing suitable windows prooved vital in determining the overall performance and thermal stability of the building. 'When it came to selecting the windows, we were targeting very high standards of airtightness and crucial levels of thermal comfort, explained Andrew Simmonds, windows have been instrumental in helping us achieve the level of sustainability we required' (Architectural Aluminium Industry, 2013). In the Centre for Disability Studies, windows played a prominent role in two ways – firstly, the heat loss despite large glass surfaces could be reduced and secondly, windows increased the possibilities for heat gain through solar irradiation. An innovative composite windows system by Internorm was chosen, which consist of triple glazing and well thermally insulating window frames which were developed to reduce the glass edge losses. Moreover, most of the UK's traditional windows consist of aluminium spacers (small edge piece that keeps the panes of glass apart) which are good thermal conductors and thus act as thermal bridges. The windows selected for the Centre consist

of the stainless steel spacers to reduce further losses and deliver thermal bridge free detailing which is critical for the Passivhaus standard to be achieved (Figure 13). The windows used reach an exceptional U-value of 0.69 W/m^2K to meet Passivhaus standard requirement for the windows U-value to be below 0.8 W/m^2K. Additionally, the overall energy transmission value (g value) was 20 % higher than with standard triple glazing. This meant that the solar energy gain was higher. Although, the properties of the chosen product were exceptional and worked perfectly with the values that architects had to achieve for the Passivhaus certification, there was a problem faced when importing them to the UK. At the time, there were no products with suitable properties available in the country. Windows had to be imported from Austria so were more expensive and arrived on site with a slight delay, which consequently slowed down the construction process. 'We had some problems with getting the windows because quite a substantial deposit was required for such a big order. That was a really huge sum of money before the windows were even made. '(Simmonds, 2014).
Moreover, as windows were imported from Austria and the electrical systems for doors and windows were supplied by the company within the UK, the interaction between two systems was difficult. 'Interaction between all electrical door and windows was provided by different company than windows itself so interaction was difficult and time consuming. Doors and windows are heavier than normal, we can't allow people to change things just like that and doors and windows had to shut properly. We were nervous about that'(Simmonds, 2014).

Figure 13 : Centre for Disability Studies - window details.

Airtightness and MHVR Unit

The envelope of a Passivhaus building is required to be extremely airtight when compared to a conventional construction. To accomplish the Passivhaus standard it is mandatory to achieve required air tightness value of $\leq$ 0.6 / hour at 50 Pa. In the case of Centre for Disability Studies, the airtightness was achieved through using air-vapour membranes to ceilings and windows (Figure 14) as well as plastered blockwork to concrete raft within foundation detailing (Figure 15). This method, as well as careful workmanship, allowed for the sealing of every construction joint and sealing of all service penetrations. Consequently, the air leakage rate was checked by means of a depressurisation test and a pressurisation test. The results attained during this tests were consecutively 0.34 $m^3/(hr.m^2)$ and 0.32 $m^3/(hr.m^2)$ at an imposed pressure of 50 Pa, when the a forementioned temporary sealing was in place. The mean average achieved a value of 0.33 $m^3/(hr.m^2)$ which is significantly below the target level of 0.60 $m^3/(hr.m^2)$ at 50 Pa, required by the Passivhaus specifications. Although, this level of airtightness saves a lot of energy which otherwise would have been lost with the escaping air, the concept still causes concerns regarding issues of fresh air supply. A mechanical ventilation system with heat recovery (MVHR) was used as the ventilation strategy for the Centre to provide high quality of air flow within the building.
The Centre for Disability Studies features three MHVR units – two central units in Wing A (Figure 16) and one

central unit, working independently, located within Wing B. Air intakes (Figure 17) and clean air filters (Figure 18) provide ventilation needs during the winter months, when windows could not be opened without losing too much heat. The MVHR units has been certified by the Passivhaus Institute with a recorded efficiency of 91% (Paul, 2009), with further claims that the efficiency of the system can reach up to 95%. This is well within the Passivhaus minimum requirement of ≥75% efficiency.

Figure 14 : Centre for Disability Studies - airtightness of walls and roof.

Figure 15 : Centre for Disability Studies - airtightness of foundation and ground floor.

Figure 16 : The MHVR Unit.

Figure 17 : Air Intake.

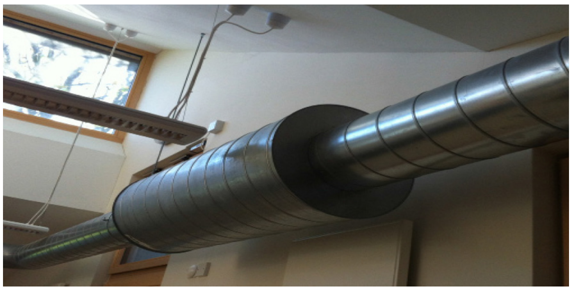

Figure 18 : Clean Air Intake.

Energy Consumption

In the Centre for Disability Studies the Passive House Planning Package (PHPP) software was used to assist in the design of buildings by predicting heating energy demand (Passive House Institute, 2012) (Table 2). With the use of the software, it was predicted that the electric energy consumption will be 6790 kWh per year. The data regarding actual electric energy consumption was calculated using the electricity bills for 2013 provided by the charity (Diagram 1). The actual consumption was 6275 kWh per year which proves the accuracy of the software when using it for assessment of the energy consumption statistics.

Measure	Passivhaus standard	Centre for Disability Studies	Was Passivhaus achieved?
Insulation Walls	U $\leq$0.15 W/m²K	0.12 W/m²K	Yes
Insulation Roof	U $\leq$0.15 W/m²K	0.08 W/m²K	Yes
Windows	U $\leq$0.80 W/m²K	0.69 W/m²K	Yes
Air Tightness	0.60 ach@50Pa	0.33 ach@50Pa	Yes
Ventilation MVHR	efficiency $\geq$ 75%	91%	Yes
Space Heating	$\leq$15 kWh/(m²/a)	15 kWh/(m²/a)	Yes
Annual PE	$\leq$120 kWh/(m²/a)	81 kWh/(m²/a)	Yes

Table 2 : Comparison of the Passivhaus requirements and values predicted by the PPHP for the Centre of Disability Studies.

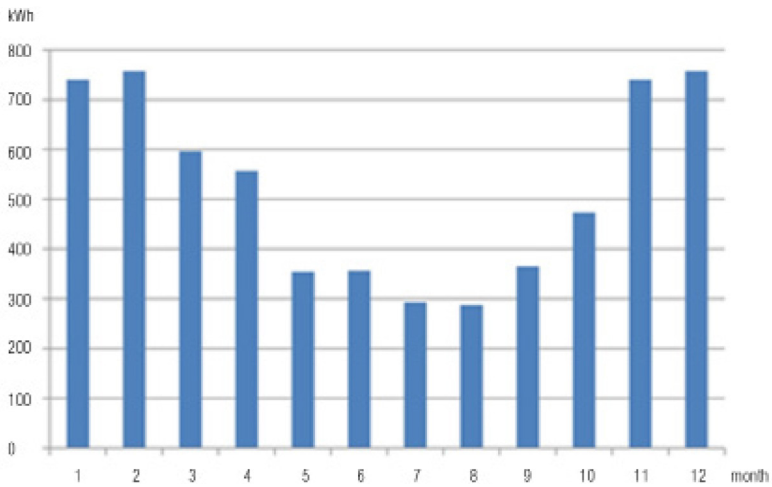

Diagram 1 : Electricity consumption in 2013.

Moreover, by studying the amount of money spent on electricity for 2012 (Diagram 2) and 2013 (Diagram 3) it can be concluded that the average monthly electricity bills are £65 for 2012 and £77 for 2013. Pet Thornton, Interim CEO, believes that values are so low thanks to well-positioned windows including the top windows which can be electrically controlled allowing for the maximal use of a daylight. Additionally, she believes that sensor controlled lighting within the whole building successfully contributes to the low electricity use. When compared, money spent on electricity in 2012 and 2013 is relatively similar, and very low for the building of this scale, which is extremely beneficial for the non-profitable organization such as the charity. 'We wanted to ensure the building's energy consumption was extremely low, wasting as little energy as possible. Utility and energy bills can be a drain on a charity's resources, so we wanted to have a building that had minimal associated cost'(Knauf Insulation, 2011). Although full data to calculate the primary energy demand for the Centre of Disability Studies was not available for this study, assuming that the prediction provided by PHPP software is accurate, the predicted primary energy consumption is 81 kWh/m^2 a year which is significantly below the mandatory Passivhaus requirement of $\leq$120 kWh/m^2 a year.

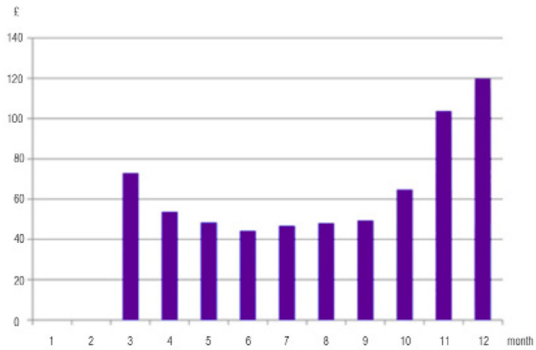

Diagram 2 : Money spent on electricity in 2012.

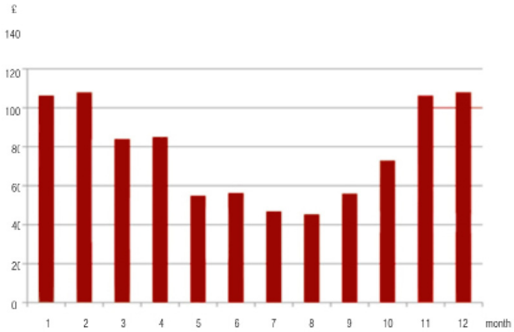

Diagram 3 : Money spent on electricity in 2013.

Additionally, the Centre for Disability Studies was assessed under energy performance which includes measurements of efficiency of building fabric and the heating, ventilation cooling and lighting systems. The Energy Performance Certificate shows how energy efficient a building is and gives it a rating from A to G. The Centre for Disability Studies achieved an outstanding value of 11 points which puts it in the 'A' range, meaning that the building is very energy efficient (buildings with a similar nature usually achieve between 33 - points) (Figure 19).

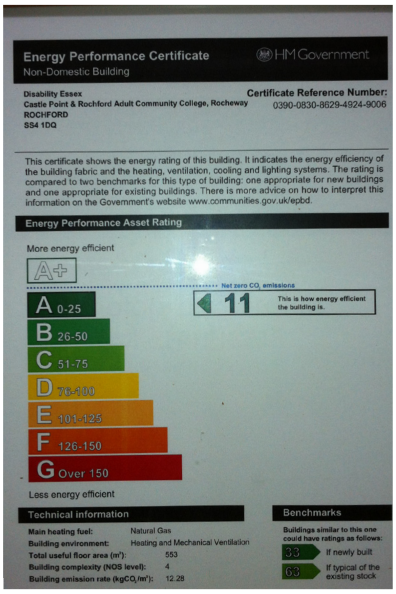

Figure 19 : The Energy Performance Certificate.

Indoor Climate, Users' behaviour and comfort

There is a strong relationship between the users' habits, the indoor climate and therefore the performance of the building to the Passivhaus standards. Thermal comfort is one of the main principles of the Passivhaus standard. However, is difficult to quantify and measure it because personal opinion is a large contributor. In the Passivhaus building, the MVHR is the main system responsible for the indoor air quality. There is a common misconception about the MVHR system being noisy. However, if designed and installed correctly it is not noisy at all and, on top, saves more energy than it uses (Cotterell, 2012, p. 27). It is worth pointing out that the MVHR unit is completely different from air conditioning; however both systems are sometimes being confused. In the Centre for Disability Studies the performance of the MHVR unit and the quality of indoor air were recorded by measuring temperature within the office space which is being used on the daily basis (Diagram 4). In the public buildings, when compared to residential construction, the higher internal gains related to occupancy density, artificial lighting, electronic equipment and glazed areas may occur. The results, measured between May and July 2010, show daily swings of 1.5-2 degrees showing relatively constant temperatures within and thus, stable internal environment in the building. However, the results also point out that the temperature reaches up to 28 celcius degrees which means that without night cooling the building can overheat.

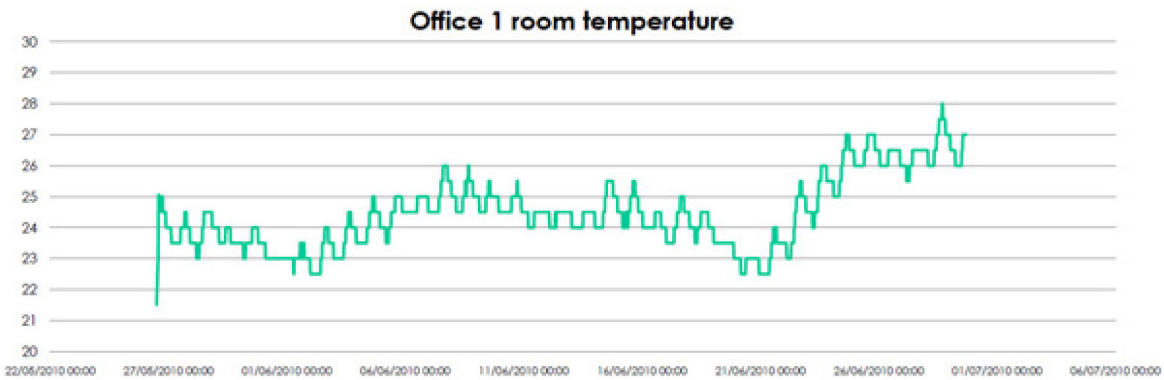

Diagram 4 : Indoor air moniotored in the office space between May to July 2010.

Nevertheless, Pet Thornton who uses the building daily, points out that it is the less physically active users who get cold more often. Although the building relies on triple glazed windows, in extreme winter conditions radiators are sometimes used. They are set only to 40 Celsius degrees so that people with sensory problems would not burn themselves and work to avoid uncomfortable internal temperatures (Thornton, 2013).

There is a common myth that windows cannot be opened in the Passivhaus building because the indoor climate is being controlled with a ventilation system. In case of the Centre for Disability Studies this is not true. Although, thermal comfort is one of the main principles of the Passivhaus standard is difficult to quantify and measure because, in this instance, the personal opinion is a large contributor.

Building caretaker Mark Rook points out that in a public building of a relatively large scale it would be impossible to control everyone. 'Sometimes I get complaints about building being cold from people who are not here every day, yet when I put the heating on I can see others opening windows' (Rook, 2013).

Additionally, to avoid any potential heat loss, members of staff as well as visitors are encourage to enter the building through the intermediate buffer zone, as oppose to the emergency entrance located within Wing A (although sometimes it would be more convenient).

Members of staff point out that a lot of visitors and temporary users do not realise that the Centre for Disability Studies is a Passivhaus building and it is difficult to provide training for everyone within short time lapse.

Overall, temporary users are very satisfied with the facilities provided, while the current members of staff believe that the building operates well and they do not experience any significant problems when it comes to adjusting things. This proves that the Passivhaus only provides energy efficiency but it is also approachable for its users.

Conclusion

While residential Passivhaus projects have been and are being built in many countries all over the world, public buildings meeting the high Passivhaus requirements are still relatively rare. There are many alternations that have to be applied to the public realm in order to achieve a superinsulated, airtight and extremely low heat demand structure needed for the Passivhaus certification. Findings show that the Centre of Disability Studies accomplished the Passivhaus criteria by using a combination of different design and construction techniques adapted to the local climate and resources. Investigation shows that it was possible to achieve Passivhaus certification for a public building which was designed to serve specific user group and therefore required a lot of design considerations. The Centre of Disability Studies also managed to fulfil main aims of maximising passive solar gain, achieving architecturally interesting form and very good level of natural daylighting. The building was designed and constructed in order to prevent heat loss through using structural components with the specific U-values as well as detailed airtightness which enabled the Centre to achieve specific primary energy demand. Although complete post-occupancy data was not available for this study in order to evaluate the performance of the Centre after its completion, findings show that current users are very content with the indoor air quality and how the building performs. This indicates that Passivhaus method can be a potential solution for achieving sustainable buildings which at the same time will provide comfortable working condition for the user.

Nevertheless, the research demonstrates that there are still some constrains that would need to be overcome.
If the Passivhaus concept is to undergo expansion within the UK then the availability of Passivhaus accredited products needs to be increased. For instance, triple glazing windows are not widely available in the UK and it proved to be challenging to import and install them. At a holistic level, if the availability of Passivhaus accredited products in the UK will not increase, it may turn out that the transportation cost will outgrow the efficiency of the Passivhaus.
Secondly, the study indicated that the focus has to be put on the education of designers and the workforce. The nature of the non-domestic buildings is usually much more complex in comparison with the residential units. The analysis shows that a well-arranged team, with the high knowledge of sustainable construction, highly contributes to the success of the project. Although the number of academic resources about Passivhaus is constantly growing, and architects gain experience with designing to Passivhaus standard, suitable training of the workforce regarding airtightness detailing would allow for more effective results in the future.
Achieving Passivhaus standards within the public sector in the UK remains problematic. The benefits of Passivhaus design within public buildings are profound, but until the constraints effecting the uptake of Passivhaus are removed its benefits will continue to go unnoticed.

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Author Information

My interest regarding issues of sustainability and buildings' energy performance has developed throughout the last six years of my Architecture education. Completing this Passivhaus project has provided me with further, valuable knowledge of advanced construction methods and sustainable design practices. Engaging with these issues has also benefited areas of my design work, during the final year of my Masters degree. The relationship between this project and current sustainable design practices will be essential for my future architectural career.

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Rural Regeneration Centre

Adam Nightingale

Location Tonbridge, Kent
Building Type Educational/Visitor Centre
Construction Type Timber frame
Floor area 308m^2
Completed September 2010
Year Certified 2010
Overall Cost £1484/sqm

Client Hadlow Agricultural College
Architects Eurobuild
Main contractors Eurobuild
Council Tonbridge & Malling Borough
Certifier Martin Such of Passivhaus Dienstleistung GmbH
Consultants and Collaborators Kraus Energiekonzept (M&E consultants) & K Harrison Associate (Structural Engineer)
Funding Sources Part funded by SEEDA (South East England Development Agency)

Abstract

In the last 10 years, 834 schools have been built using £34 billion of Government money through the BSF(Building Schools for the Future) Academies' and PCP (Primary Capital Programme) schemes. In 2011, 25 new and refurbished schools were randomly selected by the Partnerships for Schools group and assessed. Amongst other findings, the Rural Regeneration Centre uses 50% less electricity that then best performing school in the survey at a price of £1484/sqm. These findings provide a strong backbone to why interest in the Passivhaus standard is on the increase in the non - domestic building industry, despite the standard currently facing initial teething problems in the UK.

The Rural Regeneration Centre (RRC) is the first educational Passivhaus building in the UK. This study seeks to understand how the project materialised from conception to post occupancy and what challenges the design and construction teams have faced. Focus lies especially on how delivering the standard in the UK currently relies heavily upon not only comprehensive software (including BIM and PHPP) to aid both design and construction teams, but also on foreign skill and labour in an attempt to limit the potential risk that both parties currently face in the in the UK market.

Interrogating the technical, economic and cultural challenges of delivering the Passivhaus standard in the UK

Context

The Rural Regeneration Centre (RRC) at Hadlow Agricultural College, in Tonbridge, Kent prides it's self as the first educational Passivhaus building in the UK. Through a detailed analysis of the project from conception right through to post occupancy, this study seeks to identify the critical elements in successfully delivering a building to Passivhaus standard and the contextual issues surrounding its successful completion. The Rural Regeneration Centre was completed in 2010 by design and build company, Eurobuild with a budget of £537,000 (Anwyl 2013). Specialising in low energy buildings, the RRC was a critical project in Eurobuild's first venture into the Passivhaus standard - the planning and design phase was key in ensuring the project was a success.

A critical argument that James Anwyl (Director of Eurobuild) continues to push is the success that Passivhaus offers with regard to value for money. A recent report carried out by Eurobuild in collaboration with the Passivhaus Trust has identified these findings: In the last 10 years, 834 schools have been built using the £34 billion of Government money through the BSF, Academies' and PCP schemes. In 2011, 25 new and refurbished schools were randomly selected by the Partnerships for Schools group and assessed. Compared to the mean averaged result from the survey, the RRC uses 80% less energy for heating and hot water and 70% less electricity. Furthermore, compared to the best performing school in the survey, the RRC uses about 50% less heating and energy and over 50% less electricity. One may assume, these energy savings come at an extra building cost and yet, the RRC finished at £1484/m^2 whilst the best performing school finished at just over 2500/m^2 (Eurobuild 2012). These findings provide a healthy backbone to why interest in the Passivhaus standard is on the rise. The debate here is not necessarily about whether the standard is good value for money but perhaps more about how we achieve and deliver the standard in the first instance. How do we achieve the rigours of Passivhaus without relying on comprehensive software programs and imported skill and labour? The answer it seems is we cannot – the UK is still in the infant stages of Passivhaus, relying heavily on imported European knowledge as well as a comprehensive list of software programs that limit the risk designers are taking to ensure the standard is met. The RRC is a fine example of how designers are doing their best to limit the risk they are taking in this somewhat unknown and potentially lucrative scheme.

The Rural Regeneration Centre (Figure 1) provides seminar-based teaching to students of Hadlow College, one of the top three agricultural colleges in the UK (Eurobuild 2013). The building provides staff office and meeting spaces as well as an exhibition space to display a series of land based study programmes. The building sits

Figure 01 : Rural Regeneration Centre, Hadlow

within a farmyard environment and adjacent to a dairy so has provided an interesting and potentially challenging environment for which the design team needed to consider.

Four interviews have be carried out: Firstly with James Anwyl, representing Eurobuild. James is Projects Director at the design and build company who designed and delivered the RRC at Hadlow College. On the client side, interviews with the following three positions have been undertaken: Dr Howard Lee, Pat Crawford (Hadlow College Press Officer) and finally Sue Brimlow (Sustainability Co-ordinator).
Some of the key themes to which my interviews and research have guided me towards, and to which form areas of my study are as follows:

- The importance of design & build procurement – this is significant at Hadlow because as is common in the UK building industry, subcontracting is often the preferred route of project management. This can be a risky path in obtaining certification because of a fundamental lack in communication between trades. How has Eurobuild managed to ensure consistency between design drawings and construction on site?

- Why was Passivhaus standard adopted as opposed to BREEAM certification? Eurobuild point out that there is considerable value for money in Passivhaus that BREEAM cannot guarantee when it comes to energy efficiency at varies performance bands.

- The role of BIM (Building Information Modelling) in successfully achieving certification – the dependence upon BIM software at Hadlow, specifically ArchiCAD has been critical to the success of the RRC. One would argue that the use of this type of software in designing the Passivhaus has been an approach to reduce risk in a building standard where there is little experience within the UK building industry.

- The dependence on Austrian skill and labour in delivering the RRC: Prefabricated wall panels were transported over to the UK site and used to guarantee quality and airtightness whilst remaining good value for money. Reliance upon foreign skill and labour is a sign of the UK's infant stages into the standard.

- Lessons learnt from Post Occupancy Data - this is important in understanding because with so much time spent on designing the building, prior to construction, there is consequently a strong reliance upon technical design assumptions made by PHPP and Building Information Modelling (BIM). What are the implications when these assumptions regarding certain spaces are wrong or in some cases over-designed?

Planning & Procurement

One of the key themes is the significance of the procurement method in delivering the Passivhaus. The critical aspects to successfully achieving certification is attention to detail through clear communication and team management (Anwyl 2013). Eurobuild's James Anwyl, founding partner of the company, argues that a design and build procurement method is "essential" to the overall aim of obtaining Passivhaus status.

To understand why Eurobuild was chosen as lead architect & contractor, it seems appropriate to briefly explain the context to the initial stages of the project. Hadlow's original intention of the building was to build a 'low energy' building that could showcase techniques of the college but which could also be used by a wider audience and local community. The concept was pitched to SEEDA (South East England Development Agency) who provided a grant to a 'Climate Change Centre'. Drawings were sent out to tender in January 2008 by a former practice – 3 companies were short-listed in March 2008 to carry the project through, the chosen practice however did not achieve planning permission for the scheme at which point Eurobuild were asked to step in and take the project over. (Anwyl 2013)

Having spoken to both Eurobuild and Hadlow College, the company were able to provide three main benefits to the project: firstly, their credentials as a design and build company were of great value as well as their previous work on low energy buildings; secondly, the company were able to gain full planning permission by making alterations to the original proposal. Initially, the plan had been to site the building on a Greenfield site just adjacent to the current site, which planners disliked. By making use of the unused cowsheds on the dairy, the site became a brownfield site pacifying the planners allowing permission to be granted. Lastly, the local residents who were unhappy about increased private car traffic running through Blackfriars Lane were pacified by the architect's new proposal to minimise car activity to the site. As James comments,

" We alleviated their concerns with a cycle and walkway, which landed next to the bus stop so it was an integrated approach where I said 'if this is your land, lets use it' that would reduce traffic but would encourage sustainable methods of transport." (Anwyl 2013)

Eurobuild have rightly attempted to minimise the use of private car transport by integrating a cycle and walkway into the proposal. This links into the existing public transport routes in an attempt to minimise transport energy requirements. The point here is that the Local Planning Authority (LPA) should be aware of this when considering Passivhaus proposals to ensure that energy saved by the building is not offset by a surge in transport energy requirements. On a broader context, the government should take note of this if it aims to meet the 2050 carbon emission target.

Construction within the UK carries considerable risk during both design and construction phases. Even more so is this risk greater when the project requires an energy standard to be met that the contractor has never attempted before. As is the case at the RRC, contractors who have accepted this risk typically require high professional indemnity levels. Whilst the risk of design and build contracts are often greater due to increased responsibility, there are other issues with regard to following this procurement route. Design problems cause implications for cost and schedule whilst construction problems impact overall design. (Mulligan n.d.) There are considerable benefits to not only providing architectural input but also in carrying through the aesthetic qualities into the build which can often be compromised when mechanical requirements begin to take precedence. Eurobuild have avoided this by creating a multi-disciplined practice that ensures designer James Anwyl and mechanical/structural engineers are closely working in parallel to ensure both aesthetics and function are balanced. James explains how important skills as both architect and contractor benefit the overall aim of obtaining Passivhaus status,

"It's essential. In terms of it being the first one [Passivhaus project], it was fantastic to be at that level of control. A lot of people have said, 'well that's a lot of responsibility you're taking on' but in the end, it's quite a good thing..." (Anwyl 2013)

This level of control that James points out is key because it makes the distinction between why Passivhaus builds tend to be undertaken by design and build procurements as opposed to traditional procurement methods. Having spoken to James, it seems clear that the risk is minimised by keeping a close eye on sub-contractors. There are two ways to which James achieved this: by physically being on site at regular intervals and at key moments of the build but also, and possibly the more relevant factor – by using BIM to aid the understanding of the building three dimensionally at every stage of construction. (Anwyl 2013)

The barriers faced by the design and build procurement method is often characterised by a wide range of sub-contractors used for their individual skill sets – this does in fact minimise risk however often sub-contractors consider the contractor the main client rather than the user. When the end result is Passivhaus certification, this can cause problems because there may be little incentive to reduce energy use through good design (Simm and Kershaw 2014). The situation can be avoided by ensuring the lead contractor takes time to make regular communication with all sub contractors.

Designing for Passivhaus was not the original plan for the RRC– initially Eurobuild agreed the plan was to achieve BREEAM level, 'very good' but there was no formal BREEAM requirement as part of the planning condition. The jump from achieving BREEAM certification to Passivhaus certification originates from James' drive towards achieving value for money, something he believes the Passivhaus standard succeeds in.

Why Passivhaus?

The introduction of the Passivhaus in the UK has prompted a wide discussion in relation to the value for money that the standard offers to clients. Specific planning permissions for projects may come with planning conditions if granted – fortunately for Hadlow, no such conditions were attached to Eurobuild's proposal. (Anwyl 2013). However, whilst there was no requirement for BREEAM, both parties (Hadlow and Eurobuild) initially agreed on meeting this energy standard to maintain Hadlow's initial concept of a low energy building that would match the college's sustainability ethos. It was not till planning had been granted that James made the suggestion of taking the project to Passivhaus standard. James's argument lies in the reality of BREEAM. As he points out,

" I always knew that BREEAM wasn't offering necessarily the best value for clients... It's a sustainability checklist where the clients don't always benefit financially from rainwater saving or pollution credits using recycled material..." (Anwyl 2013)

BREEAM is the British Research Establishment Environmental Assessment Method. It is a certification scheme used to assess the environmental performance of new and existing buildings of various building types. Its assessment relates to nine key areas:

- Overall management of the building (12% weighting)
- Energy use (19% weighting)
- Health and well being (15% weighting)
- Pollution (10% weighting)
- Transport (8% weighting)
- Land use and ecology (10% weighting)
- Materials (12.5% weighting)
- Waste (7.5% weighting)
- Water (6% weighting)

Having spoken to Sue Brimlow, it seems that the reason behind originally choosing BREEAM was down to promoting the college's sustainability ethos,

"We just wanted a low carbon building, a sustainable building. James wanted to try and see within the remit he had with cost/time to actually see if he could get it to be Passivhaus standard so that was a bonus..." (Brimlow 2013)

It would seem James was the driving factor behind the change in certification and Dr Howard Lee points out that Passivhaus was only instigated because of James's drive towards making it happen. James pointed out that energy savings could not be guaranteed with BREEAM because the SBEM (Simplified Building Energy Model) is not accurate enough – this is the compliance tool for non-domestic buildings, much like PHPP software for Passivhaus standard (Anwyl 2013). SBEM has come up against much scrutiny since its introduction in 2006 due to its complications in providing accurate results. James' drive towards achieving Passivhaus has much to do with his belief in the importance of software and the potential it has in the future of the sustainable building industry – it seems however that BREEAM and its associated compliance tool simply do not meet the rigour that PHPP can provide when designing Passivhaus.

The core values of Passivhaus place fabric first which means the building itself is very efficient (D. W. Feist

2007). This acts in contrast to relying on bolt on renewable energy devices, such as solar panels to hit BREEAM's sustainability checklist. If we refer to BREEAM's nine key categories, the weighting for energy use is only 19% - the Passivhaus standard can only be compared to this category of BREEAM because it does not allow other elements of a building such as 'health and well being' or 'transport' to account for its overall sustainable outlook which is perhaps BREEAMS's downfall. If BREEAM's energy use category does not score highly, points can be made up in other categories essentially meaning a building could still achieve a high rating despite its energy use category scoring badly.

Feist makes a point to say that because Passivhaus is about placing fabric first, long term expenses are reduced considerably when compared to a 'normal building stock' house, even if energy costs do increase. Above all, it is the energy conservation, which reduces costs in the long term. (D. W. Feist 2007). The other factor here relating to Passivhaus economics and overall costs involved is the slow transfer of skills to the UK. According to Feist, extra build costs in the Netherlands are approximately 8-12% higher than in Germany, the UK has a similar percent increase too. However, he points out that with increased transfer of skills, components and materials to the UK, these costs could decrease by 10%, allowing a 2% tolerance for factors out of our control (e.g. exchange rates). (W. Feist 1999) If Eurobuild claims that Hadlow was completed for £1484/m^2 compared to the 2500/m^2 of the best performing school (as concluded in the Partnerships for Schools group report), this bodes well for the future of Passivhaus and it's delivery into the UK market. This would be even more impressive if we could except to see a drop in build cost as Feist suggests. (Eurobuild 2012)

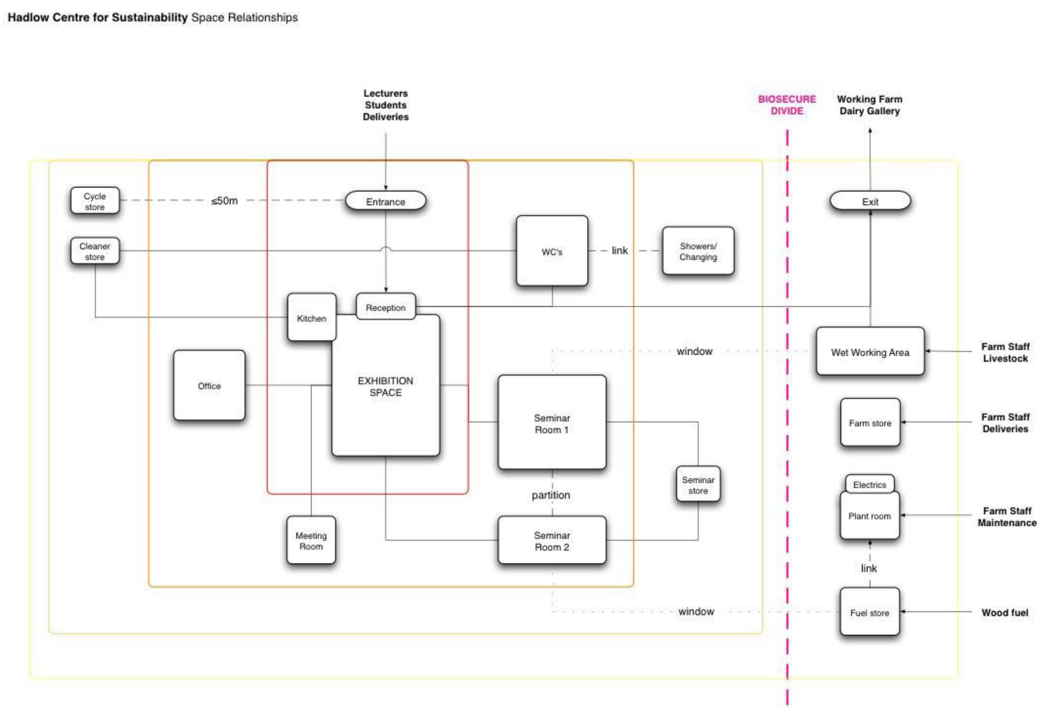

Figure 02 : Space relationships prior to final design arrangement

Function VS Form

At one given point during any design stage, form must be considered prior to on site construction. The interview guide to James Anwyl indirectly aimed to probe some idea of what Eurobuild considers to be of greater priority. It became clear that the role of both PHPP software as well as BIM (Building Information Modelling) was critical in the practice's design process and therefore in the success of achieving Passivhaus certification.

This is not to say that there is a severe lack of aesthetic consideration by the practice's ethos but more a back seat approach to the form. Figure 2 identifies the relationship between various spaces – as James explained,

" Not many architects work in this way. Our focus as a company is to really understand the users requirements – we don't come with any pre-conceptions of form. Function drives form." (Anwyl 2013)

The requirements by Hadlow college as well as a schedule of accommodation were formulated to allow the design team to map out the building purely diagrammatically to which form is then derived from. One will notice the bio-secure divide boundary (purple line in Figure 2) which forms a contextual influence upon the siting of the centre. At the time of the design process, the second case of BSE (mad cow disease) was causing concerns within the farming communities. Of course, with the centre sited within a farm environment, the building actually formed part of the bio-security strategy for the farm by separating areas of animal contamination with the human environment. In addition, as part of the planning proposal, the building required part of the existing cowsheds to be used to ensure this was not a new build on a Greenfield site. As a result, the wet working areas became principally outside the envelope of the building within the existing cow shed walls – this allowed a space for live animal demonstrations (highlighted blue in Figure 3). (Brimlow 2013)

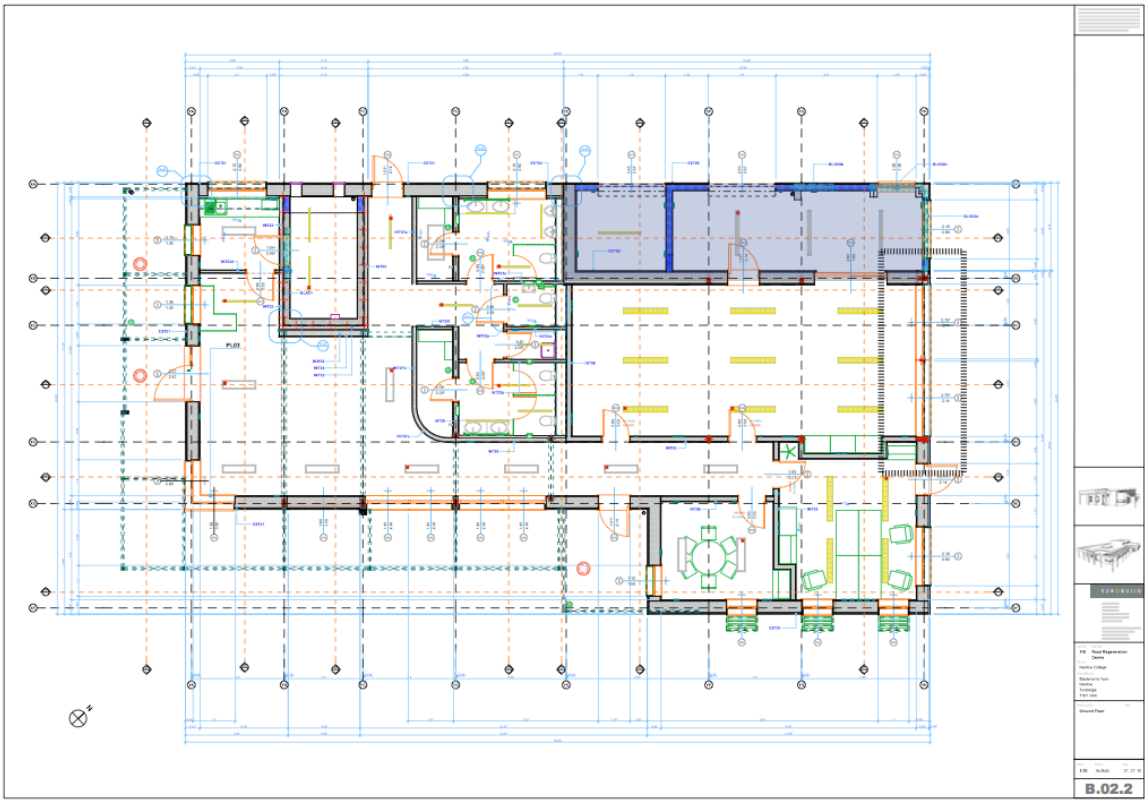

Figure 03 : Proposed General Arrangement

The Role of BIM

Ultimately, one has already identified the practice's design ethos in terms or prioritising function and user requirements when layout and plan are considered. To what extent does software come into this design process? The two critical pieces of software used in the design process were PHPP and ArchiCAD, a form of BIM software. ArchiCAD handles all aesthetics and engineering requirements through the whole design process from internal modelling right through to the construction rehearsal on site (Figure 4). As James, explains,

"In terms of meeting the budget, I don't think I could have done this without ArchiCAD...what BIM does for me is reduces risk - reduces risk because we build the building virtually first... (Anwyl 2013)

In the case of the RRC, PHPP was used as a design tool throughout the design process to ensure that changes made in ArchiCAD were adhering to the requirements of the Passivhaus standard.

ArchiCAD provides a more detailed and specific programme to which to test various design decisions prior to on site construction. For example, each window frame dimension can be specified which is key because frames have a great part to play in solar gain and therefore heat loss (Figure 5). Once assessed in ArchiCAD, the envelope data can be exported into the PHPP spread sheet through a data export feature in the program. This essentially allows the design team to run both programs in parallel throughout the design process. The team will make alterations in ArchiCAD then input this data back into PHPP to identify what effect these changes have made to the overall performance data (Anwyl 2013).

TAS (Thermal Analysis Simulation) was also used to model the RRC and to provide feedback on solar gain within the building. Extensive solar shading was required to prevent overheating on the southeast elevation – TAS enabled early stage modelling to identify solar penetration. James however admitted that this was not as accurate as PHPP software so was only used schematically in the early stages of the design phase (Anwyl 2013).

Ultimately, there is a variety of different software as James argues, about reducing risk but in this instance, it was about own personal risk to the company. This was Eurobuild's first Passivhaus project so it needed to be successful - using this software was ensuring this success. However, there are other benefits to designing the

Figure 04 : The RRC modelled on ArchiCAD

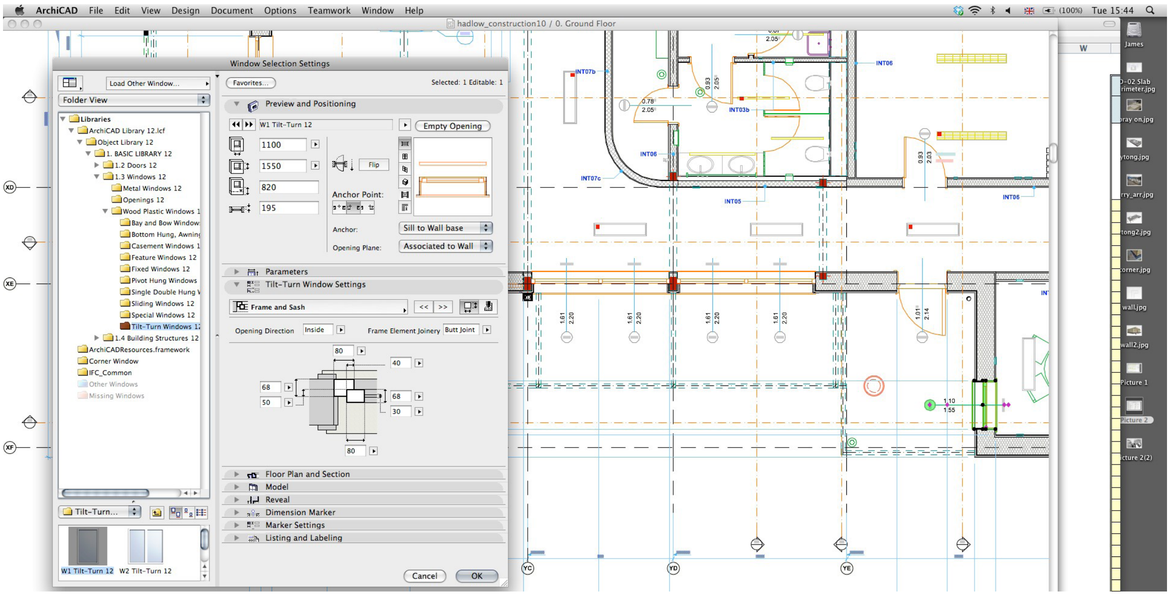

Figure 05 : Inputting window speciifcations into ArchiCAD (BIM)

building virtually. Weekly visits to site meetings ensured that the client side (Hadlow) were being updated with progress. Again BIM allowed James to produce a video which could ‘walk’ the client round the building virtually without relying on plans and orthographic drawings, which as James pointed out were not always understood. (Anwyl 2013) Furthermore, ArchiCAD allowed trades to really fully understand the arrangement of services prior to coming on site. For example, the M&E consultants, Kraus Energie Konzept worked along side Eurobuild to produce virtual models of mechanical ventilation requirements at an early stage as Figure 6 identifies.

Eurobuild are not the first company to notice the real benefits of BIM within the building industry. Its use is currently on the sharp increase for approaching design, construction and building management through the use

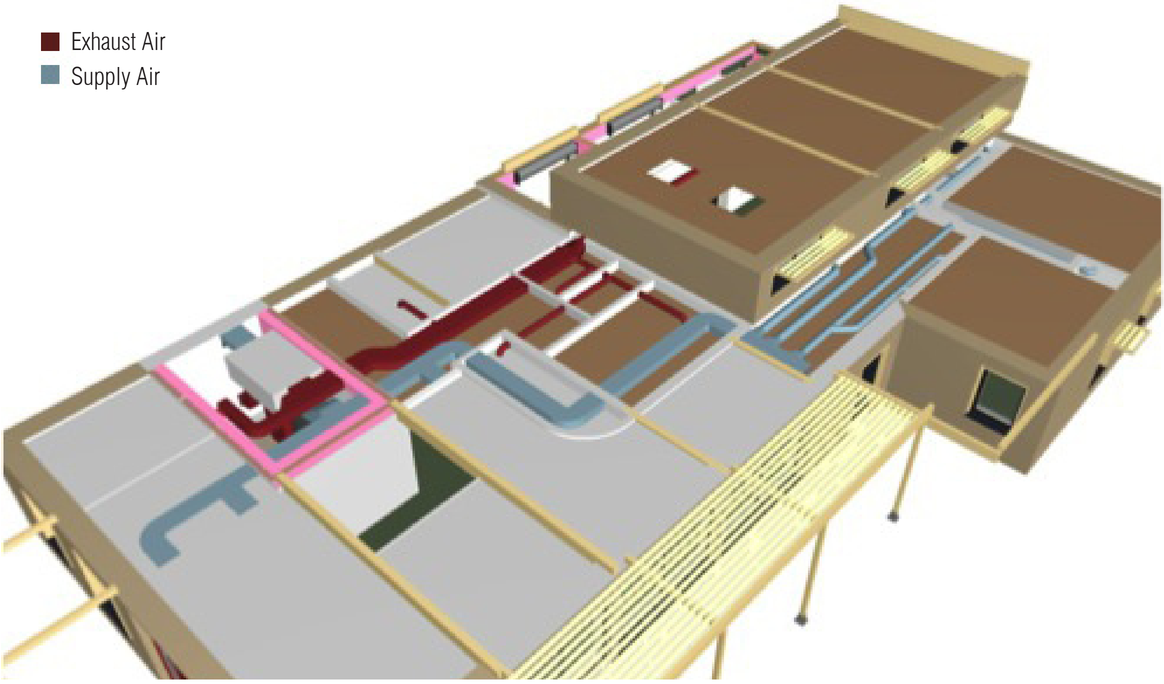

Figure 06 : Modeling of mechanical ventilation prior to construction

of digital models. The resulting model is rich in data from which views and data appropriate to specific users' can be extracted and analysed. This can subsequently generate information that in turn aids the delivery of the project. (Azhar, Hein and Sketo n.d.) As Figure 7 and 8 show, this data is very accurate limiting risk to the developer or contractor in terms of meeting the agreed design brief. In fact the UK Government has officially stated that from 2014 onwards, all contracts awarded to it's supply chain members will be required to work together through the use of BIM. (Cabinet Office 2011)

Foreign Skills and Labour

The importance of foreign skills and labour in achieving the Passivhaus standard is very relevant to the RRC. The prefabrication of the wall panels and their subsequent speedy construction on site are part thanks to the boom in OSM (Off Site Manufacturing) that has been primarily seen in Germany and Austria (DTI Global Watch Mission 2004). Whilst suppliers and engineers may attempt to provide this knowledge and skill within the UK, they are inevitably disadvantaged from lack of experience which in today's building industry equates to time and money. No wonder, that despite the Passivhaus standard being introduced in the early 1990's, the UK in July 2012 still only inhabited 5 buildings of educational building type that have been granted certification (Cutland 2012).

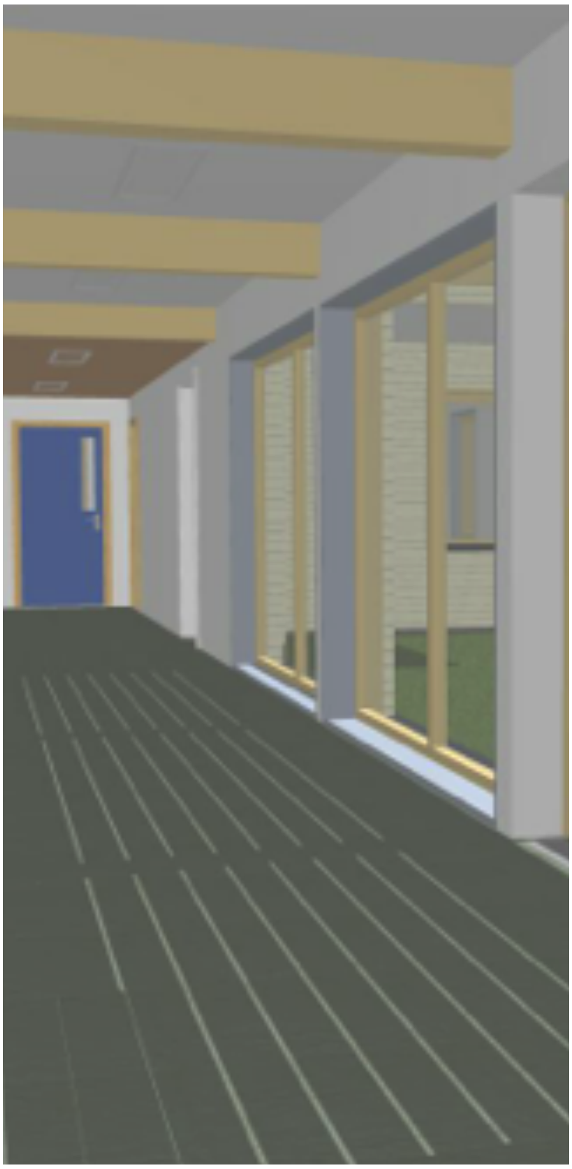

Figure 07: (Left) As Built Figure 08 (Right):Modelled

Compare this to Germany who at the same time (July 2012) inhabited 50 buildings of a similar educational nature, it asks the question as to why the UK is so far behind in the production of the Passivhaus standard.

The RRC utilises prefabricated closed panel walls and roof that are pre-insulated to Passivhaus standard. Constructed at a factory in the small town of Greifenburg, Austria, the panels were transported and assembled in 3 days and made airtight to 0.34 in 10 days. See Figure 9, 10 and 11. The panels took approximately 3 days to construct in the factory and subsequently another 3 days to transport to the UK site at Hadlow college in four lorry's. These were met by a crane on site, which finally assembled the panels into position. The panels form the external envelope while medium-density concrete-block partition walls increase internal thermal mass and absorb the solar gain from the large south facing facade.

James had been importing windows and components from Germany for 3 to 4 years prior to this project – this came down to quality and better value which the UK could not offer. Whilst becoming UK agents for the Weissenseer company which manufactured and supplied these wall panels, James realised that at the time, the company had built approximately 100 Passivhaus buildings, which was more than any supplier in the UK. Their


Figure 09 & 10 : Day 1 and Day 2 of panel installation

Figure 11 : Day 3 of panel installation

experience in the market and the quality of the product was critical in understanding why James relied so heavily upon this foreign skill. Guaranteed air tightness was key and these panels were the most reliable on this front (Anwyl 2013). One of the interesting aspects to this part of the design process comes from when we look at the relationship between the role of PHPP/BIM and the reliance upon these prefabricated panels. As James explained,

"To guarantee air tightness was the key... A lot of Passivhaus geeks will tell you, you don't need 400mm [of 'isocell' insulation], you only need 300mm. Well, I tried to cost it at 300mm and the cost wasn't a great deal different. But what 400mm gave me in u-value terms was more architectural freedom..." (Anwyl 2013)

Whilst James admits to placing function first over form, he goes on to explain that only through PHPP and BIM software was he able to really allow the architectural qualities of the building to become more prominent through 'architectural freedom' (Figure 12). It also identifies a link between good quality products imported from outside the UK (i.e. reliance upon foreign skills and labour) and the use of software. James goes on to say,

" Very few Passivhaus buildings you see large bits of glazing to the north [as shown in Figure 12] - this is the best quality light you can have so it gives you the freedom to do that… I could only have done that with the 400mm panels." (Anwyl 2013)

This reliance upon good quality products (Weiss prefabricated wall panels) and software has aided both the design elements and the functionality of the building. It is true to say that without PHPP being used as a design tool, this rigorous process of testing various design options could never come to fruition. This use of PHPP also ties in closely with the training process – my interview guide probed James into explaining how him and his team became familiar with the strict design and construction aspects required for Passivhaus status,

"the key understanding is through PHPP… by building virtually, you really tackle those issues rather than drawing... and site management is just key – the key is spending time with site managers around the table, looking at the detail at 1:5 and then in 3D and then on site with close management.." (Anwyl 2013)

It seems to be critical for Eurobuild to have a strong team – ultimately, it's the work force on site that construct the building, not the designer so ensuring the construction team fully understands what is required is essential.

Figure 12 : Large seminar room with large north facing window

Predicted VS Reality

The benefits of designing your building virtually using BIM and PHPP as guides, are as suggested more beneficial to both client and contractor than not using them at all. However, to whatever degree the building is brutally tested and analysed prior to construction, there are inevitable issues that may occur once the building undergoes occupancy and usage. At Hadlow, there in an interesting example – whilst the daylighting strategy for the building was comprehensively modelled and tested at the early design stage using PHPP software and TAS, the building actually required very little artificial lighting to be turned on when the building was fully complete. This seems to have its advantages however, one must remember that heating of a Passivhaus environment works by using a certain percentage of internal appliances and lighting fixtures that indirectly heat the spaces. As a result, if the lights are not switched on and therefore not emitting heat, then the boiler must switch on to compensate for the drop in room temperature. (See Figure 13) Notice the significantly lower lighting usage of 9.2 compared to 20.8. In order for the building to therefore compensate for lower internal heat gains, the boiler has switched on which has increased heating to 20.5, nearly double the predicted value of 9.8.

Having spoken to Pat Crawford who uses the building on a daily basis, she insists that in fact the only room which does constantly have artificial lighting on is her office. This is because blinds have been installed post completion to block out glare that hinders working on the computers in the office. As Pat points out,

" I actually have the lights on nearly all the time and that's because of the blinds and this is where the room wasn't going to be used as an office, it was going to be used as an occasional meeting room so the problem that has arisen did not arise from the architecture. " (Crawford 2014)

She points out that this problem has not arisen from the architecture but from a simple change in use. Yet, blinds have also been installed in the large seminar room to avoid glare. Potentially, this suggests a clash between programs in their analysis of specific spaces. For example, the use of Thermal Analysis Simulation (TAS) to model solar penetration has aided the design team in determining windows openings and orientation. However, a similar procedure would have occurred when inputting this information into the PHPP spread sheet. One is not suggesting that these programs are in correct but more that when combined together, these programs clash in their results causing scenarios as mentioned where a certain amount of natural day lighting has been required but to the extent where no artificial lighting is required to be utilised. In most instances this would not be an issue however because artificial lighting is so critical to internal heat gains, there are obvious knock on effects that overall increase the primary energy demand.

Primary Energy (over 2 years)	Actual metered kWh/m²/yr	Calculated in PHPP kWh/m²/yr
Heating	20.5	9.8
Hot Water	5.7	8.3
Ventilation	28.6	17.7
Cooling	6.2	0.0
Lighting	9.2	20.8
Aux Electricity	38.8*	8.1
Small Power	47.4	21.5

Figure 13 : Post Occupancy Data

The Government's commitment to reducing carbon emissions by 80% by 2050 is achievable only by ensuring that the building industry becomes committed to continuing to publicise sustainable design. In July 2012, there were 165 buildings either completed or under construction meeting Passivhaus certification (Cutland 2012). Approximately a year and half later in 2013, there were approximately 250, a 34% increase in certified buildings both non domestic and domestic meeting Passivhaus standard. This increase identifies a potential market in the UK that should be exploited in order to reach these targets. There are some critical factors however to ensure this is achievable that the Rural Regeneration Centre has highlighted.

The benefits that a design and build procurement method provide are critical: collaboration of all disciplines (as at Eurobuild) from a committed design team but also to both mechanical consultants, structural engineers and all on site workers. As identified, this procurement method takes on a considerable amount of risk however it is crucial to ensure that the design becomes coherent to the technical requirements of the standard. Continuity is key - communication between off site teams and on site teams is equally as important especially in the early stages of Passivhaus becoming used within the UK. A committed team of multi trades is advantageous to trades being sub – contracted. This avoids the risk of poor communication between trades which can jeopardise the strict requirements that the Passivhaus standard requires.

Conclusion

To ensure that all trades on site understand the critical construction stages, education is fundamental to the success of the project. This has been achieved on this project through the use of ArchiCAD (BIM) and PHPP. Walking through the building virtually and three dimensionally at different scales on ArchiCAD allowed both the design team and on site team to understand what level of quality the building required in order to meet certification. Certification requires strong use of PHPP software, as a design tool, not just at the end of the design stage to certify the building. Running both ArchiCAD and PHPP in parallel regularly through the design stage ensures the objectives and aims to meeting the standards are always top priority. From a design point of view, using PHPP and ArchiCAD throughout the design stage also has allowed Eurobuild to make important design changes to the building like for example placing large glazing on north facing windows which could only be successfully achieved through the watchful eye of PHPP.

Quality of construction is another critical factor to ensuring success in achieving Passivhaus standard. There is considerable discussion to be had regarding the degree to which the UK building industry is at a stage that can match the quality of materials that are currently imported from abroad (namely Germany and Austria). These countries have over 25 years of experience in the standard as well as an established supply chain of technologies. Importing the prefabricated wall panels from Austria is a choice made by Eurobuild who have prioritised quality not cost in order to guarantee life time performance – this has minimised risk to Eurobuild in achieving the standard. A skilled labour force experienced in Passivhaus is crucial and therefore schemes that provide training to not just a construction point of view but also in PHPP is essential. If the UK can increase skill in these areas, suppliers and contractors will become more readily available to interested clients which in turn would lower building costs. Lessons need to be taken from Germany regarding the funding which the federal government provide for Passivhaus projects – the KfW Bank is a public institution owned by the Government providing loans of up to €50,000 towards the cost of new low energy dwellings. Furthermore, the bank will also offer a grant depending on the energy efficiency level the dwelling achieves. The UK offers very little in comparison to parties looking to build to Passivhaus level – there are a number of Government mandated grant schemes but all of them are available only for the refurbishment of existing homes (Cutland 2012). If the Government are serious in promoting sustainable design, there must be money invested into the standard as we have seen abroad.

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Author Information

I am currently a Masters of Architecture student studying at the Kent School of Architecture. Having completed a small report in my 4th year on the link between the Passivhaus standard and student performance in educational buildings, I felt there was a great opportunity to be had in investigating further into the standard and it's delivery. The Rural Regeneration Centre has provided an invaluable case study into the standard whilst the buildings' success comes from it's design team and their dedication and enthusiasm for low energy buildings.

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Summary: PassivHaus as a standard for Educational Buildings

Adam Nightingale, Katarzyna Kwiatek, Sam Fleming

The three case studies have identified some key common issues that need to be overcome in the UK in order for the Passivhaus standard to be successfully applied to the public construction sector. Research suggests that the initial build costs for Passivhaus construction are higher than normal – this comes down to component and material prices that must meet Passivhaus quality. For public buildings, there is likelihood that this detracts organisations away from investing more money than necessary. For a charity organisation, this places a great risk on choosing Passivhaus. However as seen at The Centre for Disability Studies, this initial cost is quickly offset by low running and maintenance costs which need to be considered and publicized in order ensure the public do not consider this to be too high risk.

Energy use in public buildings differs from residential in terms of the occupancy periods and density, sizes of the spaces and glazed surfaces. Increased occupancy levels place pressure on the cooling strategy which must be able to cope with the change in occupancy. The RRC is a good example of how the building is able to adapt by using booster ventilation switches and as well automatic clerestory windows to ensure internal temperatures do not become uncomfortable. Great caution must be made in schools which inhabit IT services – equipment can very rapidly increase not only internal heat gains but also Primary Energy consumption taking the building beyond the standard's set limit.

Another issue common for all case studies was the reliance on foreign skills and products imported from abroad. In case of the Centre for Disability Studies architects were required to translate German construction details into common English construction methods. Products such as triple glazing windows are not widely available in the UK and it proved to be challenging to import them in a high quantities and install them within English systems. At the Rural Regeneration Centre, foreign construction skill was critical to the project's success – the quality of the prefabricated panels guaranteed airtightness levels and has ensured the building met high performance levels. If the UK is determined to increase the number of Passivhaus buildings, investment must be made to increasing the availability of Passivhaus certified products. It may turn out that the transportation cost will outgrow the efficiency of the Passivhaus if the number of UK suppliers does not increase considerably.

As for the public buildings, projects are usually of a much complex nature in comparison to residential developments. This can frequently result in the lack of communication between teams and potential problems within design and construction. In case the of the Montgomery Primary School lack of organisation caused miscommunication between the various members of the design team and the council. Additionally, the majority of the team working on this project had little or no experience in Passivhaus design, for public or indeed residential buildings. As opposed to Montgomery School, the Centre for Disability Studies indicated how cross-disciplinary team of people with previous experience on the Passivhaus design contributed to the success of the project. Although numerous problems connected with unique design and construction methods were faced on the way, good communication within the sectors allowed for delivering the project on time.

Education of users, awareness of using Passivhaus building as well as myths about constrains of Passivhaus were common issues faced. For instance, the Montgomery Primary School was not performing to its full potential due to the fact that users were not sufficiently educated on how best to use the building. A series of training days were arranged for the staff to teach them specific methods and techniques of using the building and the equipment within it. However from the outset, it became apparent that some of the teachers and staff were unaware of how to use the mechanical ventilation system and when best to open windows. In the Centre for Disability Studies, although the staff use the building on a daily basis, it became apparent that it was impossible to educate all temporary users visiting the building.

Section 02

Explorations of PassivHaus as a deep retrofit strategy

Retrofit Introduction

Rosie Seaman & Thomas Haywood

The need to significantly reduce CO2 emissions in the domestic sector is a vital component in addressing UK energy policy issues. Arguably the main focus from the UK Government has been directed on new build, as opposed to examining the potential of existing dwellings to combat energy consumption. Alongside this, the growing issue of fuel poverty in the UK, where for example as of 2013, 'low income families [are] forced to spend a third of [their] net income on housing' (Resolution Foundation, [Online]). Also, with 'soaring energy bills forcing families to spend more than ever on heating and maintaining their homes' (Poverty, [Online].), the Passivhaus standard, and the Passivhaus retrofit standard, can help eradicate the risk of fuel poverty, improve thermal comfort and increase fuel security particularly for low-income groups (BRE, 2013). Only an insignificant quantity (approximately 1%) of new build replaces the existing housing stock annually (Cotterell & Dadeby, 2012:29), therefore to reduce energy and carbon emissions in this sector, to meet the 80% target, the retrofitting of existing dwellings will be crucial in addressing UK energy efficiency and fuel poverty issues.

The aim of this section is to establish whether retrofitting existing housing stock to the Passivhaus standard is a viable solution to meeting the 2050 carbon reduction target. Currently the debate regarding future housing energy demand is unclear. Universally there is no agreed standard definition of what constitutes low carbon retrofits of housing, either in terms of what measures should be implicated or what numerical targets should be reached. In the UK more commonplace shallow retrofit approaches such as BREEAM and the Green Deal, combat relatively superficial alterations and measures rather than addressing the significant issues such as carbon reduction and improved thermal comfort, as demonstrated through the deep retrofit approach of the Passivhaus standard. Deep and shallow retrofits are qualitatively different. Shallow retrofit can be achieved by a single modification to the building such as added insulation or refitted services, however deep retrofit also requires replacement of existing heating, ventilation systems and the introduction of renewable technologies, alongside an upgraded thermal performance (TSB, 2012:6). Due to the nature of the Passivhaus methodology, it is envisaged as a more significant option compared to other retrofit strategies, due to its focus on a strict performance specification and utilisation of a comprehensive building physics approach developed by the Passivhaus Institut, which successfully the addresses the challenges of retrofitting existing buildings. This will be analysed through the following two case studies; Grove Cottage and 100 Princedale Road in terms of the cultural, economic and technical challenges presented.

In reality it is not often feasible to meet the full Passivhaus standard on a retrofit building type, due to the fixed aspects of the building such as; window placement, form, orientation, plus other constraints such as; existing occupants, neighbouring houses and conservation issues. The use of Passivhaus technology in existing buildings has the potential for considerable improvement in respect of thermal comfort, structural protection, cost-effectiveness and energy requirements, therefore a Passivhaus refurbishment standard, EnerPHit, was introduced to overcome this and encourage retrofitting of existing buildings. The EnerPHit criteria provides a reduced energy target as an 'achievable benchmark' in recognition of the difficulty of meeting new build requirements, for retrofit projects. As illustrated in the table for performance criteria, the design targets of EnerPHit require a lower heating demand of less than 25kWh/m2.yr and an air-tightness rate of no more than 1.0 air changes per hour @ 50 Pa, compared to the full Passivhaus standard.

Criteria	**Full Passivhaus Standard**	**EnerPHit Standard**
Specific Heat Demand:	≤ 15kWh/m2.yr	≤ 25kWh/m2.yr
Primary Energy Demand:	120kWh/m2.yr	120kWh/m2.yr
Airtightness:	≤ 0.6ach at 50pascals	≤ 1.0ach at 50pascals

Table showing Passivhaus Standard criteria against EnerPHit Standard criteria

The two case studies demonstrate examples of the different project variables, cultural factors and design conditions relating to retrofitting existing UK housing to Passivhaus standards. Following the guidance of the AECB CarbonLite programme, the first case study project Grove Cottage, explores the application of external insulation to an existing pre-1919 solid brick Victorian semi-detached dwelling. The projects confronts the challenges of integrating both new-build construction and existing retrofit methods. Also a solid brick Victorian building type, 100 Princedale Road is mid-terrace single property, owned by the social housing landlord Octavia Housing Group. With the building being located in a central London conservation area, there were strict limitations on altering its external appearance, therefore the majority of the retrofit was restricted to the interior, presenting additional design challenges.

Grove Cottage

Rosie Seaman

Location Hereford, Herefordshire
Building Type Semi-detached family home
Construction Type Solid brick
Floor area 135m^2
Completed 2009
Year Certified 2010
Overall Cost £450/sqm

Client Andrew Simmonds & Lorna Pearcey
Architects Simmonds Mills Architects
Main contractors Eco-DC
Council Hereford District Council
Certifier Passivhaus Institute
Consultants and Collaborators M&E Consultants - Alan Clarke & Peter Warm, Energy Consultant - David Oliver, Structural Engineer- Bob Johnson, Green Building Store
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Abstract

An extensive retrofit of a Victorian solid brick townhouse, Grove Cottage, Hereford, was the first domestic building in the UK to be certified to the EnerPHit standard. Using skills developed through the AECB and the CarbonLite Programme, architect and client Andrew Simmonds, intended for the project to act as an example for what is possible for new build extensions , but more importantly the refurbishment of existing solid wall dwellings using Passivhaus methodology. The discussion aims to investigate the validity of the use of Passivhaus for existing buildings; through analysis of the application of external insulation to create high thermal levels, the challenges of thermal bridging and airtightness, plus the feasibility of construction techniques within the context of the UK skills base. Primarily, the case study will examine the initial design and planning phases of the case study, whilst exploring the methodology used by the design team. Aiming to determine why and at what stage the Passivhaus principles were adopted and whether the introduction of EnerPHit had any effect on the project. Additionally, looking at the influences of Passivhaus on how the project was designed and the approach taken, the chosen materiality and if there were any planning issues specific to the use of Passivhaus principles.

Furthermore, the challenges of adapting Passivhaus technical requirements to the traditional construction methods used within a UK context, will be analysed through on three main technical details for Grove Cottage that are specific to the problems associated with existing buildings, and aims to establish how successfully this was received by the construction team.

Could retrofitting existing buildings to meet the EnerPHit standard be a feasible solution to aid the reduction of carbon emissions to meet the 2050 target?

Grove Cottage, EnerPHit & AECB CarbonLite Programme

Using Passivhaus methodology, Simmonds Mills Architects upgraded the original fabric of the Grove Cottage (Figure 01); a Victorian semi-detached solid brick town-house, to ensure high standards of insulation and airtightness to meet the required performance targets. Focus is placed on passive technologies, which are suitable for the established and densely populated location, whilst ensuring that whole house energy consumption is dramatically reduced compared to the measured energy performance of a typical UK dwelling.

Drawing on previous experience of designing and constructing low energy buildings, the architect, Andrew Simmonds, and the project team applied low carbon design methods developed through the AECB CarbonLite Programme (CLP). During the project the Passivhaus refurbishment standard providing reduced and 'achievable' targets, EnerPHit, was being trialled by the PHI in Germany, and it was later talked about using Grove Cottage as the first UK trial for certification of the standard. Nonetheless, the building was not retrofitted to meet the lower performance criteria; thus the design team were tasked with achieving a level of performance as close as practical to the Passivhaus standard, concurrently aiming to meet the energy performance target of the AECB CarbonLite Step 2 (Figure 02). As the Chief Executive Officer of the AECB, Andrew identified the problems within the existing house and decided to undertake the task of retrofitting Grove Cottage to the Passivhaus Standard in order to put the principles he was developing for the CLP into practice (Simmonds, 2014:01). This would provide an unparalleled opportunity to test out theories in reality and witness the process first hand, enabling quick progression of knowledge, understanding and skills.

During the early stages of the design and specification the project followed the AECB CarbonLite guidance, and common principles of energy efficiency and passive solar design. The CarbonLite Programme was introduced by the AECB as an initiative to create low energy buildings in line with existing and future legislation . Meeting the requirements of the higher level Code for Sustainable Homes (CSH) the CarbonLite steps can be readily applied to both domestic and non-domestic buildings, providing a three stage set of realistic and manageable energy performance standards which are based on a combination of limits on space heating energy consumption, primary energy consumption and CO2 emissions (AECB, 2014). The standard incorporates three levels of performance; one of which corresponds to Passivhaus while the others, Silver and Gold, set CO2 emission targets that are slightly higher and lower than Passivhaus respectfully. As a step towards Passivhaus, the CLP Silver Standard was believed to be just as suitable if Passivhaus wasn't achieved; however on the other hand the CLP Gold Standard

Figure 01: Post-retrofit illustrating externally insulated existing building and new-build extension (Low Energy Datatbase, 2010)

AECB CarbonLite Programme (CLP)

CLP Steps	Standard	Space Heating Demand	Primary Energy	CO2 Emissions
1	Silver	≤ 40kWh/m^2.yr	120kWh/m^2.yr	22kg/m^2.yr
2	Passivhaus	≤ 15kWh/m^2.yr	120kWh/m^2.yr	15kg/m^{2}yr
3	Gold	≤ 15kWh/m^2.yr	58kWh/m^2.yr	4kg/m^2.yr

Figure 02 : AECB CarbonLite Programme criteria

was disregarded due to the increased expense and little additional use (Ibid:02). Whilst unaware of the EnerPHit standards criteria, it was expected that the building would not meet the full Passivhaus standard heating demand of ≤ 15kWh/m2.yr, but it was hoped that ≤ 22kWh/m2.yr could be achieved (Simmonds & Clarke, 2008:15). Additionally to this, exceptionally challenging targets were set for improving the thermal performance of the building, including; high levels of insulation, 'thermal bridge free' junctions where possible and 0.75m3/m2hr airtight envelope (Ibid, 2008:15).

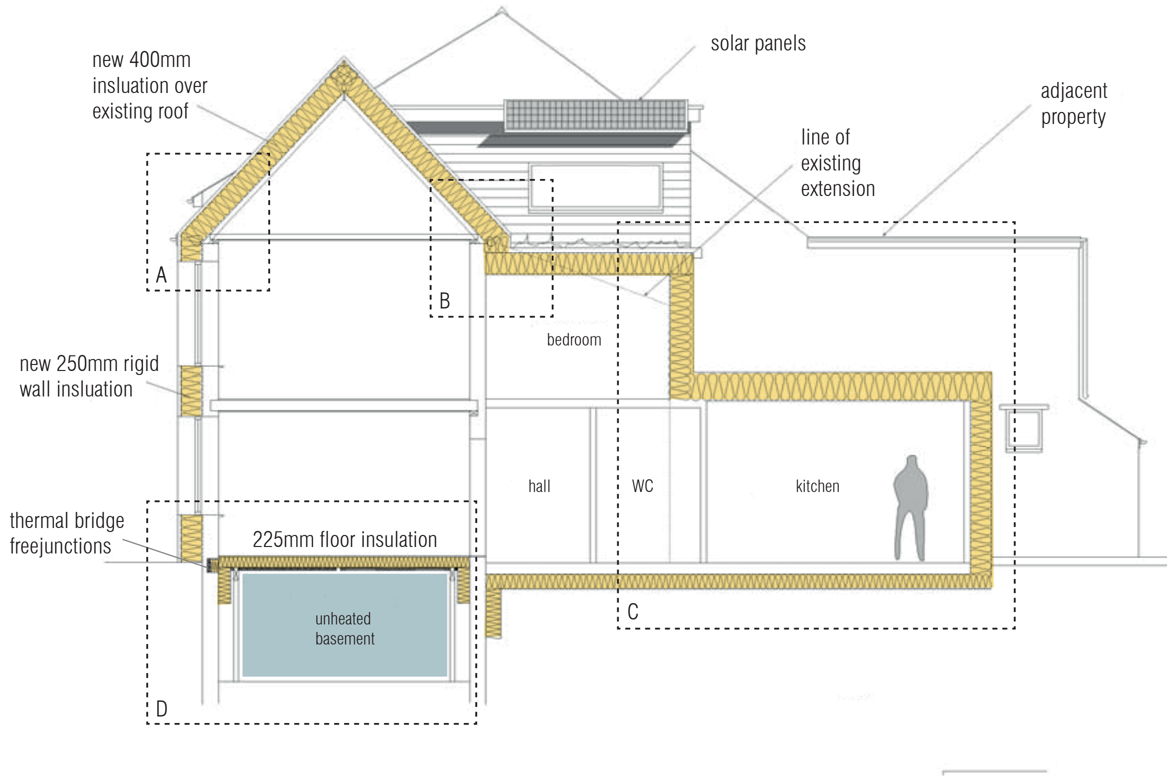
Furthermore, client's brief, Andrew Simmonds and Lorna Pearcey, required additional domestic space and an improved relationship between the habitable areas and the garden on the east side of the building; therefore a new-build extension was essential. With the aim to provide suitable space for a growing family, the strategy combines the construction of the new low energy extension with the complete thermal upgrading and refurbishment of the existing building in order for both to meet the Passivhaus standard.

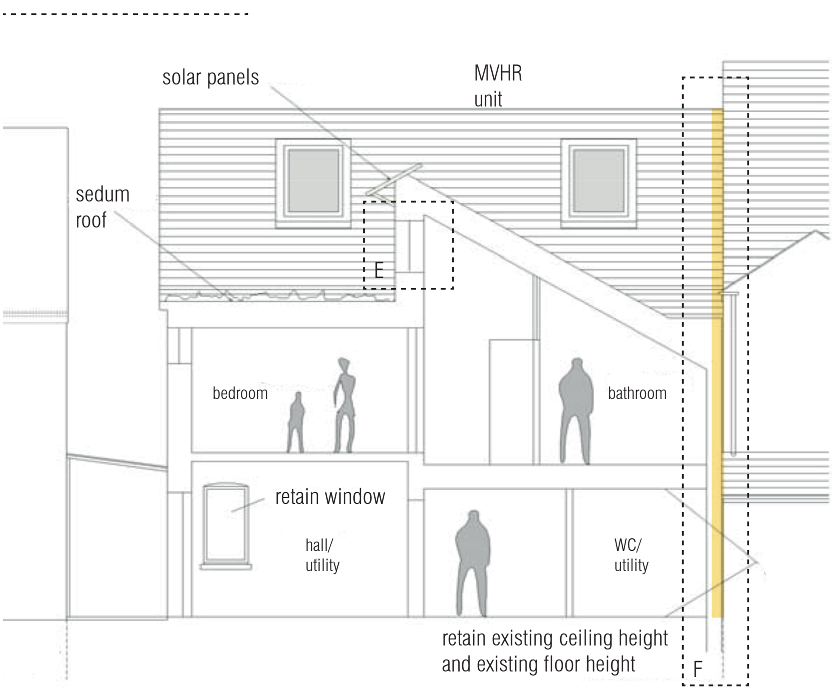
Design, Methodology and Planning

Built in 1869, the building is located on a strip of Victorian development land with limited modern infill surroundings. The subsequent Victorian dwellings on the street are a solid wall detached and semi-detached or terraced buildings, with varying facade styles and details (Figure 03). It was considered not necessary to undertake any feasibility studies prior to the design, however pre-application meeting with the planning officers were carried out in order to ensure the project would meet planning conditions (Simmonds, 2014:07). Considering the vast amount of work needed to be done to the building to meet Passivhaus standard, it was important to review the strategies proposed and examine how the building would fit into the surroundings and meet planning regulations.

One of the main aesthetic strategies of the project was to ensure that the retrofitted street elevation was returned back to as similar as possible to the original, thus demonstrating how 'radical measures (could) deliver subtle decarbonisation of existing architecture of the street' (Passivhaus Trust, 2012). Simmonds Mills Architects attempt to answer the question attempt to address how we ensure that they are still representative of British cultural identity and at the same time deliver the level of reduction in energy use required to address 2050 reduction targets. On the street side it was intended for the building to appear as if the retrofit had not took place, however at the back Andrew aimed to express what the design of the extension was trying to achieve: passive solar gain and a response to the garden (Simmonds, 2014:05). As a standard procedure to ensure that all proposed materials for the project 'harmonise with the surroundings' to meet the requirements of Policy DR1 of Herefordshire Unitary Development Plan, the planning permission document for Grove Cottage states that 'no development shall take place until samples of all materials to be used externally on wall and roofs have to be submitted to and approved in writing by the local planning authority' (Hereford District Council, 2008:01). As the frontage of the existing house was to be changed to render from bricks, it was necessary to show the planners a sample of the EPS external insulation, however this was accepted and the requirement ultimately had no implications on the design. As the external brickwork was of substandard quality it was possible to cover the exterior surface in a single uninterrupted airtight layer without greatly altering the appearance of the existing house; on the contrary if the building had been situated within a conservation zone it would have been necessary to use internal wall insulation or develop a façade system using brick slips to replicate the existing appearance. Attention was focused on detailing the street side of Grove Cottage as sensitively as possible ; thus the stone sills below the windows were recreated in polystyrene, plus the existing stone scrolls reused in order to retain existing features of the house.

Figure 03 : Grove Cottage, Portfield Street, demostrating various dwelling types and facade details (Google, 2014)





Project Overview

A - Airtightness layer connection between new timber roof deck and existing brickwork wall

B - Airtightness layer connection between exsiting building roof and new extension roof

C - New extension: form factor, planning and materiality

D - Thermally separated basement: floor/wall junction, floor insulation

E - High level South facing windows

F - Party wall insulation and gable end roof construction

Figure 04: Grove Cottage - Project Anatomy. Passivhaus strategies applied and areas analysed throughout the discussion.


Figure 05 : Pre-retrofit and post-retrofit images illustrating the approach to the facade (Low Energy Building Database, 2010)

Although not articulated in conversation with the local planning authorities, without the attention to the façade it may have been suggested that it would have been 'too blank or too insensitive' to both the appearance of the existing house and the surroundings (Simmonds, 2014:06).

The arrangement of Grove Cottage as existing (Figure 06), consisted of communal areas on the front, street side of the house, kitchen and utility to the rear leading on to the large garden, plus an inhabitable basement below. On the first floor two bedrooms and small landing room with attached bathroom led off either side of the stairwell, with a relatively large unused loft space above. An inefficient internal arrangement and lack of space was not suitable for the clients, therefore alongside the refurbishment of the existing house, the design proposed the new super-insulated and airtight extension to the rear of the house; an optimal location that would not unduly impact on the neighbours. Providing a large single storey kitchen and bedroom on the first floor above what was originally a 'lean-to' utility room, it was also proposed that loft space be converted and roof-lights installed in order to make the space habitable.

Limited mainly by the presence of existing windows in the wall of the neighbouring property to the North, the form of the extension was greatly dictated by 'pragmatic and planning' related issues (such as overlooking), representing architectural form derived from passive solar and daylighting (Simmonds Mills Architects, 2008:02). Reducing the space heating demand through passive solar gain became a main strategy throughout the design of the extension in order achieve low energy performance, thus the orientation, proportion of building form and size, and placement of the openings was carefully considered (Figure 07). Initially the extension was proposed as a 5x4m rectangular form with a single-sided sloped sedum roof to incorporate high level windows, housing the kitchen with a new entrance to the side of the house through a utility, plus incorporating a new WC facility (Figure 06). On the first floor a new bedroom was created above the utility room within the original footprint on the building with a flat roof, and the existing bathroom extended to use the space of the landing room and the roof rebuilt to create a single-sided slope addressing the Southerly aspect of the extension to maximise solar gain and daylighting (see planning drawings). Where possible a Passivhaus building should be 'orientated along an East/West principle axis so that the building faces within 30 degrees of due South,' allowing the maximum benefit from useful solar gains to be received (Passivhaus Trust: 02). With the street on a mainly North-South axis the existing fenestration for Grove Cottage faces East and West, the intention for the extension was to integrate large areas of new South-facing windows to provide a net gain of solar heat during wintertime. Without this design consideration, it may

EXISTING GROUND FLOOR PLAN PROPOSED GROUND FLOOR PLAN

Figure 06 : Existing and initial plan proposal for retrofit and extension demonstrating rectangular form (Simmonds Mills Architects)

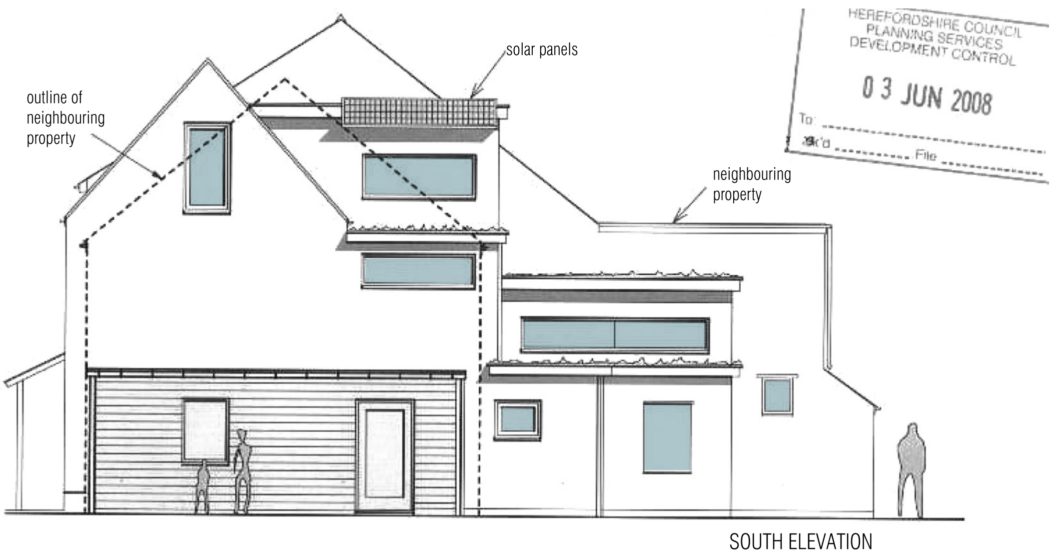


Figure 07: South elevation highlighting South facing windows for solar gain (Simmonds Mills Architects, 2008)

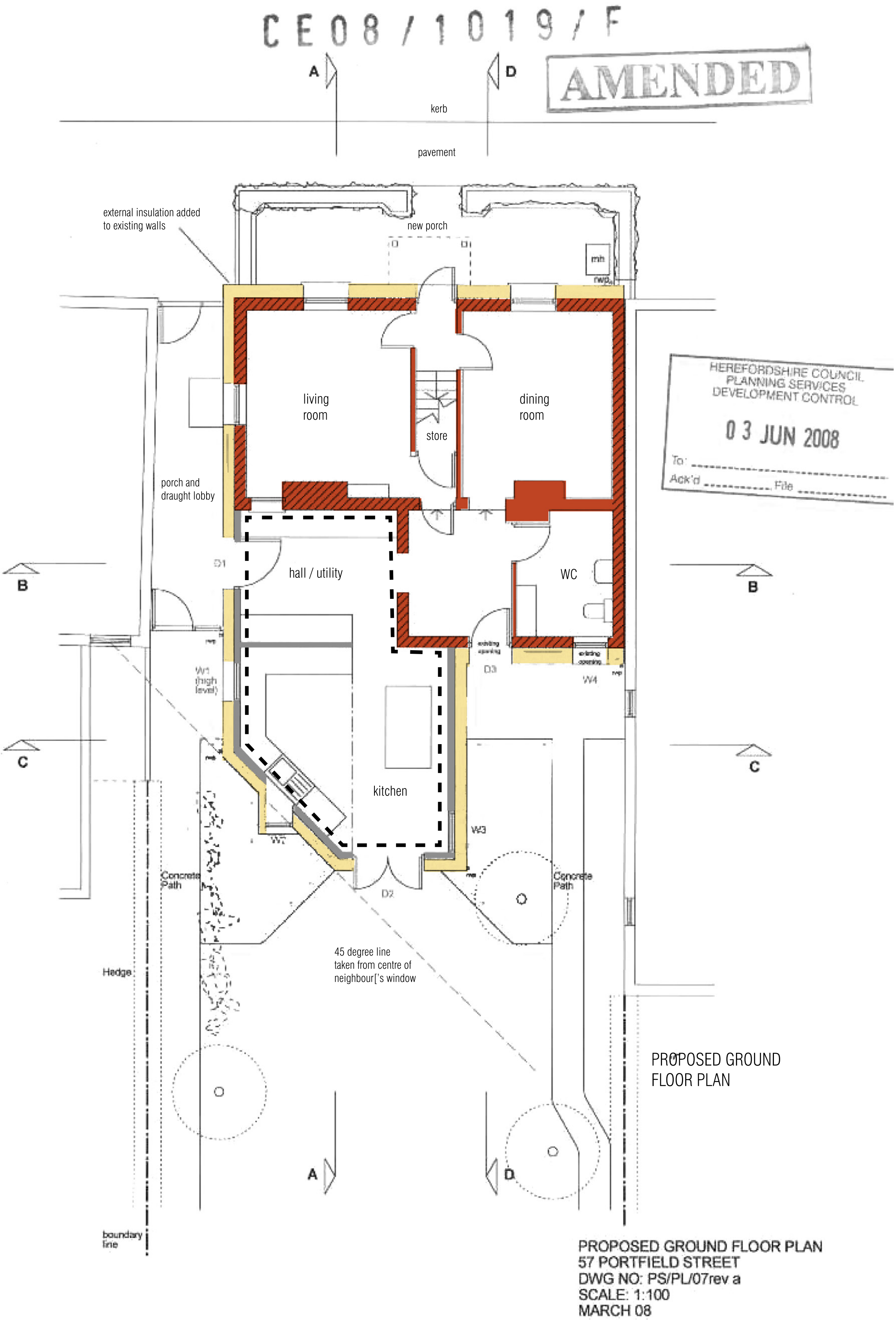


Figure 08: Amended proposed plan showing the new extension cut at 45 degrees (Simmonds Mills Architects, 2008)

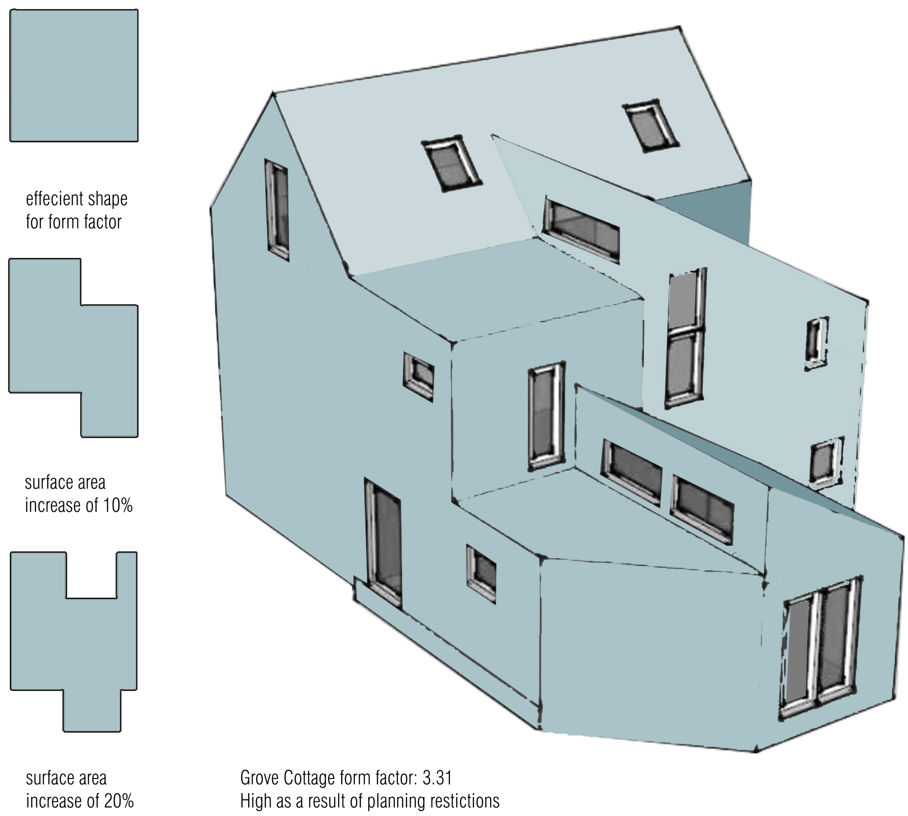


Figure 09: Diagram illustrating complex building for and high surface area of existing building and proposed extension

have been possible to realise Passivhaus performance targets, however the annual heating demand may have increased by 30-40% as a result (Passivhaus Trust:02). Overall the design was welcomed by the Herefordshire planning authorities, as it was seen as a potential opportunity to have a low energy building as an example in their district, nonetheless the application had to go to committee as the original design was objected to by the neighbours (Simmonds, 2014:06). To meet the neighbours' concerns, changes were made in discussion with the planning officer for the extension, however on the whole no issue was raised with the Passivhaus retrofit of the building. The extension was widened and cut at an 45 degree angle from the centre of the neighbours window moving the form away from the existing property to address privacy issues, whilst responding the to the context of the garden and the functions within. Attention was focussed on planning the internal arrangement to allow easy movement between the new and existing building, and details incorporated specifically to respond to the client's needs; such as an extra wide door as a new side entrance to the house, designed particularly to allow a double pushchair through as the clients had twins at the time (Pearcey, 2014:04).

As an additional complication to the complexity of the existing building fabric, it can be calculated that extension and retrofitted house would not follow the classic compact Passivhaus building form. Designed to meet the tight planning constraints, the result was a relatively high surface to volume ratio and high form factor . As identified by the Passivhaus Trust a Form Factor equal to or less than 3 is beneficial for reducing heat losses through the exterior surfaces. The ideal shape for a low Form Factor is simple, therefore the more edges the building has in comparison to its volume, the higher the Form Factor. The design of the extension to focus of passive solar gain results in a more complex building form, consequently creating a form factor of 3.31, which became a limitation of the design and had to be compensated through higher levels of insulation, exceeding the standard recommend U-values for walls floors and roofs.

Passivhaus Planning Package (PHPP) & THERM

With planning permission approved for the retrofit measures and extension before the building was modelled and assessed using PHPP , precautions had to be took to ensure that the design would not change dramatically from the planning drawings during construction. It was anticipated that U-Values more efficient than those specified in Passivhaus and CLP criteria would be required, due to the 'likely extent of heat loss associated with the existing building; such as the foundations, the party wall and considering the difficulty of incorporating high levels of insulation into the walls (Simmonds & Clarke, 2008:15). Consequently, it was hoped that low U-values for the walls and roof would compensate for this, and thus large amounts of insulation we pre-empted and incorporated into the planning drawings to represent realistic construction depths, and increase to the wall and roof thickness. As the insulation would have such a significant effect on the overall appearance of the building, it would necessary to highlight this prior to planning approval to avoid problems that may have compromised the insulation thickness later in the project.

PHPP was used prior to gaining building regulation approval, to refine the thermal envelope, openings and passive solar design to meet Passivhaus standard. Primarily a crude version was calculated, inputting all the data including the data from appliances, and heating system pipes in order to optimise the design of the heating and hot water system, however focussing mainly on the fabric of the building and the space heat demand (Simmonds, 2014:13). It calculated the specific heating demand as $\leq$ 19kWh/m2.yr (close to the $\leq$ 15kWh/m2.yr Passivhaus target) (see Figure 10 for PHPP results graph) whilst aiming to achieve 0.6ach, however omitting a few unaccounted areas of the existing construction that give rise to 'linear thermal bridging' and were considered unsuitable to affordably thermally upgrade. As the PHPP and certification process requires the quantified input of all significant thermal bridges, the construction details of the irregular thermal bridges at the junctions required accurate modelling of individual thermal bridges using specialist software. Few retrofit projects fully embrace thermal modelling, due to concerns of high cost and limited scope for improvement, however in the case of Grove Cottage the data provided by thermal modelling aided the reduction of costs overall. Specific details, such as the joists/wall junction supporting the suspended floor in the basement, were modelled separately to obtain the psi values using THERM, and it was calculated could add around 1-2kWh/m2.yr to the overall figure, thus the heating rose to 21kWh/m2.yr. At the time not all junctions were modelled using THERM, therefore worst case scenario assumptions were made for those thermal bridges (Ibid:13).

The first strategy in thermal bridge free detailing is to identify all possible thermal bridges at the outset of the project and design them out systematically; therefore, as discussed with lead contractor for Grove Cottage, Mike Neate of Eco-DC, the use of PHPP to ensure that targets are met is essential. PHPP is fundamental in ensuring that the space heating demand is met through the correct heating system and it is possible to argue that you cannot guarantee how the building will perform without the programme. On a current Passivhaus project, Mike explains how the architects made the decision not to disclose the PHPP results; therefore although the U-values for the walls and other elements were known, details for the project were speculative and the team were unable to scrutinise the programme to see if the decisions made were correct. Although it was possible to do their own U-value calculations for various methods and detailing, it was not possible to see the overall effect of the construction choices as a numerical value which PHPP would provide. Additional to the success and ease of detailing a Passivhaus, PHPP also plays a vital role in budgeting a project. If the architects are not working in line with the quantity surveyor, or there is not one involved, PHPP becomes useful in determining how cost effective the detailing can be and ultimately whether the project is within financial reach (Neate, 2014:04).

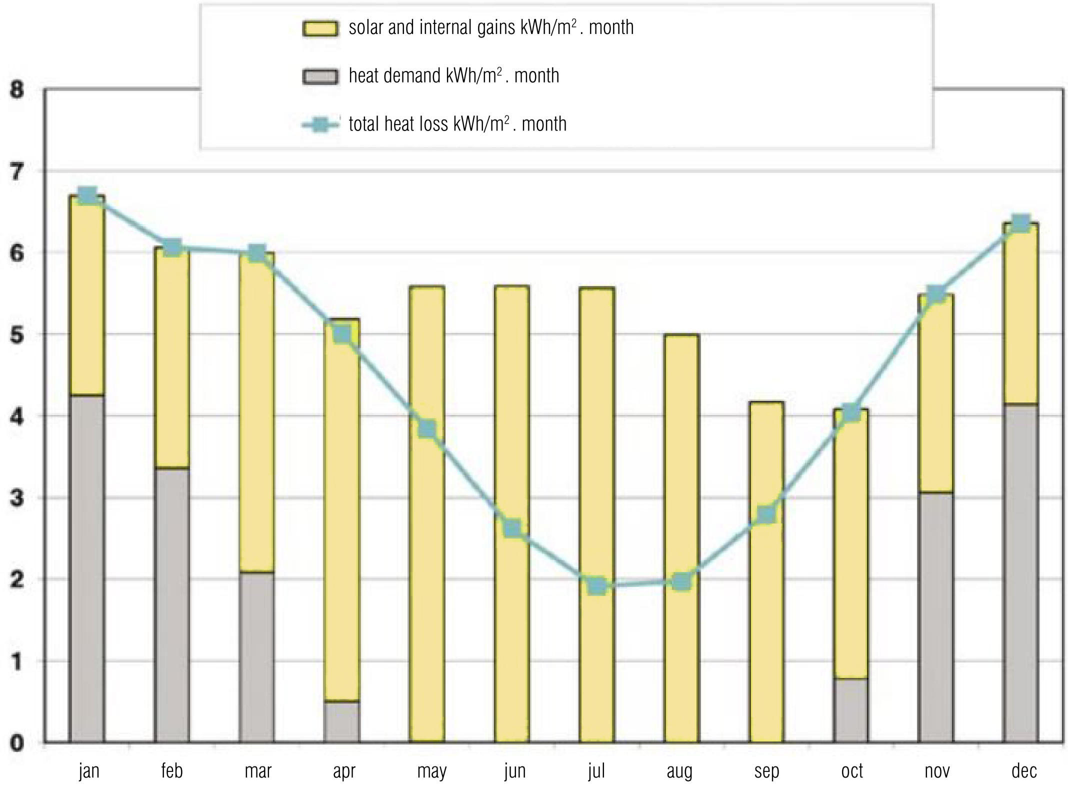


Figure 10: Gains, heat demand and heat loss projected by PHPP, using an internal temperature of 21 degrees (EST, 2010)

Passivhaus Constructions & UK Skills

At the same time as developing Grove Cottage, Simmonds Mills Architects were also working on the Centre for Disability Studies, Essex, and although Grove Cottage was built first, both projects were part of the same exploration of Passivhaus. Alongside the progression of the two projects, the CarbonLite Guidance was being written; each of the three having an affinity and being developed simultaneously. Iterative of each other, the building designs and the CarbonLite Guidance developed through the use of the German book of construction details; Passivhaus-Bauteilkatalog: Details for Passive Houses. The construction techniques detailed in the Bauteilkatalog were processed through examining how UK buildings are constructed, and developed to adapt to UK methods and a requirements using the CLP Volume 5: Design Guidance Passivhaus / Gold Standard , whilst solving design problems and changing construction where necessary (Simmonds, 2014:02). Even though Grove Cottage and the Centre for Disability Studies were different sized buildings, of different uses, much of the design and detailing was synonymous throughout the two, with relatively the same window, foundation and wall systems; however more importantly followed the same principles of energy efficiency such as passive solar gain (Ibid:02). The importance of airtightness was not yet fully realised by Simmonds Mills Architects, thus adapting construction techniques to allow thermal bridge free design and maintaining a high level of airtightness were two of the main challenges the project team faced.

Appointed as planning permission was approved, lead contractor Mike Neate of Eco-DC and the construction team, were employed on a basis of a day rate with between 3 to 4 builders on the site each week, preparing both the project schedule and the cost plan (Simmonds & Clarke, 2008:18). The project relied on a trusting working relationship and close communication between the architect and contractors, in order to ensure that careful consideration and attention was given to situations where the airtightness and thermal bridging strategy might be compromised and thus planned accordingly (Neate, 2014:07).

As PHPP software was used to refine the design prior to building regulations, much of the specification for the construction was already developed before the contractors were involved. Andrew's experience with the AECB and CLP allowed the design to be developed to an accomplished stage, and then further resolved on site collaboratively with the construction team; however this raises the issue of whether this would be possible for a Passivhaus retrofit of a typical dwelling. Explicit to Grove Cottage, Andrew was both the client and the architect, thus it was possible to commit fully to the project and oversee the progress on site throughout the whole construction process. As explained by Andrew, without his presence on site as the architect, far more drawings and technical details would have needed to have been completed and resolved before the commencement of construction, and as the client the amount of detailing work would not have been affordable. The involvement individuals who had knowledge of Passivhaus and typical building construction allowed decisions to be made quickly on site, which would of otherwise required paperwork. Due to the project being a highly complex build a substantial amount of time was dedicated to drawing and solving specific details, such as maintaining insulation thickness and providing a continuous airtight barrier, in-situ on the 'back of an envelopes' with the Andrew and Mike working together (Simmonds A, 2014:08). Skills were gained and refined along the way as the building progressed and the complexity of detailing increased, resulting in a sharp learning curve for the project team. It is hoped for future retrofits, a source of tradesmen well trained in Passivhaus methodologies, will allow the architects and designers to solve as many problems as practically possible prior to construction and the next level of decision making, as demonstrated by Andrew and Mike, will be sole responsibility of the contractor (Ibid:09).

Walls, Roof & Airtightness

Alongside super-insulation, the central aim of the project was achieving exceptional levels of airtightness for the new extension and retrofit of the existing house where feasible; therefore the aim for Grove Cottage was to meet the Passivhaus Standard's 0.6ach@50pascals, with a more realistic ambition not to exceed 1.0ach@50pascals. To ensure that the airtightness layer was continuous throughout the project, the strategy of designating the outer face of the solid wall as the airtightness zone was developed and proved to be a successful design decision.

The majority of the walls including the existing brick and new concrete blockwork extension were externally insulated, and the external face parged with a cement based slurry to create an airtight layer. For the existing building the choice of external insulation was fairly straightforward: the clients did not want to lose space within the house, and have tradesmen within the property to install the insulation as they lived in the building throughout the project, plus the external insulation formed an effective source of thermal mass. The 'Permarock EPS – Platinum insulated render system' (Neopor) (EST, 2010:18), was adhesively bonded to the wall and mechanically fixed with ties to the existing masonry (Figure 11). Based on a 'high performance expanded polystyrene' (thermal conductivity of 0.030W/mk), it was directly rendered with a 'self-coloured proprietary render', employing full coverage adhesive bonding rather than the common method of ribbons of adhesive so that there was no risk of air movement behind the insulation boards (Simmonds & Clarke, 2008:18). Ideally a system with only adhesive fixed insulation would be used to create a thinner more economic wall, but as the existing walls had previously been painted with masonry paint it would have been a risk to rely on the adhesive entirely, especially in areas of very thick insulation, therefore the masonry ties were used for extra security.

Devised to a meet a tight specification, specific details were designed for how the EPS insulation should sit off the ground, around the windows and how it should be applied to the wall to ensure a continuous airtight layer (Figure 12). However issues arose as the Permarock installers came without the correct drawings due to a breakdown in communication between the supervisor and the technical department who approved the details and the team continued to treat the insulation in the normal way they would for 50mm or 100mm, rather than for 250mm and

Figure 11: Permarock EPS insulation applied to existing building (Low Energy Database, 2010)

Figure 12: Permarock EPS external insulation detail to the floor and appearance once rendered (EST, 2010)

Figure 13: Repairing and making airtight the gable wall end next to the neighbouring house (EST, 2010)

Figure 14: Airtightness membrane clamped to roof structure and sealed with bitumen tape (EST, 2010)

adhering to Passivhaus principles (Simmonds A, 2014:14). Further to this it was discovered on site that the EPS blocks were not perfectly square, due to deformations when cut, resulting in gaps between in pieces; therefore it became an unexpected task to set up the lines of the insulation properly and shave the pieces to the right size. Through verbal explanation and closely overseeing the construction it was possible to overcome the problems and overall the installation was successful, however that lack of specialist skilled tradesmen in the UK was clearly an issue (Neate, 2014:05).

Despite thorough planning to overcome issues of airtightness and thermal bridging, some unexpected work with the project was required. The insulation of the party wall between the two houses, plus the repair and rebuilding of the top of the gable wall became complicated issues which can be directly linked to the retrofit of existing buildings. The area associated with the junction between the existing houses turned out to be one of the most complex and expensive elements of the project.

Albeit certified as semi-detached, an approximately 250mm gap existed between the gable walls of the two properties, for which a suitable solution had to be devised to stop heat loss and air leakages. Although PHPP discounts party walls for energy consumption as it will assume that the both properties have the same internal temperature, this is an unreliable assumption in refurbishment as the badly insulated and airtight house will have more heat loss than a new build. To overcome this, the gap was filled with expanding polyurethane foam (ZODP) to insulate the wall and add to the airtightness of the area. Unfortunately, much more foam was consumed than predicted, increasing the costs and resulting in only 70% of the area being covered (EST, 2010:21). Furthermore there is an uncertainty to whether the foam has entirely covered the area, as post-construction thermographic imaging showed there were possible small voids (Figure ??). Nonetheless, the decision is believed to have been imperative, as the air movement through the gap and the neighbouring house would have greatly affected the thermal performance of the building, plus the party walls surface compromised the airtightness layer (Simmonds A, 2014:16).

A major part of the refurbishment led to the whole existing roof being re-roofed, however when deconstructing the original roof the top of the gable wall disintegrated, due to both age of the building and a the lime construction, therefore required repair; mainly prompted by the need to create a structurally sound gable end for the airtightness membrane to adhere to (Figure 13). It was important to think laterally about how to rebuild the structure, creating an effective way to seal the membranes for the airtightness layer to the existing structure in order to ensure a robust and durable result, plus using materials that were easily accessible and time saving (Neate, 2014:03). The resulting detail being; the airtight barrier lapped down from the timber roof deck over the existing brickwork, the immediate area of brickwork sealed using a bitumen primer, then the barrier sealed to the brickwork using the bitumen tape (Figure 14) (EST, 2010:30). Additionally, problems arose where the new rear extension roof hipped into the existing roof. Here the airtightness layer applied to the existing building was difficult to connect to the airtightness layer of the new extension, therefore the airtight membrane of the roof was taken between the two roof constructions and connected to the airtightness layer inside and again sealed with bitumen tape (Bates, 2012:32).

Overall, through applying both the insulation and airtightness layer to the exterior façade of the walls it was possible to achieve the high levels of airtightness required to ensure thermal comfort, efficient operation of the MVHR system and to reduce the risks of interstitial condensation and mould growth within the construction. Nonetheless, due to the combination of existing and new build construction, alongside complex geometries and design based around solar gain, completing this task successfully was a challenge for the project team. Explained by Mike, there were areas of the project that could have been undertook differently; such as using 18mm OSB boards or plywood for the airtightness layer on the dining and kitchen ceilings which would have saved a substantial amount of time. As the associated skills and knowledge of the subject were developed during construction, it is possible to suggest that this added to the issues of how the airtightness strategy was approached, however with further training minor issues of experience can be resolved (Neate, 2014:06).

Floors and Basement

One of the main achievements of the retrofit was finding a solution for insulating and making the existing suspended floor above the basement airtight. As the basement was unheated as existing, the decision was made to thermally separate it from the rest of the building because it would have been impossible to cost-effectively thermally upgrade it.

At the front of the house the timber joists supporting the suspended floor were severely decayed, consequently a detail had to be devised in order to address the decay as well as cold bridging at the floor to wall junction (Figure 15). To resolve the dual problem, the joists along the wall were re-underpinned and the timber wall plates replaced with cellular foamglass load bearing bricks . The heavy duty foamglass, used for structural applications, have a thermal conductivity 0.055W/mK (Bates, 2012:25), thus effectively reduced but did not eliminate the thermal bridge completely. For the area of the damaged wall the specific psi value was thermally modelled so the detail could be appraised, and a negative thermal bridge created (-0.019W/mK). Without the thermal modelling to prompt the design decision, an external trench adjacent to the brick wall would have been dug and EPS insulation installed approximately 1200mm below ground against the existing brickwork (Simmonds A, 2014:13).

The floor was treated in a relatively unconventional way, as lifting the floorboards was considered a far too destructive and unsuitable approach as they ran across the whole of the house with the partition walls situated on top (Neate, 2014:07). Subsequently the insulation and air barrier were placed beneath the structure despite the fact that the air membrane could not be positioned in the typical position relative to the insulation, as this was the easiest way to ensure airtightness (Figure16). As timber floors tend to suffer from air leakage careful attention is required to ensure that all joints between the floorboards and floor are adequately sealed; however what was not fully understood during the retrofit was the amount of moisture produced from damp masonry walls in contact with the ground. The timber moisture content for a standard untreated basement may be approximately 17/18% and the relative humidity acceptable because it is often masked by the ventilation rate; however when the floorboards are covered ventilation is reduced thus relative humidity and the moisture content of the joists increases. To overcome this, the joists were insulated with Thermafleece sheep's wool insulation in-between a build-up of OSB, with the aim to equalise the moisture content of the timber. As it was too complicated to put the airtightness membrane on the warm side of the insulation an extra layer of Thermafleece was placed underneath the structure. Problems arose through the use of the intelligent vapour membrane (INTELLO), which although claimed to have a particular face to allow water vapour through one direction in certain conditions, allowed a transfer of moisture both directions from the basement to the house because of the high vapour pressure in the basement. Due to the cold edges at the wall to floor junction the moisture content of the timber is high and the rate of decay of the floor joists has increased, and although the construction is adequate, the joists will need to be replaced with plastic timber in the future.

In hindsight Andrew states how he would have decided to approach the basement in a different manner; placing the airtight membrane and insulation below the floor joists and accepted the reduced head height, or invested more money in underpinning the house to make the basement deeper, then used a vapour closed membrane which would be possible due to the airtight layer being on the right side of the joists when kept warm (Simmonds A, 2014:17).

Certification & Post-occupancy

Although certified to EnerPHit using the performance criteria, it is important to acknowledge that throughout the project the aim was to meet Passivhaus targets as mush as feasibly possible rather than the lowered EnerPHit targets. When modelled in PHPP for certification the process was much more rigorous and the specific heating demand was pushed up to 25kWh/m2.yr from the original 21kWh/m2.yr predicted previously. Meeting a specific primary energy demand of 120kWh/m2.yr and airtightness of 1.0ach@50pascals, Grove Cottage fell short of the Passivhaus performance targets, however inadvertently met the targets for EnerPHit. As a result of the retrofit, discussed with the client Lorna Pearcey, the most significant change is the improvement of the heat distribution throughout the house. Rather than having a focus of heat in one specific room, the temperature is consistent throughout, thus it is possible to occupy the whole house (Figure 19) (Pearcey, 2014:03).

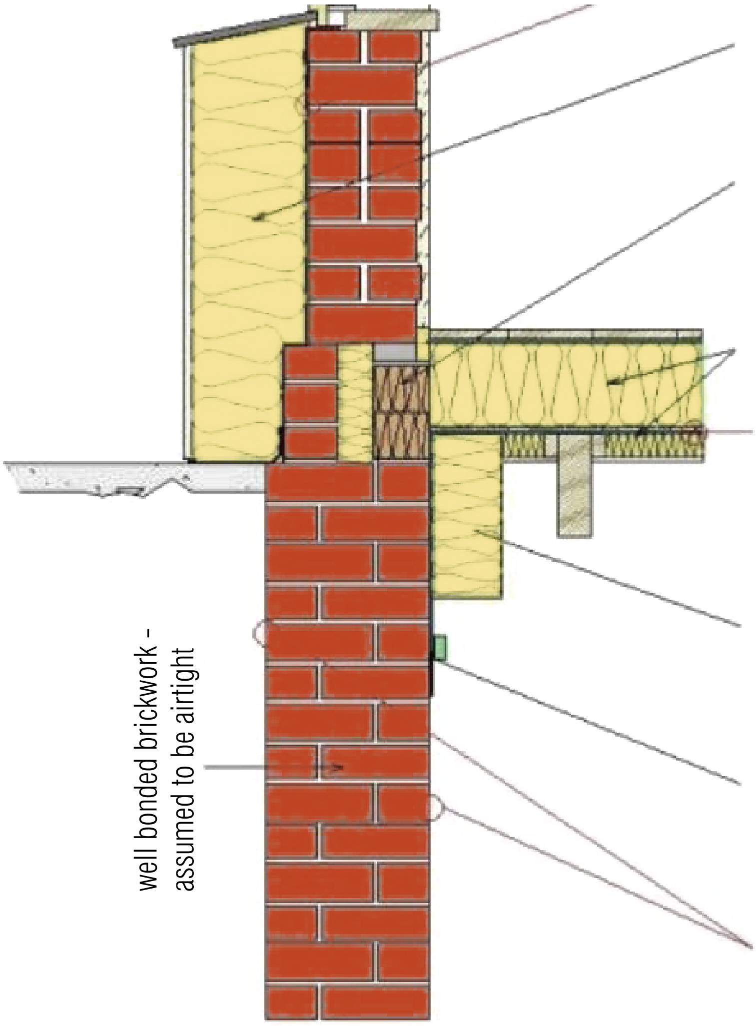


Figure 15: Detail of suspended floor to wall junction (Simmonds, A. & Clarke, A., 2008)

Figure 16: Applying and sealing the Intello vapour membrane to the underside of the suspended floor (EST, 2010)

Despite the measures to reduce carbon emissions, there is evidence of a 'performance gap' between predicted and actual energy use in buildings. Measured over 12 months, it was recorded that to heat the house it required 24,000kWh/yr natural gas and 4,300kWh/yr electricity pre-retrofit. A successful outcome would result in 80-85% reductions in the CO2 emissions, compared to the average of typical UK house of the same size. Converted into carbon emissions the building used a considerable 55kg CO2/m2 annually, which was reduced to 25kg CO2/m2 post-retrofit. Figures 17 and 18 represent the forecast and measured primary energy requirement compared to the pre-development figures. Although greatly improved from the original figure, the primary energy requirement forecast at 108kWh/m2.yr actually measured 120kWh/m2.yr in 2010; a 60% reduction from 2005, clearly highlighting a performance gap (Low Energy Building Database, n.d.)

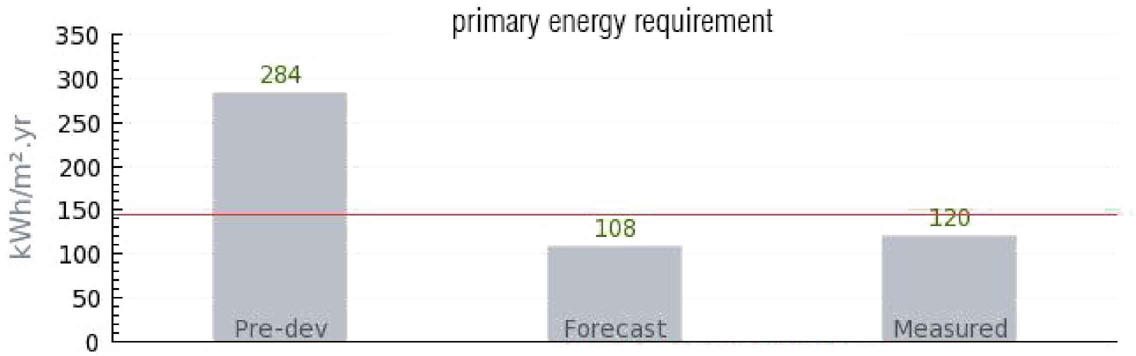


Figure 17: Primary energy requirement showing performance gap between forecast and measured (Low Energy Database, 2010)

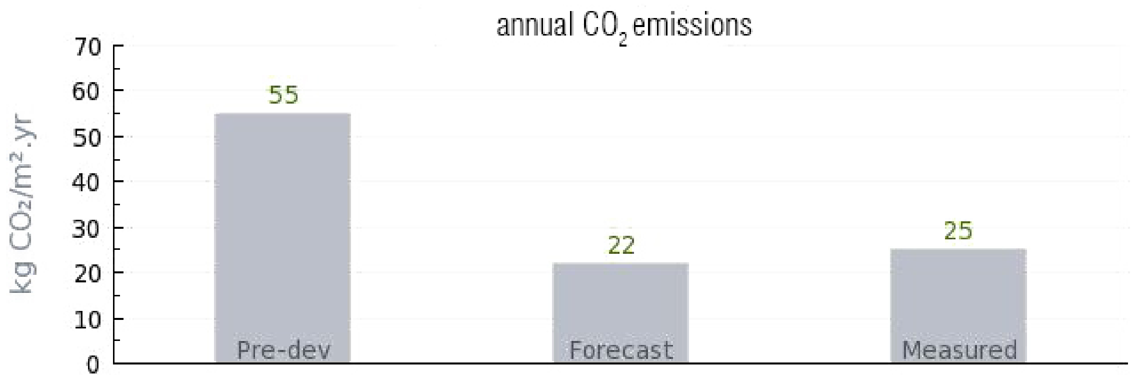


Figure 18: Annual CO_2 emissions showing difference between forecast and measured data (Low Energy Database, 2010)

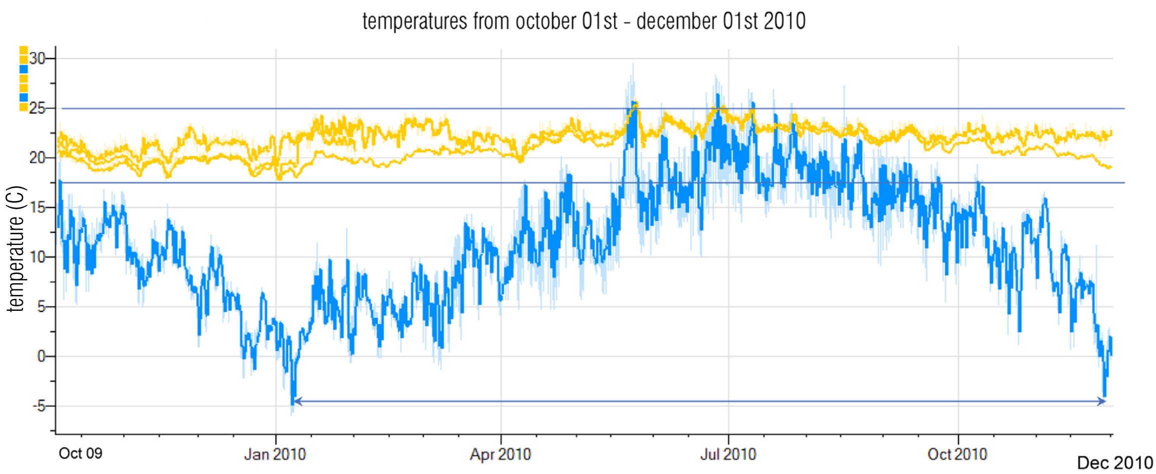


Figure 19: Comparison between internal and external temperatures post-retrofit (Simmonds Mills Architects, n.d.)

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Author Information

A final year Masters of Architecture student, I am highly interested in sustainable design and the way in which we should approach architecture in the future using sustainable methodologies. The interest in this topic developed during my part one year in industry, and completing this research has fuelled a new found interest in Passivhaus, which I hope to continue developing further in my career.

Acknowledgements

Firstly I would like to thank Dr Henrik Schoenefeldt for the supervision with compiling and writing the information for the section on Grove Cottage. Without his dedication and guidance this discussion would not have been possible. Additionally, I am extremely grateful for the invaluable information provided by Andrew Simmonds, Lorna Pearcey and Mike Neate on the case study, which has allowed an in-depth and thorough investigation.

100 Princedale Road

Thomas Haywood

Location Notting Hill, London
Building Type Single, social housing dwelling
Construction Type Pre-1919 solid brick
Floor area 115sqm
Completed December 2010
Year Certified March 2011
Overall Cost £178,290

Client Octavia Housing Group
Architect Paul Davis + Partners Architects & Urban Designers (pd+p)
Main contractor Princedale Homes (Ryder Strategies Europe)
Council The Royal Borough of Kensington & Chelsea
Certifier WARM: Low Energy Building Practice
Design Consultant/Project Manager Green Tomato Energy
Environmental Consultant Eight Associates
Cost Consultant Pellings LLP
Funding Sources Technology Strategy Board (TSB) via the 'Retrofit for the Future' programme (R4tF): £150,000 competition funding.
Octavia Housing Group: £28,290 (top-up costs)

Abstract

The Technology Strategy Board's 'Retrofit for the Future' project was established as a consequence to the issues and policies raised in the Heat and Energy Saving Strategy consultation produced by the UK Government in 2009. As a result, 100 Princedale Road, together with 85 other schemes, were seen as an 'innovative experiment', in order to meet these future targets in all existing social housing, of which the findings were to be closely monitored by the Energy Savings Trust (Passivhaus Trust, 2013 [Online]). Completed in December 2010, the Passivhaus refurbishment at 100 Princedale Road was originally an existing three storey solid-brick Victorian mid terrace house. The vacant social home property at the time, is located within the Norland conservation area in Notting Hill, London, where the scheme was declared the first retrofit project in the UK to be certified to full Passivhaus standards (Passivhaus Trust, 2013 [Online]).

Case Study - 100 Princedale Road

Introduction

It is envisaged that the Passivhaus standard, along with the Passivhaus retrofit standard (EnerPHit), can help eradicate the risk of fuel poverty, improve thermal comfort and increase fuel security particularly for low-income groups in the UK (BRE, 2013). With reference to this case study, there is a real need for social housing companies in particular, to search for alternative methods in achieving deep carbon emission cuts in existing UK social housing stock. The £17m 'Retrofit for the Future' programme launched by the TSB in 2009, was created to kick-start the retrofitting of social housing in the UK. In this case, the whole-house retrofit of 100 Princedale Road demonstrated the full potential of improving the energy efficiency of existing social housing, despite its technical difficulties. Also on reflection, the project highlighted the benefits alongside the current shortcomings of implementing the full Passivhaus standard in the UK to such a challenging context.

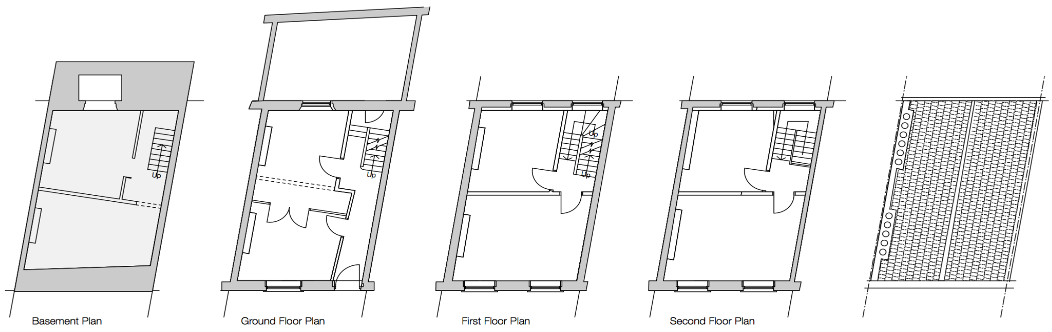
Anatomy of the Design

From the very beginning of the project, the client recognised the Passivhaus approach to be the most appropriate building and performance method to retrofit 100 Princedale Road, compared to other available standards at the time, including Decent Homes Plus and BREEAM's Domestic Refurbishment assessment tool. According to the primary research, the main motive for the uptake in the Passivhaus standard by the client was not only due to the increased building performance the Passivhaus method demonstrates, but with the successful experience the social landlord had with Passivhaus rated new-builds, Octavia Housing were keen to use this standard on the retrofit building type, and consequently this scheme (Baeli, 2013 [Interview]). With the property being located within a Royal Borough of Kensington & Chelsea (RBKC) conservation area, 'there was strict requirement that its external appearance remain as existing (AJ, 2012), (fig. 2).
Certainly conservation areas serve the right to preserve the appearance and aesthetics of culturally important and historic buildings, however, 'protected status' often restricts the opportunity for low-carbon remedial work' (Moorhouse & Littlewood, 2013). The existing condition of the house was in a very poor state as seen in fig. 5 and 7, where the project team highlighted a number of existing issues including, uneven and non-plane ceiling joists, an unstable staircase, drafty and leaky windows and a damp basement. Considering the existing condition of the house and the imposed planning restrictions on the external appearance, the design team made the decision to strip back the entire property as far as the façade, which therefore included the removal of all internal walls, ceilings, staircase and the chimney breasts, to then conduct the whole-house deep retrofit.

Figure 1 : 100 Princedale Road located in Notting Hill, as viewed from Google maps.

Figure 2 : Existing elevations - 100 Princedale Road

As noted by Marion Baeli the project architect for the scheme within a separate case study report entitled 'The cost of retrofitting to Passivhaus standards', she explained that, 'the strategy for the retrofit is based on the introduction of new (yet traditional) materials and technologies within the external skin of the existing building' (2012 [Online]). Although, new materials were not necessarily introduced for the retrofit, more so 'standard building techniques and accessible materials [were] adapted' in order to produce the inventive building solutions necessary to achieve the necessary performance levels a Passivhaus demands (Passivhaus Trust, 2012 [Online]). In order for the proposed low-energy home to achieve the Passivhaus standard, the project team established five main design principles to address the design challenges.



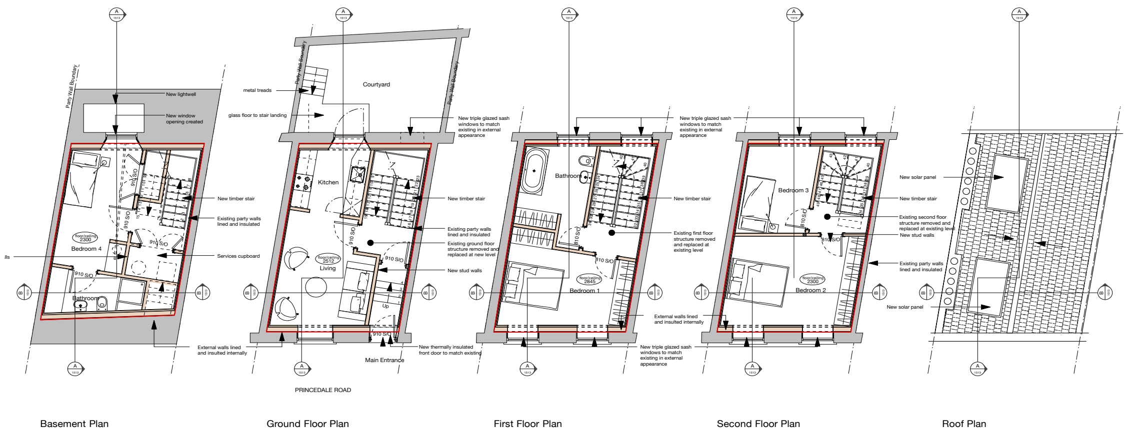


Figure 3 and 4 respectively : Existing and proposed plans - 100 Princedale Road

Figure 5 : Condition of the existing staircase - 100 Princedale Road

Figure 6 : Existing front and rear elevations - 100 Princedale Road

Figure 7 : Internal view of the existing butterfly roof structure - 100 Princedale Road

The main solutions adopted by the design team are as follows; 1 – an uninterrupted and continuous whole house insulation, 2 – whole house airtight layer of which again being uninterrupted and continuous, 3 – mechanical ventilation throughout with a heat recovery unit, 4 - new triple glazed windows and 5 – provision of an underground heat exchanger (Baeli & Pelsmaker, 2011).

The research uncovered that the appointed contractor, Princedale Homes, also worked on another Passivhaus retrofit project simultaneously to constructing 100 Princedale Road, being Lena Gardens also located in west London (see fig. 20). Although the property was also a solid brick terraced house and located in another conservation area, the refurbishment was not part of the 'Retrofit for the Future' scheme as the property is privately owned. Incidentally, the Lena Gardens property is owned by the C.E.O of Green Tomato Energy Tom Packenham; the company who also assisted with the design and project delivery of 100 Princedale Road (Proffit, 2013). With this in mind, there is already an interesting team dynamic emerging with regards to overcoming the inevitable challenges and logistics of a Passivhaus retrofit project in the UK, particularly at this time. Alongside this team aspect, the cultural impact of a Passivhaus retrofit on this property is equally important to consider. In the case of Princedale Road, the impact of the new windows to meet conservation area conditions is clear; and there are cultural influences because of this, such as, from an internal perspective the whole house impact of the Passivhaus standard does indeed transform the interior of existing homes. For instance, the internal chimney-breasts were removed as part of the works, not only to increase the amount of floor space but also to minimise areas of the house which may be vulnerable to thermal bridging and heat loss. The impact of the new Passivhaus rated sash windows can be seen in fig. 16 and 17.

The project team were also keen to implement a familiar construction culture of using standard UK building skills and systems, as opposed using experimental, or emerging contemporary materials. As the contractor declared during the interview process on this subject, the team "used conventional materials, but in some cases engineered them in a certain way" (Proffit, 2013). For instance, in the case of the proposed construction build-up against the existing party wall, instead of using traditional metal or plastic fixings to hold the insulation and OSB board in place, 'adhesive was used to further minimize thermal bridging [U-value, 0.27W/m2k]" (Kingspan, 2013 [Online]). Alongside the more traditional building techniques used, the Passivhaus approach was indeed very influential towards key areas such as the heating and cooling strategy, the new basement design, typical wall and floor details, and the new windows. As mentioned above, due to the nature of the Passivhaus method, the existing sash windows had to replaced with new mock-sash triple glazed, Passivhaus rated windows. With the project being a retrofit, Princedale Road contained more challenging junctions and room designs compared to a typical

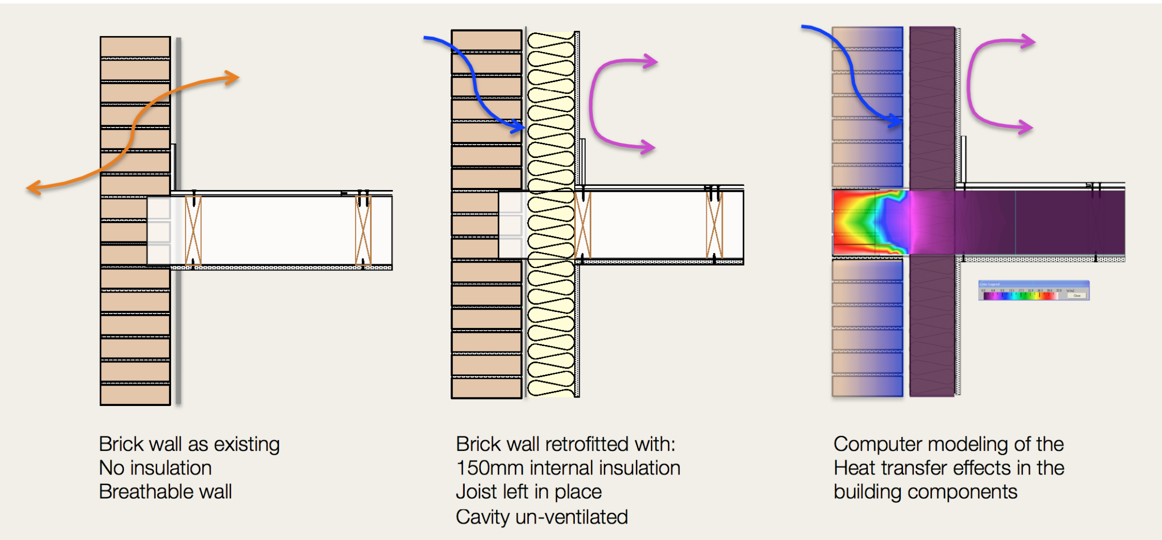


Figure 8 : Existing staircase - 100 Princedale Road

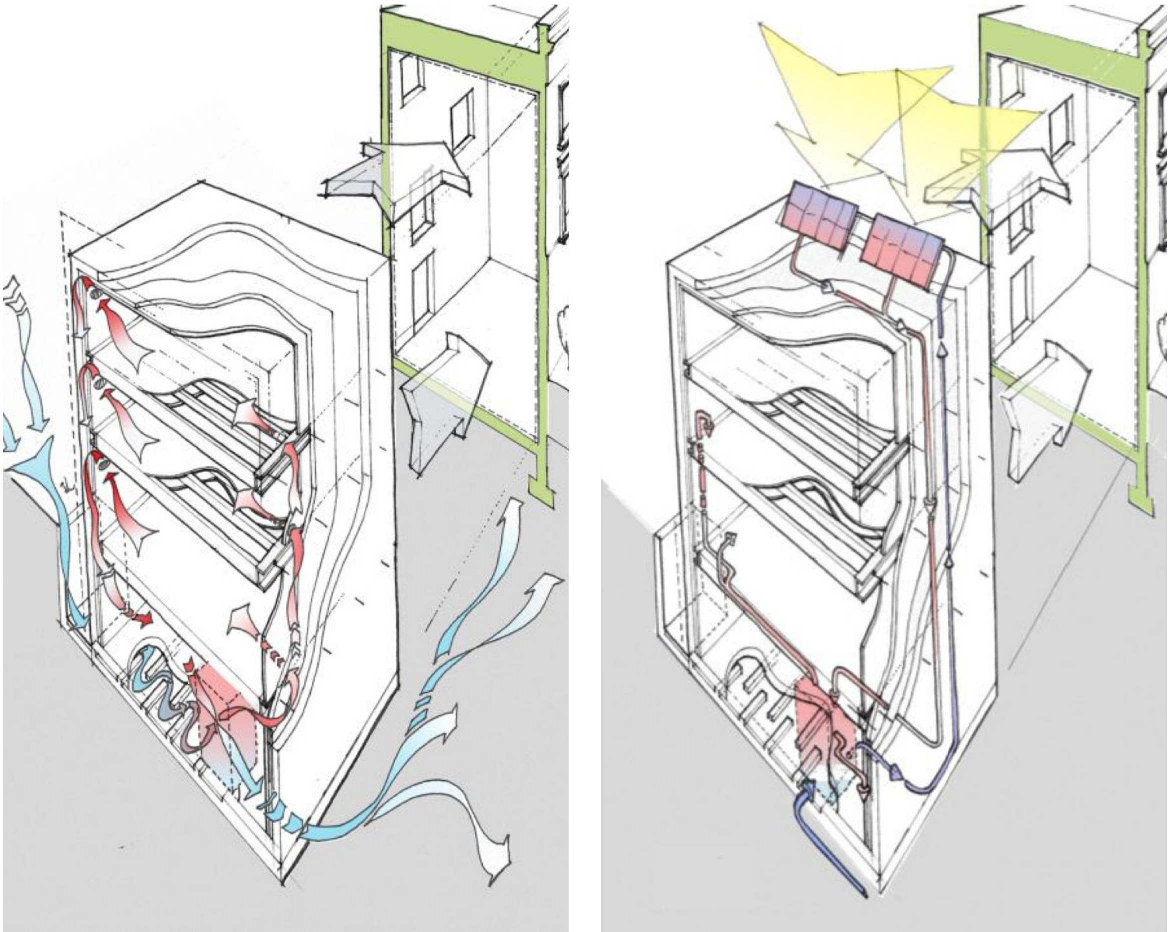
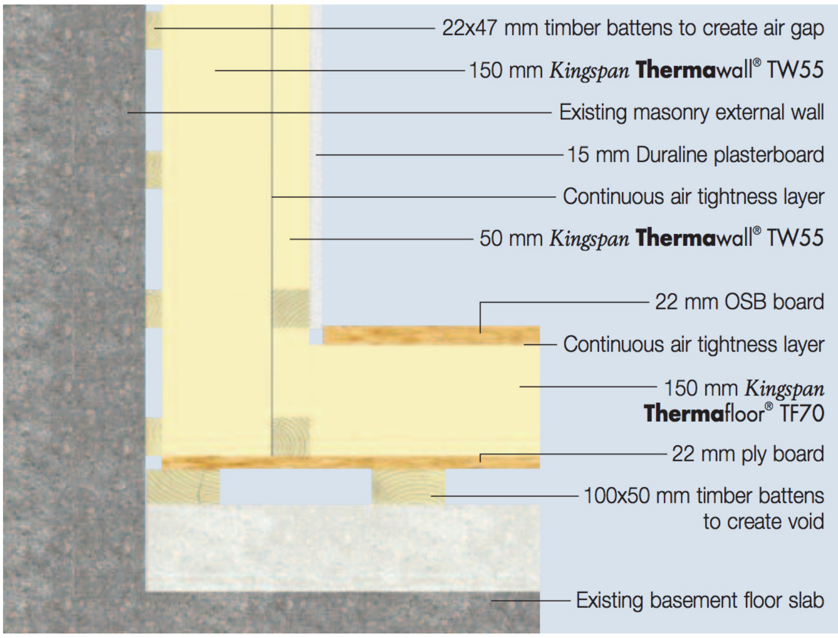


Figure 9 and 10 respectively : Architect sketches displaying the environmental strategies

purpose built Passivhaus, therefore the design and detailing had to be carefully planned and carried out. Due to space constraints within of the property and with all insulation having to be internally fitted, space-saving was a major priority for the retrofit, and this was evident through the type of insulation specified. The team undertook three different insulation strategies to treat the party walls, the external walls and the proposed roof construction build up, in order to maximise as much space internally for the eventual residents. For instance, in terms the party walls, 25mm of Kingspan Thermawall was applied followed by 12mm OSB to ensure airtightness, then a further 25mm Kingspan with a plasterboard finish.

Due to the complete overhaul of the existing interior to the property, it gave the design team a 'clean slate' to custom-design the heating and cooling strategy for the retrofit, as shown in fig. 9 and 11. As part of the Passivhaus model requirement, the team fitted a whole house mechanical ventilation system with heat recovery (MVHR) as the proposed ventilation system strategy. Careful consideration was taken by the design team in terms of the positioning of the ductwork system in order to limit intrusion into room space, therefore the vast majority of the ducts were installed under the ventilated timber floor system.



Twinned with the MVHR system, the design team implemented an underground air to heat exchanger labyrinth as part of the strategy. Fig. 11 displays the new level base concrete slab detail, which was laid to the existing basement with a layout of concrete ducts. The ducts were ‘designed to capture the heat of the day or the cool of the night, and slowly release the thermal energy to help warm or cool the building’ (FMLink, 2009 [Online]). Using the relatively constant ground temperatures, the ground to air heat exchanger in the basement provides additional pre-heating for air in the winter an cooling during the summer. The MVHR combination unit controls the necessary switching between cooling and warming the internal spaces using the basement floor heat exchanger. In terms of hot water production for the property, two solar thermal panels installed on the butterfly roof are connected to two hot water cylinders, one of which comes pre-bolted on to the MVHR combination unit. Plus, as a backup system, a small air source heat pump can top up the performance, integral to the MVHR unit.

Figure 11 and 12 respectively : Basement wall/floor detail and the retrofit process of the basement conversion

Figure 13 and 14 respectively : Working construction photographs showing the new thermal build-up

1 Existing rendered façade
2 Existing exposed brick façade
3 Existing party walls
4 New timber floor structure, OSB and timber joists

5 New triple glazed sash windows

6 New internal lining to external walls comprising of:
25mm vented cavity
150mm PU foam insulation boards
12mm OSB timber boards - airtight layer
50mm PU foam boards (service zone)
15mm duraline plasterboard

7 203x133 UB steel channel resting into party walls

8 New internal lining to party walls:
25mm PU foam insulation boards
12mm OSB timber boards - airtight layer
25mm PU foam insulation boards
12mm plasterboards

9 New underground heat exchanger comprising of: 18mm OSB timber board
150mm PU foam insulation boards
18mm OSB timber - airtight layer
67mm concrete baffle / void (acting as air ducts) 15mm screed under baffles
(1:40 falls towards gutter) 125mm new concrete slab

10 New roof insulation:
250mm PU foam insulation
12mm OSB timber board - airtight layer 50mm battens - service void
12.5mm plasterboard

11 Existing butterfly roof retained as existing

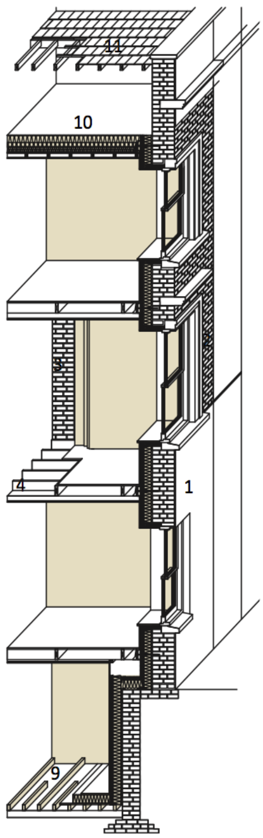


Figure 15 : Sectional perspective showing the proposed build-up of the Passivhaus retrofit principles

The typical proposed wall build up was created utilising the exterior facing brick of the house and wrapping the inside face with 200mm of insulation, effectively establishing a continuous thermal envelope. The thermal envelope was then made airtight, as the design team followed this by using a continuous layer of OSB boards. A 25mm cavity was left between the existing and proposed build up to create a breathable wall without compromising the integrity of the thermal envelope. Although, as revealed by the contractor, the MVHR system could have been much more efficient in its design and implementation.

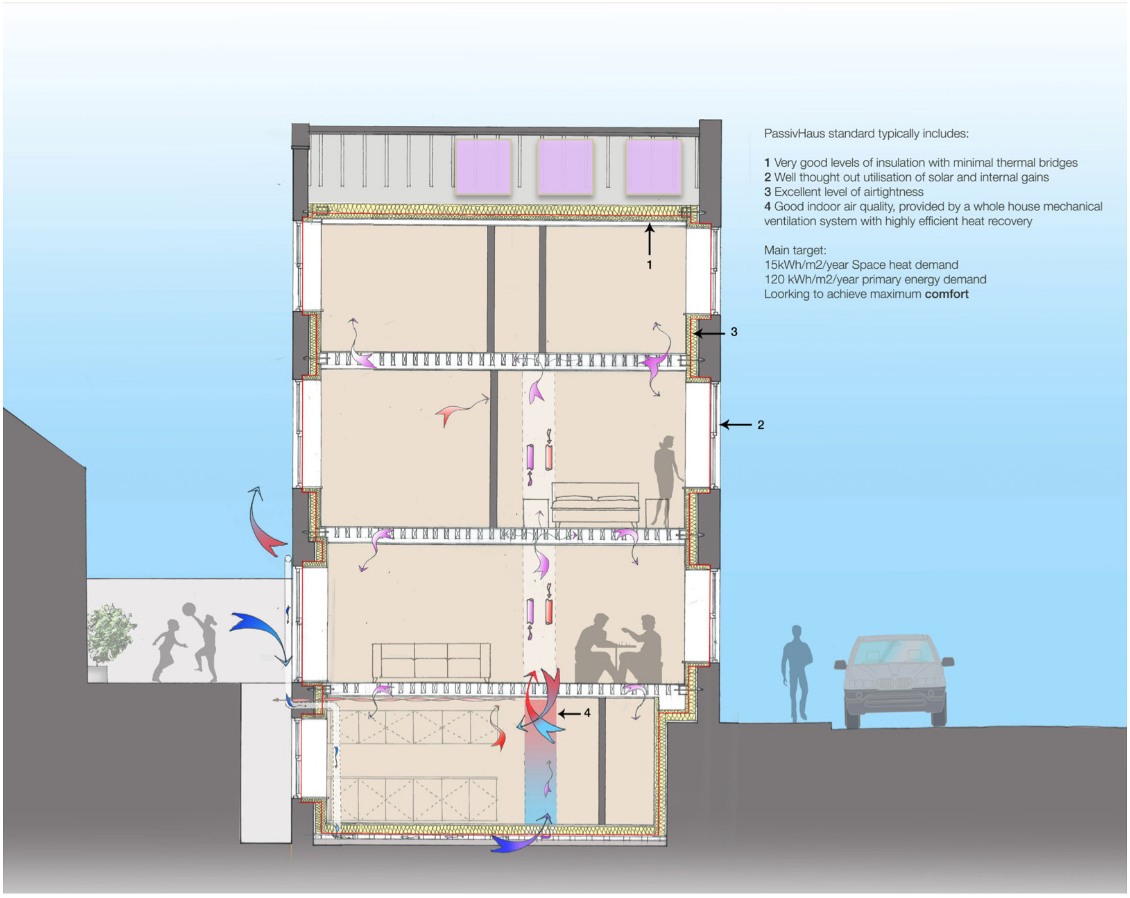


Figure 16 : Environmental strategy section - 100 Princedale Road

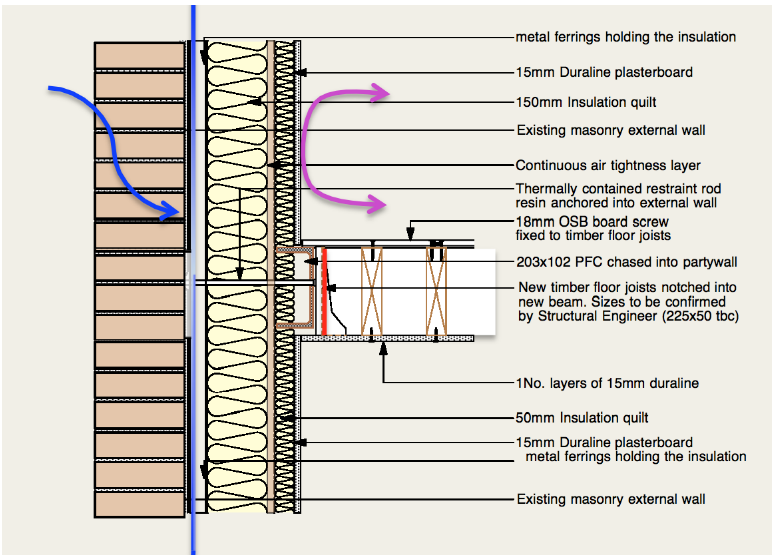


Figure 17 : Proposed typical floor to wall detail - 100 Princedale Road

Figure 18 : Diagram showing the MVHR system and the new plant room

In terms addressing the new timber floors for the ground and first floors, to combat the potential problematic issue of thermal bridging and potential moisture build-up, the decision was taken to re-hang new timber I joists onto new steel beams that were embedded into the party walls; of which 'themselves would rest in insulated pockets [using foam glass] within the party wall' (Baeli & Pelsmaker, 2011). As discussed by Marion Baeli at PLEA 2011 the 27th Conference on Passive and Low Energy Architecture, she 'argued that the steel beams are not part of the energy efficient measures themselves, but they are essential to this project' (Baeli & Pelsmakers, 2011. [Online]). Amazingly from the research, there appeared to be very little on-site issues or problems during the build. But as explained by the contractor, to assist with the successful delivery of the project, he surrounded himself around other like-minded technical people including plumbers, electricians and steel workers, who had the knowledge and understanding to build to the level a Passivhaus expects.

But crucially the contractor highlighted that having a "good team" and diligent "communication" across the spectrum were critical aspects to the retrofit. Alongside the entire design team, the client Octavia Housing were also heavily involved throughout the entire process. For example the client were present at every design and site meeting, which allowed a transparency and clear dialogue with the rest of the team. Even from the beginning of the process, the "client saw a really good advantage in not having a gas connection" to the retrofit property (Baeli, 2013), where this decision was essentially made in reaction to their previous experiences in using gas connection boilers within social housing. According to Octavia Housing, gas requires more regular maintenance and are can be somewhat unreliable, compared to the proposed system.

Conservation Area Planning Restrictions - Culural & Technical Impact:

Due to the age and location of the terraced property, situated within the conservation area of Norland; there were clear limitations from the outset on the flexibility of the proposed design, to transform the vacant property to a fully refurbished Passivhaus retrofit standard home (RBKC, 2011. [Online]). As discovered from primary and secondary sources, there is clear evidence to suggest there were challenges during the planning process in enabling the design to gain permission for the retrofit. The use of external insulation was not possible as part of the planning conditions, so consequently the whole house was internally fitted with continuous layers of insulation and OSB boards, which to a certain extent influenced certain design decisions that altered the historic character of the existing house. Many internal features were completely overhauled including the staircase, chimney breasts, fireplaces and the traditional sliding sash windows were also removed. This is an important concept in terms of the impact internally of Passivhaus retrofits generally, from an aesthetic point of view, as period features are currently very desirable in the UK. But the architect explained that there were no features to be kept in the existing house as it was fairly derelict, and not of particularly historic importance.

Although Baeli commented that with regards to the new mock sash windows, the as-built deep reveal details "are common in many Victorian houses where you have internal shutters". She explained further, "if we had put some shutters there it would have worked to refine the sections of the window internally" (2013. [Interview]). With reference to the RIBA's 2012 research report on 'The way we live now: What people need and expect from their homes', is summaries that 'many participants were keen to have homes with 'period' features…and therefore preferred older properties' (RIBA, 2012. [Online]). This essentially raises an interesting question, as to the cultural impact of the Passivhaus retrofit to existing housing stocks, and the significance it could have on the number of people willing to live in them in the future, should the trend continue. Although for Octavia Housing and the social housing sector, this may not be a major concern. Due to the stringent and demanding performance regulations set by the Passivhaus standard, one of the key historic features of the home at Princedale Road, the sash windows, were lost. Currently under both BREEAM and EcoHomes environmental assessments, historic windows located in a conservation area can be adapted rather than replaced to meet accreditation.

Figure 19 : A thermal imaging photograph of 100 Princedale Road as existing, showing the heat loss issues with the fabric

Figure 20 : Before and after front elevation photographs of 100 Princedale Road.

Understandably so, the environmental and energy efficient benefits to replace old windows under Passivhaus principles to triple glazed units are evident. But for example, with this case study, despite the custom-made mock sash windows, the period features were somewhat lost especially from the inside, with the thickness of the glazing units and the side hung operable casement (see fig. 21 & 22). The focus here is on the financial savings the family have made alongside the improved air quality and overall comfort inside the home. But is the reduction in 'period' features of Passivhaus retrofitted homes being overlooked? We can compare 100 Princedale Road with other similar case studies including Grove Cottage, a Victorian retrofit in Herefordshire, and Lena Gardens also located in west London; in order to cross-examine any similar challenges these projects encountered. Fortunately for the Grove Cottage project, the existing Victorian townhouse was not a listed property or located in a conservation area, therefore there was greater flexibility in terms of the proposed Passivhaus design (Passivhaus Trust, 2012. [Online]). Similarly to Princedale Road, Grove Cottage was constructed of solid masonry, however the use of external insulation and slim-line aluminium framed windows were permitted allowing for more versatility and permitted space internally.

Relaying the question back to the Princedale Road case study, it is apparent how problematic conservation area planning circumstances can be to achieve the high performance standards Passivhaus entails, whilst capturing the culture and aesthetic quality of 19th century, period properties.

Figure 21 : The existing sliding sash windows of 100 Princedale Road, before works began

Figure 22 : The new mock sash windows with a side hung bottom casement and fixed upper pane

Funding the Project - Impact of the Technology Board's (TSB's) 'Retrofit for the Future' scheme:

The £150k funding budget awarded by the TSB's 'Retrofit for the Future' programme was a major subsidy towards the scheme, posing the question of how economically viable a Passivhaus retrofit scheme can be, especially one located in a conservation area. In fact, according to a recent paper by Brunel University in 2012 entitled, 'Domestic UK Retrofit Challenge: Drivers, Barriers and Incentives', all of the 86 proposed retrofit schemes conducted by the TSB each received the £150k donation towards their project ([Online]). The capital costs as shown in fig. 26, are of course considerable. What is also significant is the amount spent on the new windows and doors amounting to £32,007. But as explained by the architect during the interview process, considering this retrofit was the first of its kind in the UK, future projects of a similar nature should cost less to construct. As for the new windows, Baeli explained the "£32k actually includes £20k of equipment and now that the equipment is purchased it does not need to be purchased again so I think it could be brought down to…£14k we figured out" (2012. [Interview]).

As sourced from the competition documents of the 'Retrofit for the Future' programme (TSB, 2009. [Online]), the procurement route and funding was split into two phases (see fig. 18). Phase one consisted of a feasibility stage where companies were awarded a maximum of £20k funding to generate a technical study of their proposals, and essentially aimed to cover all design and planning costs before pre-construction. As stated in the competition documents, Phase two is the actual build stage, whereby contracts are awarded and funded in the region of £150k following the technical work completed during Phase one. Questionably, this perhaps demonstrates an economic and cultural limitation in implementing the Passivhaus standard in the U.K? But this public funding stage is perhaps necessary and inevitable in order to experiment and make low-energy and particularly Passivhaus retrofits the norm in the future, for existing social and even private housing stocks.

Phase 1 feasibility/design

The feasibility/design Phase 1 is funded to a maximum of £20K and is intended to generate a technical feasibility study. The present economic climate is putting great pressure on the construction industry. Phase 1 funding is provided to help companies prepare for the future retrofit market and take risk out of the application process for the Phase 2 build stage. The funding will cover specific technical work and may include:

- Technical assessment of primary energy use and CO_2 emissions using appropriate modelling software.
- Detailed design proposals.
- Planning report, Conservation Officer report or Building Control Officer report where appropriate.
- Air tightness measurement (by demonstration, all testing must be carried out in accordance with ATTMA[1] Technical Standard 1 and CIBSE[2] TM23).

The Technology Strategy Board will require SAP modelling during Phase 1. To facilitate comparable data, the Technology Strategy Board will provide a set of technical and energy modelling guidance notes to successful applicants. These will ensure that the assumptions entered into SAP by competition entrants are uniform, thereby removing the potential for discrepancies.

Although not mandatory, feasibility/design studies that also model their proposals in PHPP[3] or similar, would be particularly welcome and would enhance Phase 1 work. PHPP may facilitate the optimisation of energy and CO_2 reductions at a more detailed level. For instance, PHPP incorporates an explicit overheating target with external temperatures that can be modified and locations changed, thus allowing some analysis of future climate change resilience.

The results of the feasibility phase will be assessed by expert assessors and a number of the most innovative and effective projects in terms of ambition and cost-effective carbon and energy reduction with potential widespread applicability will be funded and taken forward to the Phase 2 retrofit build.

Phase 2 retrofit build

The retrofit build Phase 2 contracts will fund the implementation of those proposals generated during Phase 1 feasibility work into demonstrator low rise houses. A maximum of £150K will be available in Phase 2 for carbon reduction measures only and not standard refurbishment costs. It is envisaged that during Phase 2, single houses, or small numbers of houses will be retrofitted with particularly effective, replicable and innovative technologies within the maximum £150K potential budget.

The monitoring and measurement of the retrofit demonstrators is crucial to the success of the competition. This will be funded and managed by the Technology Strategy Board but will require the cooperation of the successful companies and social landlords in each case. More details on this subject will be provided prior to Phase 2.

Key dates

Pre-application launch	
Feasibility application forms available	April 2009
Modern Built Environment Knowledge Transfer Network brokering events	April - May 2009
Consortia bid planning	April - May 2009
Deadline for feasibility applications	Noon, 24 June 2009
Phase 1 **Feasibility/design (funded – £20K max)**	
Assessment of feasibility applications	July 2009
Notification of decision	15 July 2009
Feasibility contracts awarded by	16 July 2009
Feasibility/design stage work begins	3 August 2009
Feasibility/design stage ends	23 October 2009
Phase 2 **Retrofit build phase (funded – £150K max)**	
Assessment	November 2009
Notification of decision	23 November 2009
Build contracts awarded	26 November 2009

Figure 23 : A screenshot taken from the TSB's 'Retrofit for the Future' competition documents

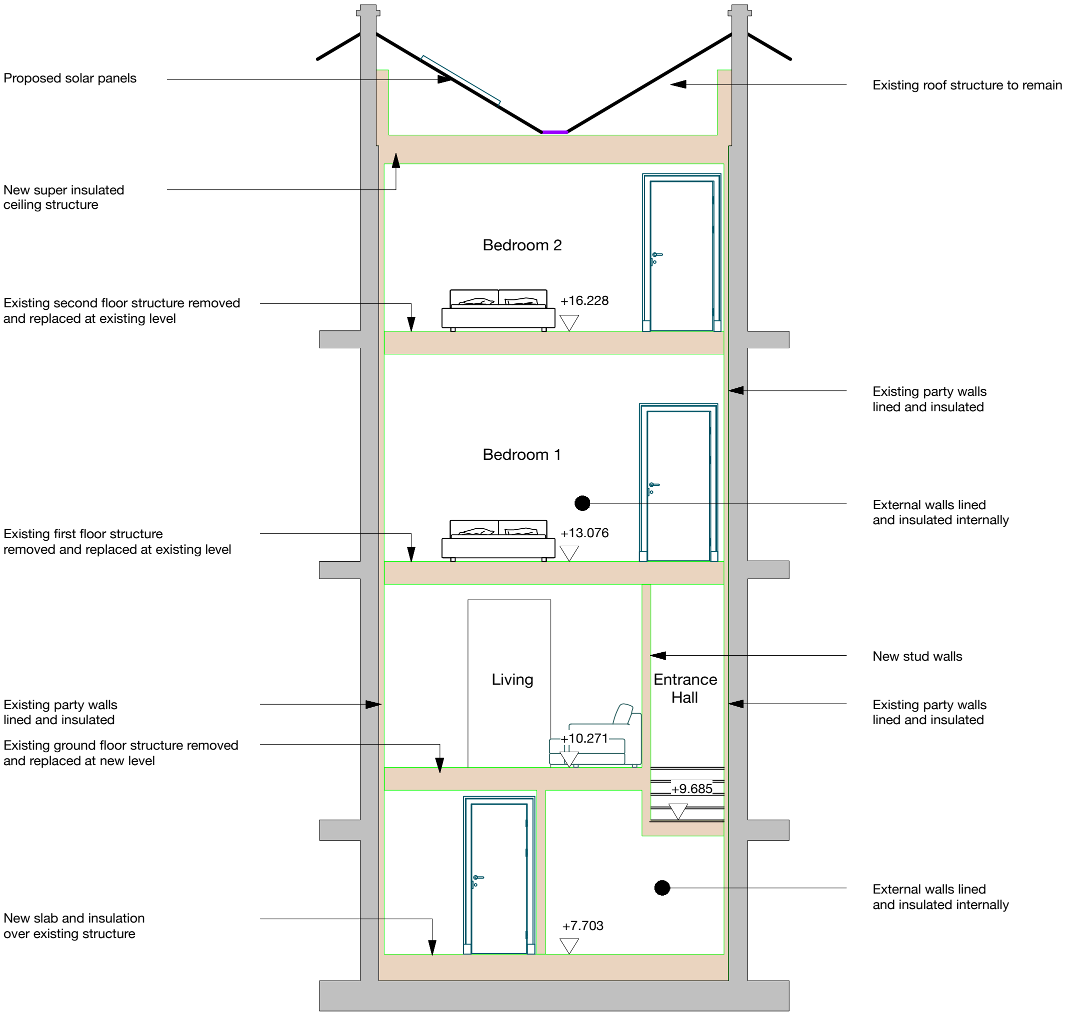


Figure 24 : Section displaying how the £150k funding was spent on the retrofit

Figure 25 : Completed photographs of the Passivhaus retrofit at Lena Gardens, London

Considering the total project cost was £178,290 and from the outcome of the interview process, we found that the client Octavia Housing topped up the financial support for the scheme from the original TSB funding. Despite this, the purpose and direction of the scheme looks to be a very positive one. Cotterrel and Dadeby write in their recent publication 'The Passivhaus Handbook' echo the general negative culture in the U.K. regarding our lasting investment in such matters. They explain, we 'appear to have lost the ability to make strategic, long-term decisions to commit to capital-intensive infrastructure projects that would bring medium and long-term benefits' (2012).

As shown in fig. 26 and 27, the tables compare the costs of Princedale Road with other similar Passivhaus retrofit projects across the UK. Generally from fig. 26 the costs appear to balance each other out in contrasting the budget against the total floor area of each respective project. However there are some key differences. For instance, we should notice the costs for Grove Cottage, a similar building and scale of work to Princedale Road, however the average square metre cost was £500 lower. Grove Cottage is not located in a conservation area. Therefore the specification for the replacement triple glazed windows may not have been as strict, meaning the costs were considerably lower in this part of the budget. Additionally unlike Princedale Road, the fabric of the existing house at Grove Cottage was not completely over-hauled, but rather the floors and ceilings were upgraded, therefore avoiding significant and expensive whole house alterations. As sourced from the paper entitled 'The Cost of retrofitting to Passivhaus standards: three case studies of UK pre-1919 homes' (Baeli & Pelsmaker, 2011), fig. 27 compares Princedale Road with two other mid-terrace, solid brick properties, converted to Passivhaus standards, where all of whom also participated in the 'Retrofit for the Future' programme. From the numbers presented; although the total costs for Princedale Road are considerably more than Midmoor and Hawthorn Road, Princedale Road was the only retrofit to achieve full Passivhaus criteria of 15KWh/m2/year.

Project:	Princedale Road	(1)
	Lena Gardens	(2)
	Totness Passivhaus	(3)
	Grove Cottage	(4)
Type:	Victorian pre-1919 solid brick	(1, 2 & 4)
	Cavity wall	(3)
Conservation Area:	Yes	(1 & 2)
	No	(3 & 4)
Total Build Cost:	£178,290	(1)
	£226,384	(2)
	£226,800 (approx)	(3)
	£140,000	(4)
Total Floor Area & Cost (m2):	115 m2 & £1,550	(1)
	195 m2 & £1,161	(2)
	162 m2 & £1,400	(3)
	145 m2 & £1,036	(4)

Figure 26 : Cost comparison table of UK Passivhaus retrofit projects

	Princedale Rd	**Midmoor Rd**	**Hawthorn Rd**
Floor Area:	115m2	110m2	109m2
Cost (per m2):	£1,550	£927	£1,289
Measures			
Roof:	£1,554	£8,200	£15,500
Walls:	£19,330	£30,300	£30,000
Windows/ Doors:	£32,007	£9,000	£20,000
Mechanical:	£30,240	£21,000	£15,000
Total energy Measures:	£83,131	£68,500	£80,500
Others:	£90,141	£33,500	£59,970
Total:	**£174,991**	**£102,000**	**£140,470**

Note – The total figures shown include the cost of materials, labour and preliminaries only.

Figure 27 : Cost breakdown comparison table of three pre-1919 soild brick, UK Passivhaus retrofit projects

This analysis demonstrates the importance of the EnerPHit standard. In recognition of the difficulty in meeting new build Passivhaus performance requirements for existing buildings where building elements are fixed, i.e. window size and orientation. The design targets of EnerPHit require a lower heating demand of less than 25kWh/m2.yr and an air-tightness rate of no more than 1.0 air changes per hour @ 50 Pa, compared to the full Passivhaus standard. Additionally, EnerPHit can also provide more economic and cost stability for retrofit projects, due to the less rigorous performance targets.

Figure 28 and 29 respectively : Steel beam detail for Princedale Road & roof build up for Lena Gardens

The Design and Construction Team - Collaborative Nature of Work:
One of the key reasons for the successful nature of the retrofit at 100 Princedale Road was the knowledge and skill-set of the appointed contractor, Princedale Homes Ltd, and its wider construction team (see fig. 31).
A report by the National House Building Council (NHBC) Foundation entitled 'Lessons from Germany's Passivhaus experience' stated that 'builders have sometimes found it initially hard to achieve the very stringent air-tightness and thermal bridging targets of Passivhaus' (Cutland, 2012, p22). The knowledge and the team of people appointed by the contractor were all important in terms of how successful the technical work undertaken at Princedale Road was. One of the most interesting points picked up from the discussion with the contractor, was how and where the specialist Passivhaus materials and specifications were sourced for the project. Interestingly, he noted how the majority of local based suppliers and trades-people "were very rough and ready, and not into passive houses at all. I wanted someone that had knowledge about it" (Proffit, 2013 [Interview]).

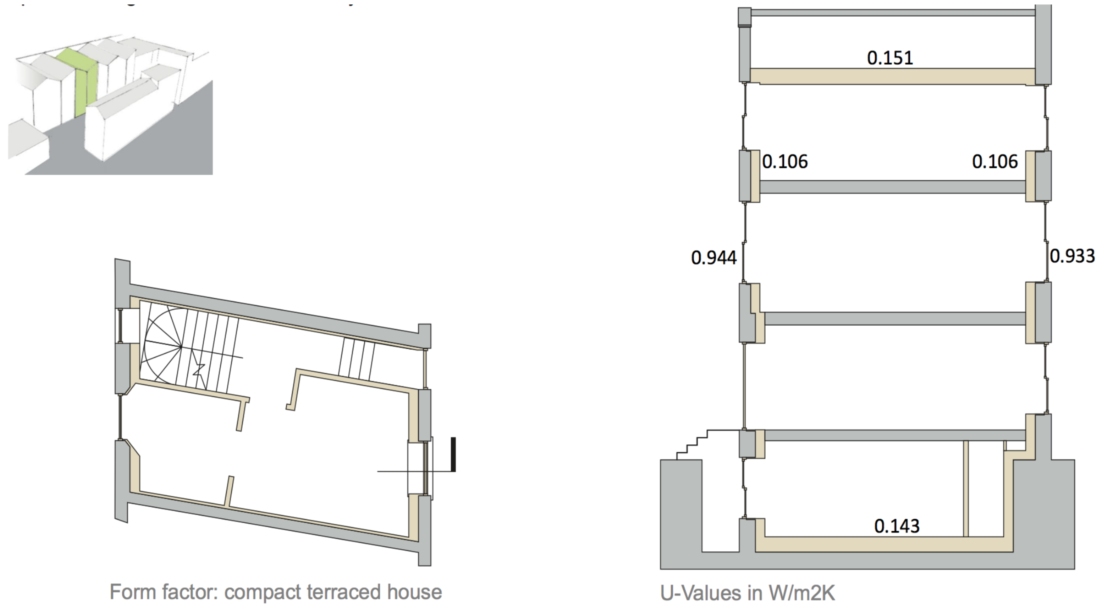


Figure 30 : Successful nature of the Passivhaus retrofit - as shown through the performance and airtighness figures

Figure 31 : The team responsible for the design and expert technical input for the retrofit at Princedale Road

Figure 31 : Working construction photograph displaying the new steel beam and timber joists

The contractor also went on to explain how he also helped train up his team, being workers on-site and colleagues from Green Tomato Energy who assisted with the drawing and administrative work. Therefore the collaboration that existed on this retrofit between the design and construction team, was not only during pre-build and on-site, but also involved close working relationships with suppliers and experts locally and abroad. The contractor explained, “I got these contacts through the ‘passive house platform’ that was set up to get Passivhaus’ moving [and set up] in Belgium” (Proffit, 2013. [Interview]). Therefore one could argue that one the key challenges in progressing the uptake of Passivhaus, particularly Passivhaus retrofits in the UK is a stable supply chain, and getting the right professionals on board who have experience with Passivhaus or are willing to adapt and learn to the demanding building standard.

The architect also revealed some insights into how the entire design team worked together, explaining how they “we were very close together before the project went on site, we had many meetings” (Baeli, 2013. [Interview]). To have numerous meetings involving the entire design team during design development right up towards construction shows how important communication and a collaborative approach are in achieving success in Passivhaus retrofits. The architect also commented on how through the collaboration with the contractor and technical consultants there were various design and construction methods that were done differently to a normal retrofit. For example with the case of 102 Princedale Road which was retrofitted to a Decent Homes Plus standard, the design of the joists was an issue when speaking with the architect for 100 Princedale Road. As also revealed through the interview process, the contractor, Princedale Homes, and Green Tomato Energy were also responsible for the design and construction of Lena Gardens in Hammersmith, London. The collaboration and teamwork involved with the contractor and the design consultant is quite remarkable, considering two challenging Passivhaus retrofits were built at the same time, and very successfully.

Post Occupancy Evaluation

100 Princedale Road was part of a three-way cross-examination involving two other properties on the same street, both of which were also owned by the client, Octavia Housing. Naturally, the performance of 100 Princedale Road was conducted as a standalone Passivhaus retrofit. But to allow for a more intriguing analysis, number 89 was a typical scheme, i.e. left as existing and 102 Princedale Road was recently retrofitted to Decent Homes Plus standard (see fig. 34). First of all, the results for the primary and final energy demands for each property displayed some interesting findings. For instance, considering 100 Princedale Road was a retrofit of a pre-1919 Victorian mid terrace house, the performance data is surprisingly successful as it performs just as well as a newly built purpose made Passivhaus. As shown in fig. 36, the final energy demand was reduced by 83% from the data of the typical house at number 89 and the Passivhaus retrofit at number 100 was only 19kWh/m2 short of the full Passivhaus standard (Baeli, 2013. [Online]). The architect clarified the terms of both primary and final energy. Baeli clarified that “final energy demand means what is metered, and primary means it takes account the energy lost in the grid from the power station to the entrance door” (2013. [Interview]). 100 Princedale Road was also on average 35% more efficient in terms of both primary and final energy demands compared to the Decent Homes Plus house at number 102.

Figure 33 : The first tenants at the completed Princedale Road retrofit in March 2011

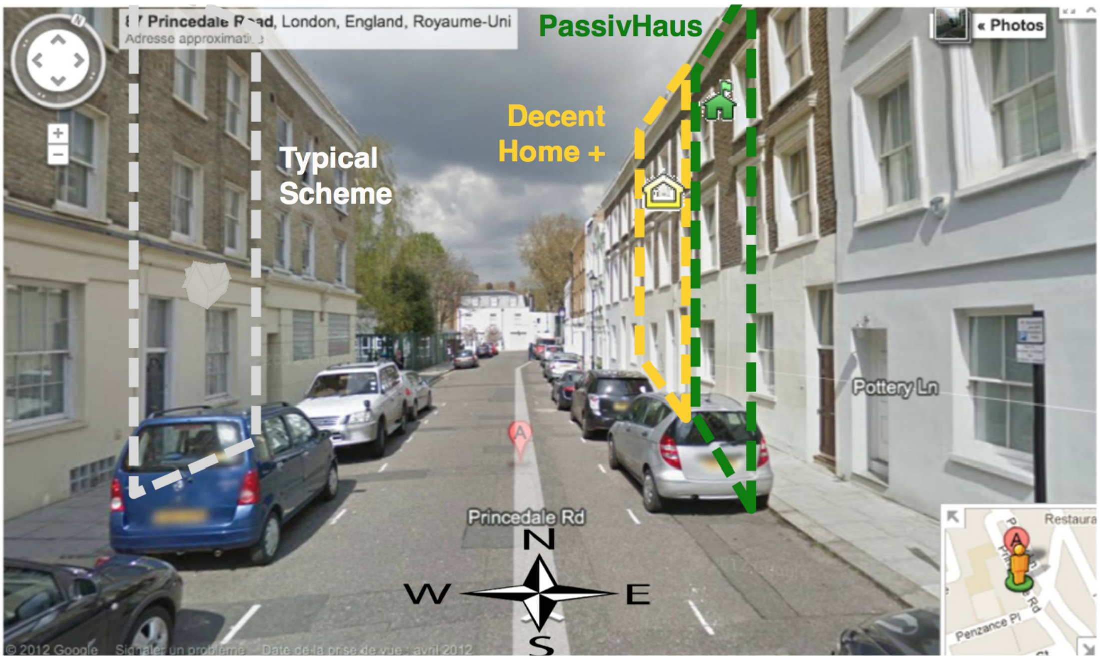
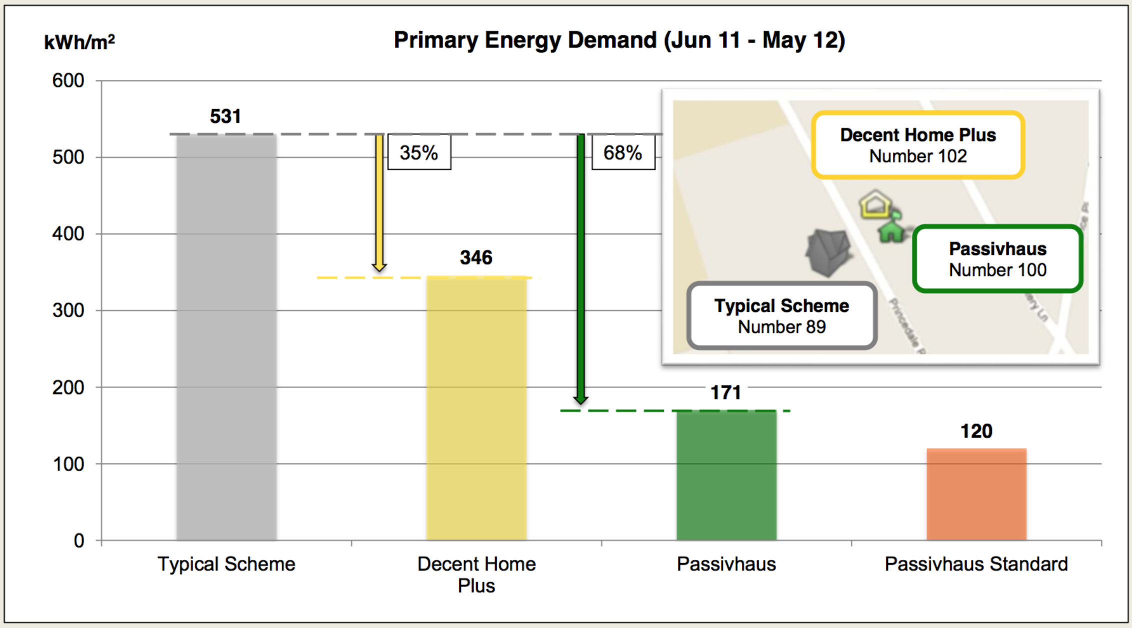


Figure 34 : A Google Streetview showing the three properties under a cross-post occupancy evaluation

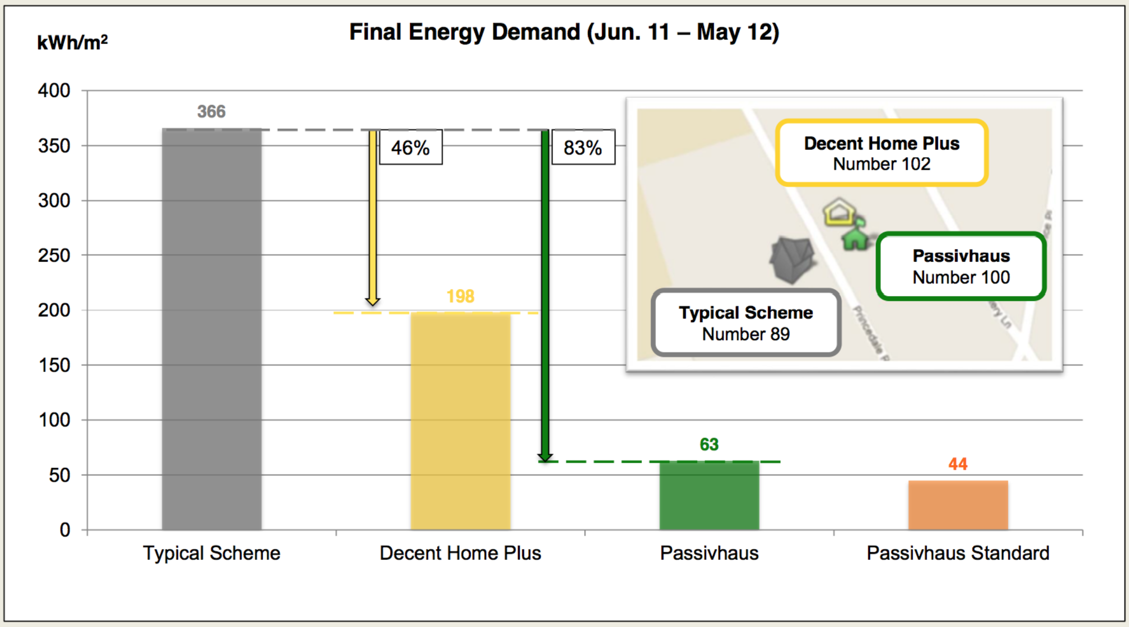
Primary Energy Demand
was reduced by 68% in the PassivHaus and 35% in the Decent Home Plus



Source: Eight Associates analysis based on monitoring figures

Figure 35 : Primary energy demand table of the properties, also compared to the Passivhaus standard

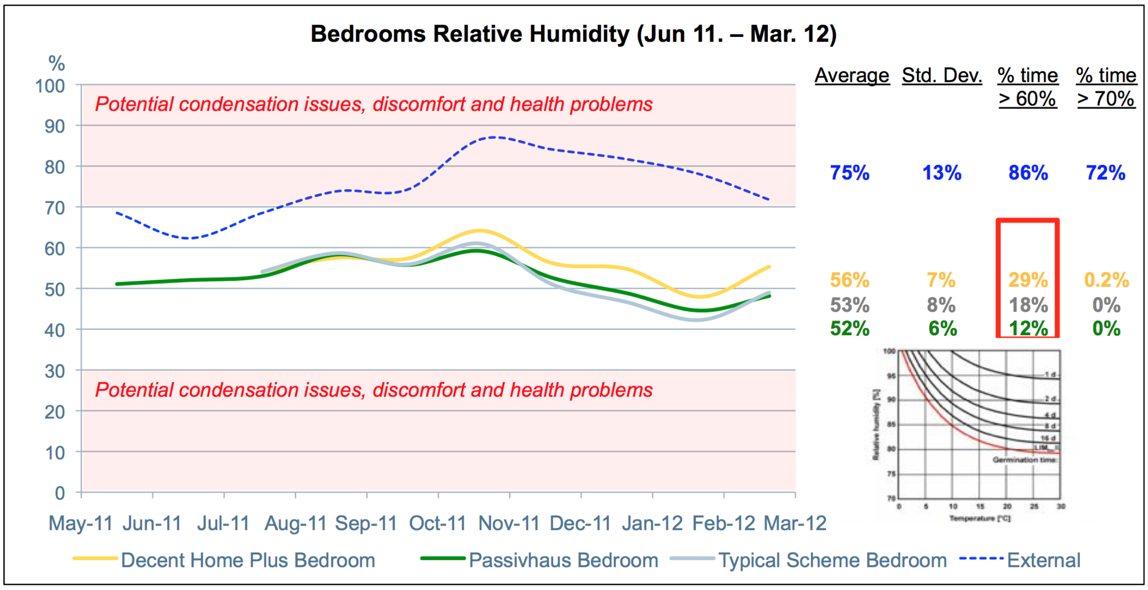
Final Energy Demand
was reduced by 83% in the PassivHaus and 46% in the Decent Home Plus



Source: Eight Associates analysis based on monitoring figures

Figure 36 : Final energy demand table of the properties, also compared to the Passivhaus standard

Although the capital costs are higher, the evidence suggests that this investment is worthwhile, as explained by both the architect and the contractor. In the case of 100 Princedale Road, with the utilisation of a combi-unit, there was no need for the use of gas at the property that not only allows for more inferior monthly bills, but also there is considerably less maintenance involved for the system. In fact, in the view of the contractor the recorded primary energy demand of 62kWh/m2/year as revealed in fig. 35, could have been much more efficient still, despite beating the original targeted value of 81kWh/m2/year (Passivhaus Trust, 2012. [Online]). He explained, "…the MVHR system and solar thermal systems are a bit cumbersome in the house and quite complicated" (Proffit, 2013. [Online]) The contractor suggested that to improve the whole house arrangement, a hot water cylinder with a heat pump should have been used to heat the cylinder and combine that with the solar thermal panels, instead of using an MVHR system that already contained a hot water cylinder already contained inside. Therefore despite the positive post-occupancy data collected, there may be certain design elements that can be improved upon for future projects of a similar nature.



Source: Eight Associates analysis based on monitoring figures

Figure 37 : Graph to show bedroom relative humidity between of three properties

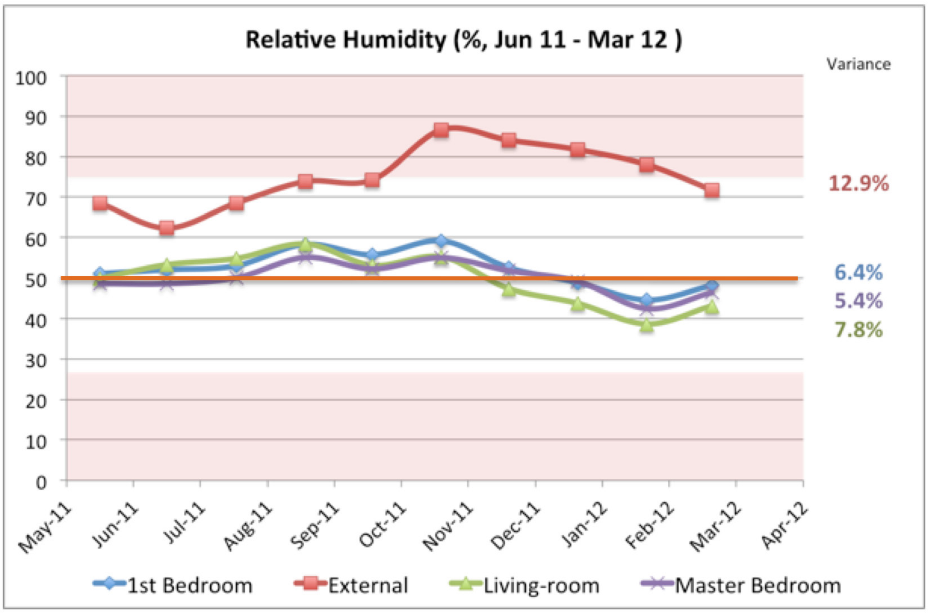


Figure 38 : Comparison of relative humidity recordings against external temperature data, of the retrofit home at Princedale Road

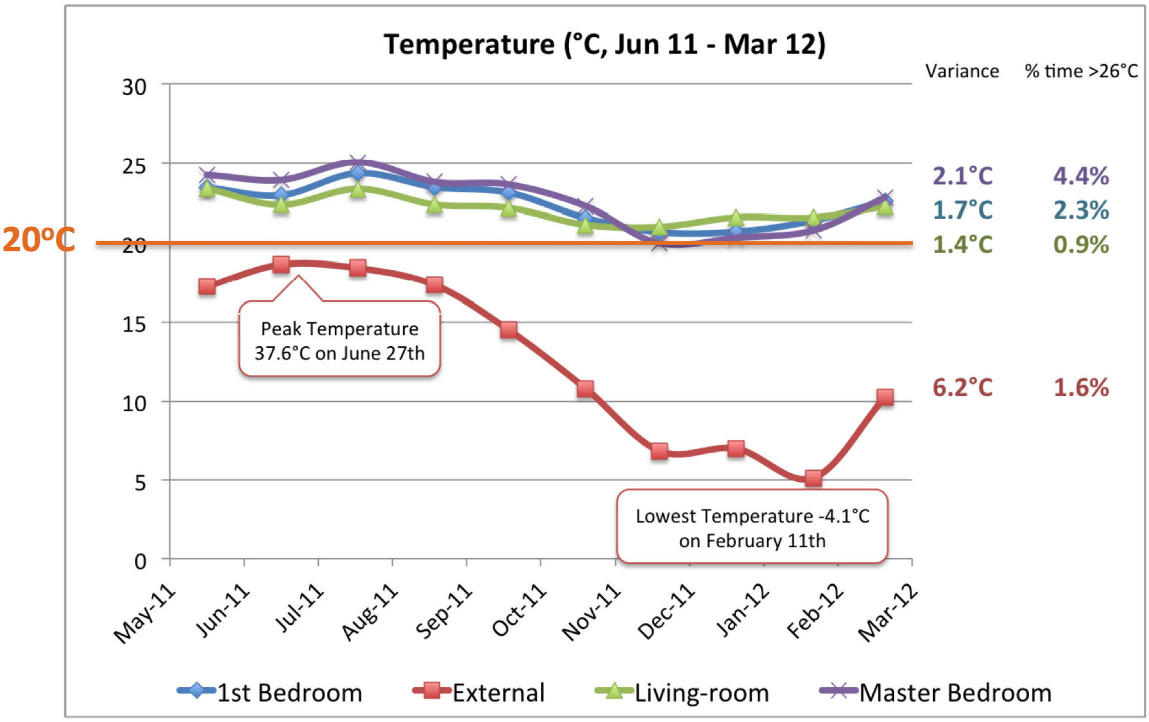


Figure 39 : Comparison of room temperature recordings against external temperature data, of the retrofit home at Princedale Road

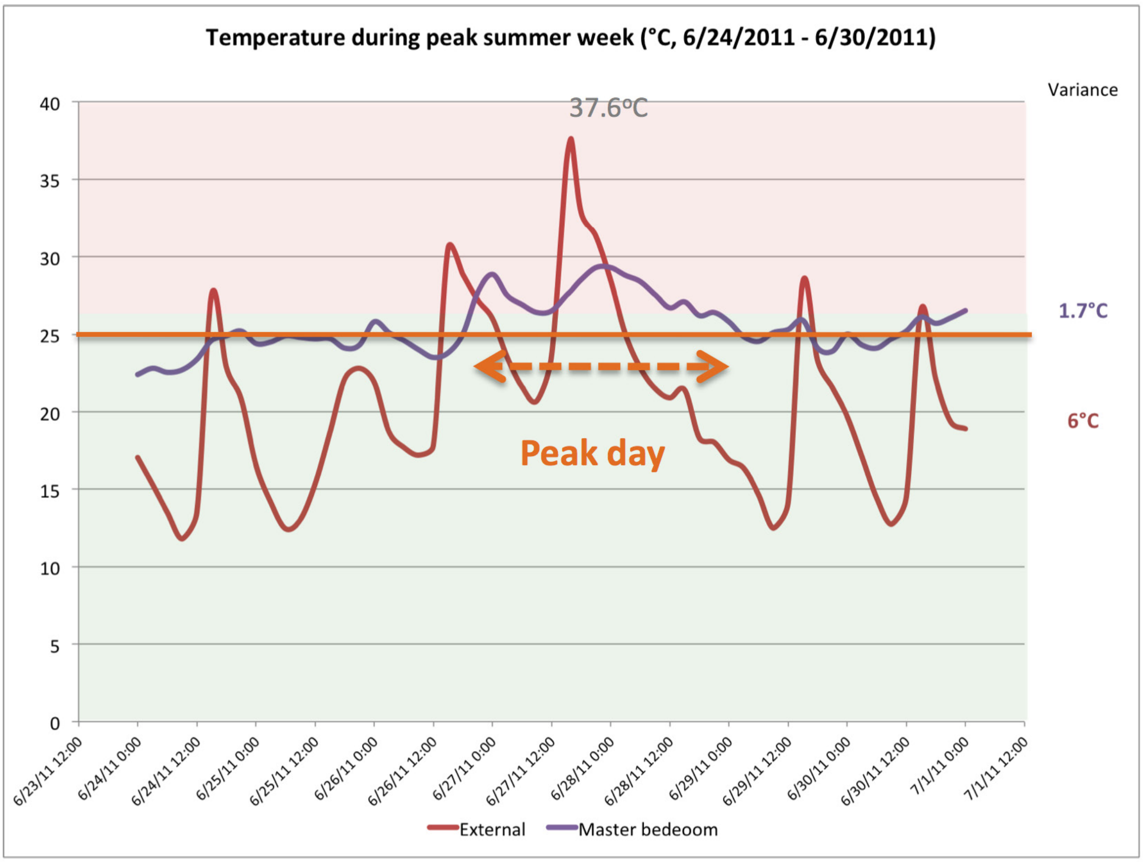


Figure 40 : Temperature recordings during peak summer week of June 2011 of 100 Princedale Road

The retrofit at 100 Princedale Road generally performed well in terms of overall internal comfort, as sourced from the monitored data, particularly being compared to the Decent Homes Plus property and the existing solid brick terrace house. In terms of relative humidity as shown in fig. 38, between June 2011 and March 2012 the houses' internal humidity was between 40% and 60%, which is well within the recommended and comfortable value. As shown in fig. 39, and as stated by the architect, 'the internal temperatures stayed relatively stable throughout the year, despite the constant fluctuation of external temperatures' (pd+p, 2012). From the tenant feedback of the family of four living at the property owned by Octavia Housing, Bouchra Bakali declared, 'I haven't had to adjust any of the settings once since we moved in' (pd+p, 2012), providing how successful the performance was. Additionally as displayed in fig. 35, the internal temperature readings during the peak day of the warmest summer week of the year in 2011, was over 25 degrees. However, the overheating values were only 4%, which is well within the levels set by the Passivhaus Institute of 10% for accepted internal comfort. Also, with the property predominantly facing a south-westerly direction, sun exposure and additional heat gain was to be expected.

There is a bit of indifference however in terms of the amount it would cost to turn an existing property into a Passivhaus. The architect stated that 'for a capital investment of £75k approx, this starts to be financially viable' (2011. [Online]). Whereas the contractor expresses his views on this saying, "it would cost around £45-50k more to make the house passive. Marion quotes that it would cost around £75k but I don't think that's true" (Proffit, 2013. [Interview]). While the retrofit costs may appear high now, particularly with conservation area projects, the evidence, as discussed previously tells us future schemes should become more affordable. Additionally, as expected, the data confirmed that that 'the costs energy efficiency measure are longer to pay back, but are expected to efficiency protect occupants from fuel poverty'. The architect went on to explain that, the Passivhaus retrofit standard in this case does reveal how this "holistic approach in building…gives confidence to people if being done properly. I cannot think of any other standard that could do that. "If you look at BREEAM for example in terms of building physics, they are completely flawed, it is not an approach for building physics, while Passivhaus is. You can guarantee the durability of the building in the long term" (Baeli, 2013. [Interview]). On the whole, with regards to the scale and context of the project at 100 Princedale Road, the scheme can be seen as a success considering the challenging nature of the site and the demands of the Passivhaus approach.

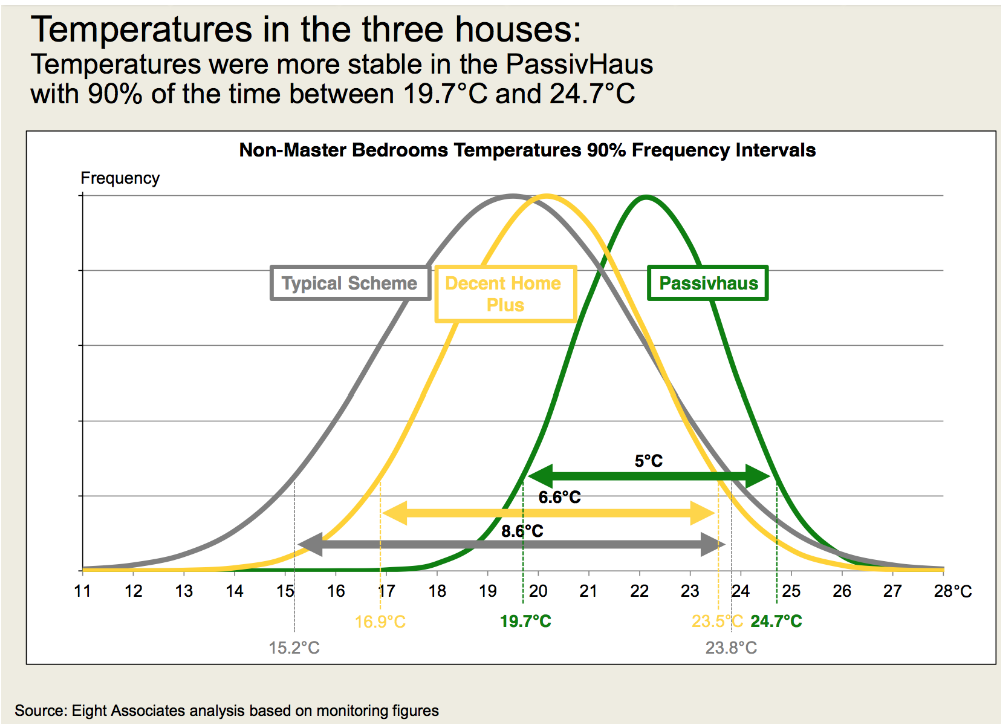
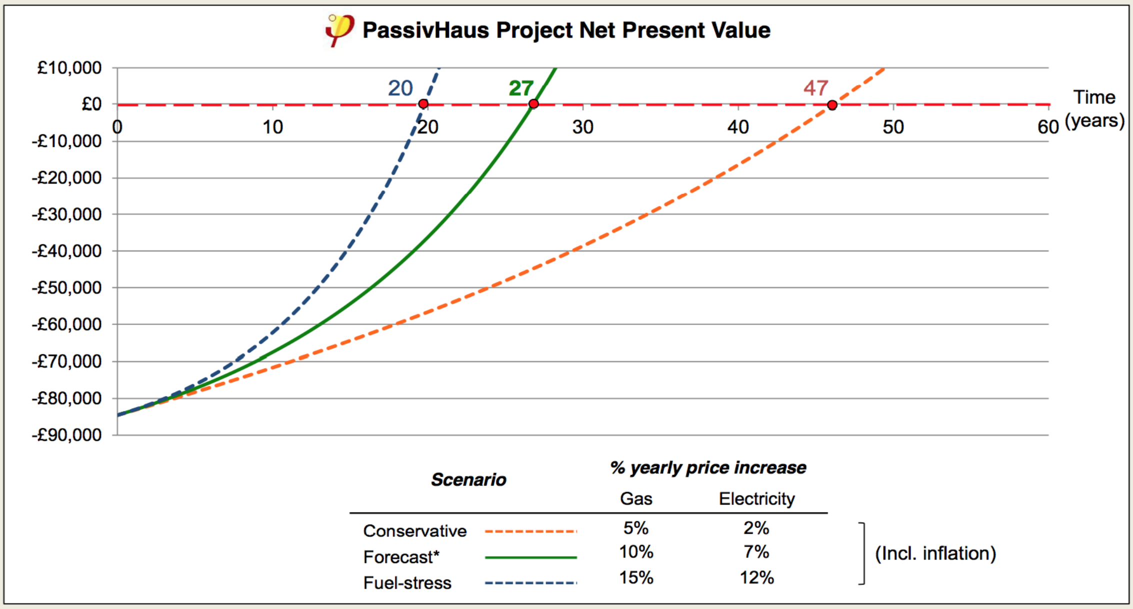


Figure 41 : Comparison of relative humidity recordings against external temperature data, of the retrofit home at Princedale Road

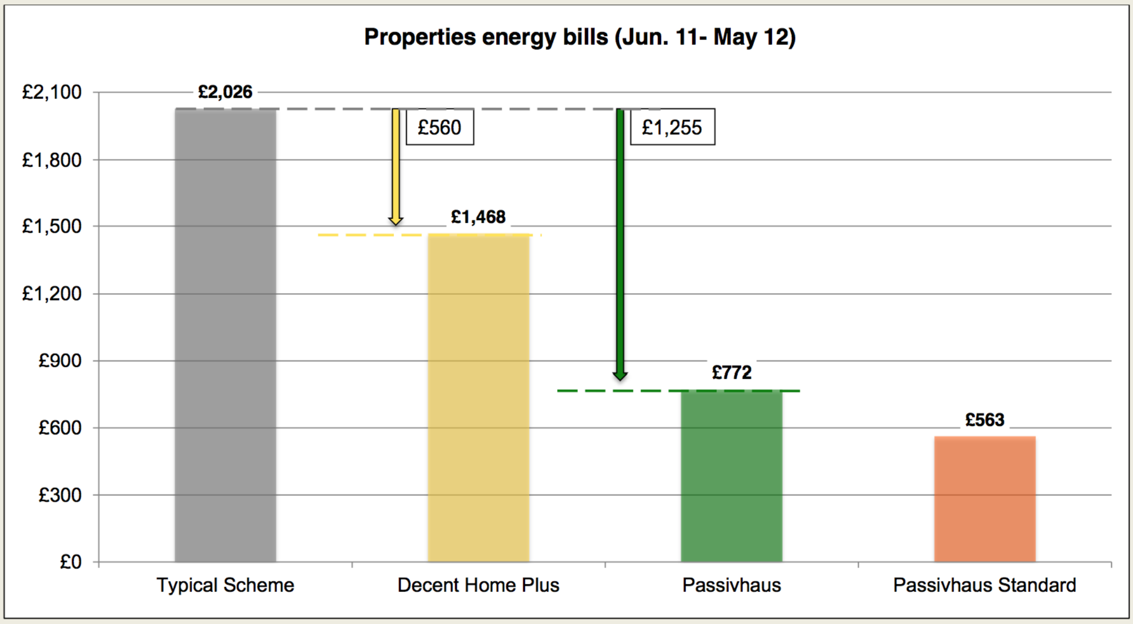
Payback time:
The PassivHaus expected to “payback” within 27 years



Source: Eight Associates analysis using the Green Book guidance for discounting.
(*) Forecast scenario corresponds to the average yearly increase (CAGR) in fuel prices from 2001 to 2011 (DECC, 2012)

Figure 42 : Comparison of room temperature recordings against external temperature data, of the retrofit home at Princedale Road

Bills:
reduced by £1,255 yearly in the Passivhaus
reduced by £560 in the Decent Home Plus



Source: Eight Associates analysis based on monitoring figures, and Southern Electric current tariffs for quarterly payments on receipt of bills

Figure 43 : Temperature recordings during peak summer week of June 2011 of 100 Princedale Road

Conclusion

100 Princedale Road overcame considerable design and performance challenges to become the first UK retrofit to be completed to Passivhaus standards in 2011. As acknowledged, the costs and economics surrounding the case study do provide cause for concern. However as mentioned, the scheme should be envisaged more as a feasibility and research project, showcasing the possibilities that it is technically possible to apply the demanding Passivhaus methodology to an existing solid-brick building type, particularly to one located in a conservation area. As shown in this case study, the deep retrofit building approach of Passivhaus, as opposed to more shallow retrofits such as Decent Homes Plus or BREEAM, demonstrate the practicality of improving the whole-house performance and thermal comfort of existing housing through its high standards and benchmarks. The post occupancy results of 100 Princedale Road also reveal this argument and it also starts to address wider issues such as, fuel poverty, fuel security, and the reduction in carbon emissions. In some cases, conservation 'issues can limit the opportunity for retrofit' (Moorhouse & Littlewood, 2013), where in this case, the planning requirements very much dictated the choice and flexibility of the proposed retrofit solutions to the Victorian building, particularly regarding its external appearance. But despite this obstacle and other difficult circumstances presented to the project right from the outset, it has been demonstrated that with the right combination of informed technical input, simple yet effective teamwork and clear communication and training throughout the construction team, the Passivhaus method is very achievable in such a difficult environment.

Cost was a major issue for the retrofit at Princedale Road, which became more apparent due to the conservation area conditions as previously noted. For instance, the new sash windows had to be custom-made to suit both the airtightness requirements of the Passivhaus standard, and the strict aesthetic planning conditions set by the RBKC, in replacing the existing sliding sash windows. With the project being the first of its kind in the UK at the time, the TSB and the client Octavia Housing envisaged this project as being an 'eco-experiment' in terms of the ambitions into ultra low-carbon retrofitting for existing social housing. Therefore the project is a showcase for the technical possibilities in transforming poor thermally retentive building fabrics such as Victorian solid brick, into super-efficient, comfortable, sustainable homes. Of course, while considering future projects of a similar nature to Princedale Road, the economics of such a Passivhaus retrofit should be more considered, in order to further promote the short and long terms benefits of this building standard in the UK. Fortunately for Princedale Road, the design and construction team were fully informed of what the Passivhaus method demands from the outset. From pre-construction planning, through to appropriate on-site building techniques; the team were fully aware of how advanced and technically challenging Passivhaus retrofits are compared to conventional refurbishment methods. It is important that the UK establishes specially trained teams of tradesmen to ensure that retrofits are completed correctly, reducing risk and jeopardising the airtightness layer or thermal bridging issues.

But, there were some difficulties at times during the process, predominantly because of the new windows. The contractor even admitted the team were "quite lucky" in terms of finding the right people, company contacts and materials to get the prototype mock sash windows designed and manufactured correctly (Proffit, 2013 [Interview]). As discovered, one of the key stumbling blocks for implementing the Passivhaus in the UK, is the current supply chain for materials and Passivhaus rated products, especially in this case of the triple-glazed mock sash windows and ventilation system. The contractor highlighted that at the time "in the UK there probably isn't that much competition for it (Passivhaus) so it's going to be quite expensive" (Proffit, 2013 [Interview]). But with the other 85 'Retrofit for the Future' projects, this should help to invigorate the supply chain needed to accommodate Passivhaus products and expertise in the UK. Overall, what this case study has demonstrated is that despite the apparent difficulties involved with a Passivhaus retrofit, particularly for a solid-brick pre-1919 Victorian terraced house, of which located in a conservation area, the Passivhaus standard is still very achievable within the UK despite these evident challenges. The Passivhaus standard is essentially the most suitable retrofit method for existing, single residential properties. The recommendation from this author is to utilise the successful Passivhaus retrofit at 100 Princedale Road as a precedent, in order to learn and further develop the domestic standard in the UK.

Figure 44 : Tenant at 100 Princedale Road Bouchra Bakali, adjusting the settings to the MVHR system

Figure 45 : Google Streetview image showing the completed Passivhaus retrofit at 100 Princedale Road

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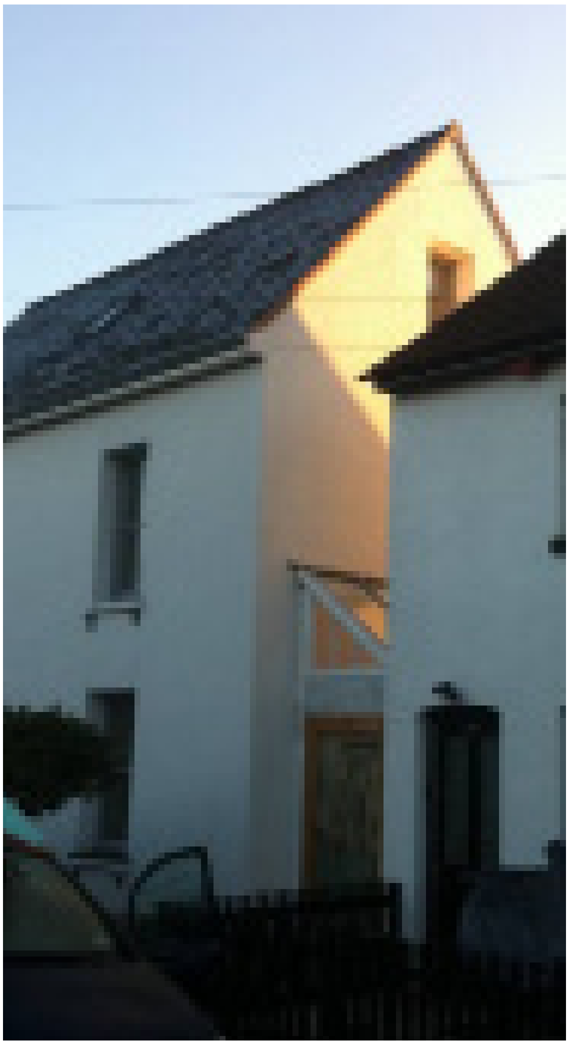
Retrofit Discussion

Rosie Seaman & Thomas Haywood

Retrofitting the existing housing stock presents a large scale and complex engineering problem; thus to reach the 2050 target, the UK cannot rely solely on the shallow retrofit modifications to existing buildings through current strategies. As shown in the three case studies a deep retrofit building approach, as opposed to shallow retrofit, demonstrates the feasibility of improving the performance and thermal comfort of existing housing through Passivhaus standards. From the research presented, all of the three case studies successfully overcame the technical and cultural challenges to achieve the Passivhaus standard within their respective, existing building fabric. Whilst Princedale Road and Totness achieved the full Passivhaus standards, Grove Cottage also aspired to achieve as close to Passivhaus standards as feasibly possible, however they fell short of the criteria, emphasizing the importance of the more achievable EnerPHit status for retrofit projects. The research uncovered various common themes that challenge the practicality and long-term viability of integrating the Passivhaus method to existing housing and the UK generally. The common themes and challenges are, planning and consultation process, cost and project funding, construction and site management, and the Passivhaus skill-set of the UK building industry.

In some cases conservation 'issues can limit the opportunity for retrofit' (Moorhouse & Littlewood, 2013). In the case of the retrofit at 100 Princedale Road; despite this obstacle and other difficult circumstances presented to the project right from the outset, it has been demonstrated that with the right combination of informed technical input, simple yet effective teamwork and clear communication and training, the Passivhaus method is very achievable in such a challenging context. Unlike Grove Cottage where the property was not subject such strict planning regulations, the conservation area requirements at Princedale Road, played a key role in the overall feasibility, design and delivery of the Passivhaus retrofit. Although fully supported by the local planning authorities, issues during the design process only arose due to concerns by neighbours and the constraints of the site, thus Passivhaus arguably presents itself as a potential option for the UK, and suggests a method that allows both architectural preference and pragmatic design. With the challenges of an existing building, the design of Grove Cottage was based around solar design dictated by the orientation and tight planning constraints, resulting in a high from factor and the need to compensate for heat losses; thus illustrating the importance of specialist software such as PHPP and THERM in order to refine the design to reduce thermal bridging and prompt suitable decisions. On the other hand, for the case of Princedale Road, the conservation area planning status very much dictated the choice and flexibility of the proposed retrofit solutions to the Victorian building fabric, particularly regarding its external appearance. Similarly to the Totness Passivhaus, although not located in a conservation

area, planners resisted modifying the original form of the building as it was not in-keeping with the architecture of the neighbouring housing, which is part of a master planned housing estate. Deep retrofit methods present many more challenges than a typical retrofit scheme compared to other refurbishment standards such as a Decent Homes Plus or Green Deal project, as the high performance standards of Passivhaus cannot be compromised, when designing within existing residential vernaculars and historic neighbourhoods.

Cost was a major issue for the retrofit at Princedale Road, which became more apparent due to the conservation area conditions as previously noted. For instance, the new, replacement sash windows had to be custom-made to suit both the airtightness requirements of the Passivhaus standard and the strict aesthetic planning conditions in replacing the existing traditional sash windows. Although the economics of the project should be noted, it is though crucial to consider the context and aspirations of the Passivhaus retrofit at Princedale Road, being a product of the innovative and experimental 'Retrofit for the Future' programme. With the project being the first of its kind in the UK at the time, the TSB and the client Octavia Housing envisaged this project as being an 'eco-experiment' in terms of the ambitions into ultra low-carbon retrofitting for existing social housing. Therefore the project should be seen more as a research project, showcasing the technical possibilities in transforming poor thermally retentive building fabrics into super efficient, comfortable and sustainable homes. Of course, while considering future projects of a similar nature and ambition to Princedale Road, the economics of a such a Passivhaus retrofit should be more considered, in order to further promote the short and long terms benefits of this building standard.

Whilst deep retrofit strategies are necessary for the private housing sector, it is possible to argue that the associated costs outweigh the aim to reduce carbon emissions, which may take Passivhaus to a point that is not affordable for the majority. To achieve the same internal temperature for Grove Cottage post-retrofit (21C) through the use of current retrofit strategies, such as Green Deal measures, much higher energy consumption and increased energy costs would incur. Without adequate research and guidance, the Green Deal provides only superficial amendments to buildings and has no specific energy target, thus a clear strategy for delivering retrofit on a larger scale in the UK is required. Approaching retrofit as a series of disconnected inadequate strategies, such as those promoted by the Green Deal, is unlikely to optimise the potential a fabric first approach and cost effectively reduce carbon emissions; thus the solution points to an integrated strategy from the beginning, even if the works themselves are staged. Designed to incorporate a phased approach in order to allow the retrofit and extension to be built in stages, Grove Cottage demonstrates how a staged approach to Passivhaus may provide an alternative to shallow retrofits and also a more suitable method of refurbishing the private housing stock to a higher standard without the need for high expenditure.

The requirement of a high skill level in the building industry that does not exist the same way in the UK as it does it Germany, ulitmately becomes the biggest challenge in promoting Passivhaus as a suitable solution. In order to apply an untrained builder to a retrofit project, as vast amount of descision making and input is required from the architect, which overall is not feasibly cost efficient for the client. As demonstrated by the project team for Grove Cottage it was possible to solve technical issues regarding thermal bridging and airtightness on site thorugh the collaboration of the architect and contractor, however this may not be possible for most situations. Problems with the construction team arose through miscommunication and a lack of specialist skills, such as during the application of the external insulation, which added to the difficulty of the project overall. Fortunately for Princedale Road, the design and construction were fully informed of what the Passivhaus method demands from the outset, in terms of pre-construction planning through to appropriate on-site building techniques, particularly for a retrofit which is more technically challenging to achieve the necessary performance standards. It is important that the UK establishes specially trained teams of tradesmen to ensure that retrofits are completed correctly, reducing the risk of jeopardising the airtightness layer or thermal briging.

In terms of performance, the three case studies have demonstrated an overall improvement of thermal comfort, through upgrading the thermal condition of the entire building fabric. For instance the post occupancy evaluation data collated for Princedale Road displayed the significant thermal performance data of the Passivhaus retrofit compared to an existing property (89 Princedale Road) and a shallow retrofit completed to Decent Homes Plus standards (102 Princedale Road). Despite the technical difficulties of upgrading a pre-1919 solid brick terraced property, particularly one located within a conservation area where the external appearance could not be altered, a Passivhaus retrofit was still possible producing similar performance data of a new-build Passivhaus.

Section 03

An investigation into the use of Passivhaus in domestic housing

Housing Introduction

Current Government estimates indicate that there are almost 28 million dwellings across the United Kingdom, with over half of these built before 1965. As well as sticking closely to a familiar set of dwelling typologies - primarily consisting of detached, semi-detached and terraced family houses – the UK house-building industry has maintained a strong tradition of masonry cavity-wall construction throughout recent centuries. Even though thermally inefficient double-thickness solid brick walls had given way to double-leaf brick-and-block cavity construction by the early 20th century, actively insulating external walls still did not become common practice in the UK until the 1980s.

Though the UK house-building industry has experienced an overall downward trend since the 1970s, we have built an average of 140,000 dwellings per year over the last ten years, even taking into account the Great Recession. Accordingly, in 2006, the UK Government announced its commitment to all zero-carbon dwellings from 2016. Since 2007, the Code for Sustainable Homes has existed as an additional standard alongside Part L to promote sustainable house-building ahead of the 2016 zero-carbon target. Though only intended as a step-change, the Code has performed admirably in forcing the country's volume house-builders to confront the realities of sustainable construction. Despite its noble intentions, the Code is now being officially phased out, and its more successful elements incorporated directly into incoming Building Regulations. Consequently, there is an increasing emphasis on energy consumption targets and building service performance, albeit with more freedom in how these targets are achieved. The result of this is that by 2050, the country will have an anticipated 32 million dwellings, of which 28 million have already been built, including almost 13 million built before the first Building Regulations were introduced in 1965.

Adopting the German Passivhaus standard is one of the several options available to the UK in its quest to reduce household carbon emissions from new homes. The reason targeting the new housing market in the UK is crucial because of the predicted rate of growth. This implies that improving the sustainability and reducing the carbon footprint of new dwellings will have a dramatic impact on lowering the UK's emissions by 2050.
In order to establish whether Passivhaus could be the standard by which Britain builds new housing, part three will explore several case studies of Passivhaus built in the UK, of the 250 completed and certified in 2013. Each case study highlights different aspects of implementing Passivhaus. Adapting the Passivhaus Standard poses a number of challenges, ranging from the use of PHPP Software during the design stage to the high level of quality control required during construction; 7 detailed case studies were conducted to investigate these in detail. Grey

Lyn investigates the qualities necessary adapted, with the Passivhaus methodology as key, to achieve a holistic approach to sustainability in a contemporary family home, including the integration of modern renewable technologies. The Camden Passivhaus case study will investigate the iterative use of PHPP in the design process will be the early focus of the study, leading to a discussion on the understanding of Passivhaus in the UK construction industry and the impact of contractor skill levels throughout the project. Denby Dale's design team structure has become a specific area of investigation, which includes the team organisation, roles of responsibility and the procurement route. The nature of the construction industry will also be considered in terms of how the notoriously slow acceptance of change can be overcome. The importance of education for all team members of the design principles of Passivhaus and how its practical application can be accomplished is also investigate. Underhill focuses primarily on the difficult planning situations encountered in rural Britain and how Passivhaus can work within those constraints. The Wimbish scheme will look into designing multiple, affordable Passivhaus units in the UK. The effects of user behaviour will be explored given the scale of the scheme to understand the relationship between how Passivhaus is designed and used. How Howe Park Passivhaus used form factor calculations within the PHPP to stimulate the architectura; design objectives resulting in an optimum design for thermal comfort and air quality. Finally, Crossway, a bespoke 3 bedroom house in Kent, questions the potential adaptations required to achieve Passivhaus certification throughout the design and construction stages of the scheme.

Grey Lyn

Miguel Angel Peluffo Navarro

Location Faversham, Kent
Building Type Single family house
Construction Type Timber frame
Floor area 229m^2
Completed August 2013
Year Certified not certified

Client Justin Ford and Trudy Tarrant
Architects Conker Conservation
Main contractors Ecolibrium
Council Swale Borough Council
Consultants and Collaborators Invicta Clean Energy (renewable energy consultant)

Introduction

The case study at hand covers the contemporary family house built in a heritage protected area in Faversham known as St Ann's Orchard. Starting in 2008, the main project objective was to achieve Passivhaus standard using sustainable principles and construction methods, characteristic of Conker Conservation's practice and approach to design. As the clients run Invicta Clean Energy, a company providing consultation and installation of renewable energy technologies, they strived to lace their new home with clean-energy generating apparatus. Originally, in the planning application, the clients included that the house would qualify as a minimum Level 5 in CSH, but they dropped that objective fairly early in the planning phase because of the cost implication of pursuing that route, when the primary objective was achieving Passivhaus standard. At the time, it was cheaper to go through Passivhaus certification than doing the full CSH assessment as the latter required a lot more paperwork with no extra justification on the final outcome compared to Passivhaus certification (Mallion, 2014). The project was completed in August of 2013 but it is yet to be certified. However, the challenges that arose throughout the project's development bring light to the factors on delivering and, more importantly, adapting the standard to the context of the UK. With Grey Lyn, Conker Conservation have demonstrated a capacity to use Passivhaus principles as an integrated approach to design development, enabling the design to address sustainable as well as contextual values.

Design Anatomy

The overall design of Grey Lyn is a carefully balanced scheme between its response to the sensitivity of the surrounding environment and Passivhaus principles. Matters of privacy, respecting neighbouring amenities and achieving the desired home for the clients, have all been integrated with the Passivhaus methodology that Conkers Conservation employ in their projects (Ford, 2009). The building was built on a site of a former bungalow because of the width at that point in the site, allowing for more solar gain on the south side, and to reduce the visual impact from neighbouring properties. With this in mind, it became an objective to try and stay within the physical parameters provided by the previous bungalow. The footprint only increased by 19m2 and a flat roof allowed for a one-storey tall building with an increase of only 0.18m above the previously existing ridge of the bungalow. A recession of the first floor, as shown in Figure 2, tries to hide the building behind the barn on the east to minimise its presence on the street of Nightingale Road (Ford, 2009). The plan of the house is oriented around a double height space created by two load-bearing internal walls made of rammed chalk. The open kitchen and sunspace area allow for light to filter deep into the house, which is further amplified by the skylight over the double height space. On the first floor the bedrooms are likewise oriented towards the double height space, giving the house a very communal and centrally unified character.

The north façade is subject to two curved walls which were adapted for two reasons. The first one, on grounds of aesthetics, by implementing a curve it helps alleviate the visual impact of the double height frontage and gives the barn more visual presence when approaching the narrow drive through to the house. Secondly, on a technical bases, the curves help keep the north elevation as efficient as possible by reducing thermal bridging. By having a curve instead of a corner, it effectively avoids the problem of detailing a corner of a timber frame that could potentially cause unwanted heat loss (Mallion, 2014).

Placement of windows required vital consideration from both a Passivhaus standpoint and responding to the sensitivity of the area by restricting views that overlooked adjacent properties. Glazing on the north elevation had to be primarily restricted to minimise heat loss and keep efficiency, as well as limiting the views into the opposing property. The front face only has one long horizontal window on the first floor (refer to Figure 3) placed at head level to avoid direct views to the neighbours and, similarly, the recession of the timber cladded face prevents the same from occurring. On the western side, specifically the first floor, no windows could be placed because it directly overlooks the neighbour's garden on the west. Windows on the eastern elevation face the neighbouring

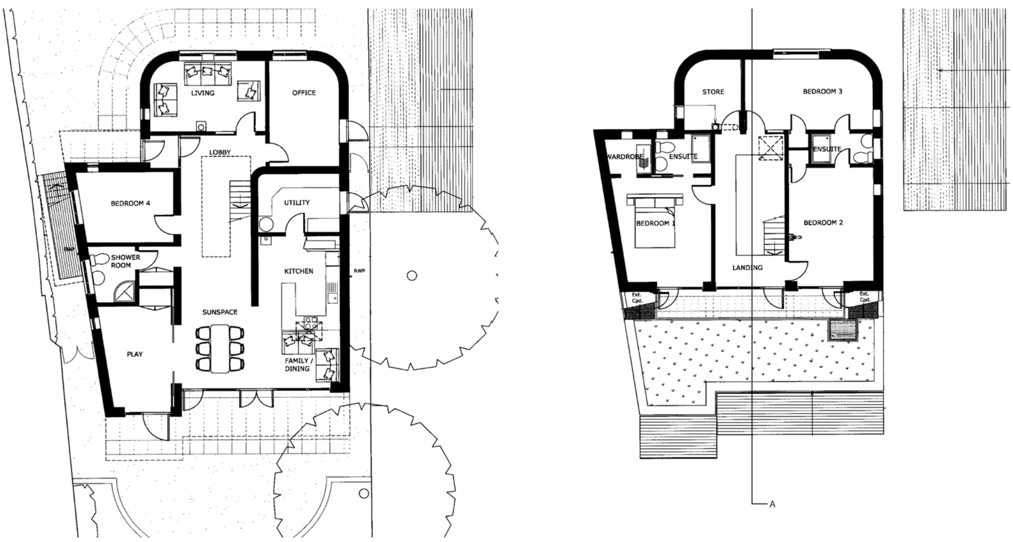


Figure 1: Ground Floor (left). First Floor (Right)

barn with the sole purpose of bringing daylight into the bedrooms and bathroom. In contrast, the south aspect of the house, where the communal spaces of the house are oriented, capitalize on glazing, thus providing views of the long garden and maximizing solar gains (Ford, 2009).

The construction of the house is a timber frame, made up of timber I-joists by Steico, which sits on a brick cavity plinth with two internal load-bearing rammed chalk walls. The timber I-joists are essential to reducing thermal bridging in the structure making them very suitable for Passivhaus construction. Three types of insulation were used, the primary one being Steico flex, a natural wood fibre composition that was applied to the walls and roofs to fill up the void between the I-joists; the second, Celotex PIR (polyurethane), used for the ground floor and to infill the cavity plinth; and third, foam glass, a structurally compressive material, mainly used to eliminate thermal bridging in the block work detailing. All these construction materials were chosen on the bases of having an A or A+ rating from the BRE Green Guide and their opportunity to be locally sourced. The greatest opportunity arising from the bed of chalk that lay below the topsoil of the site. With the excavation done for the basement, it was possible to obtain sufficient chalk to create the two central walls that sandwich the double height space (Ford, 2009). The chalk provides the lightweight structure with thermal mass and through its hygroscopic properties, helps improve the indoor air quality by restricting fluctuations in humidity.

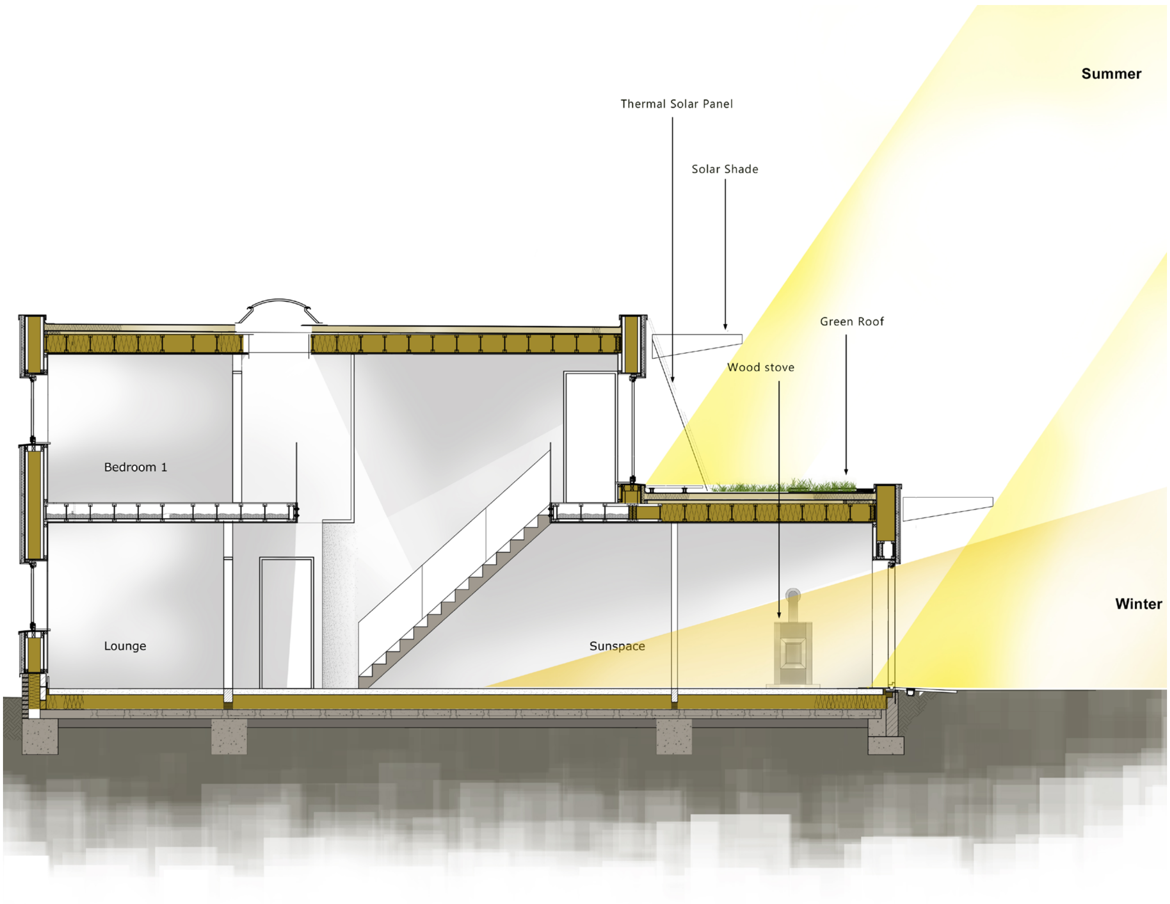


Figure 2: Section AA.

Design Development

Conker Conservation, led by Paul Mallion, was chosen on the basis of their locality and more importantly their ability to deliver the Passivhaus standard (Ford & Tarrant, 2013). Mallion's company is officially registered as a chartered building surveyor and has been designing ecologically since 1999, essentially taking on the role of the architect for countless projects. Characteristic of their designs is the combination of modern and traditional construction in conjunction with ecological alternatives and, since 2005, the Passivhaus standard. In many respects their background as building surveyors has allowed them to intrinsically adapt the Passivhaus methodology in their design approach because of their technical background (Mallion, 2014).

The site at Grey Lyn was perfectly orientated to maximise passive gains and the south views of the garden on a north-south axis, but the slimness placed restrictions on the form the design could adapt. Mallion graphically demonstrates the implications of the parameter of the site in his early sketches. They explain the ideal form, shown on the left, where the majority of the house is receiving solar gains and daylight, while maintaining a compact form; the sketch in the middle, Mallion shows that because of the slim nature of the site it becomes more restrictive for the north part to benefit from the sun. The sketch on the right explores some early conceptions of

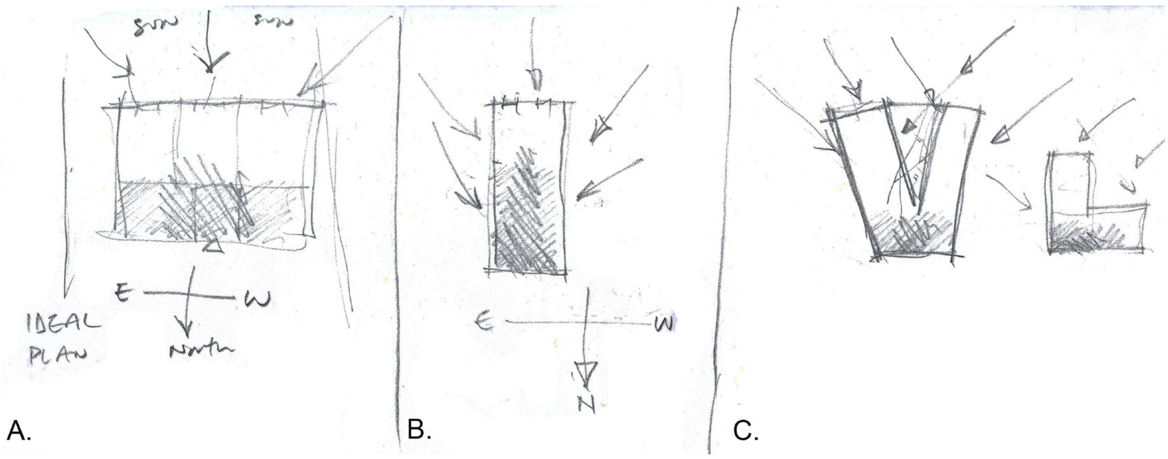


Figure 3: Initial sketches by Paul Mallion to Justin and Trudy Ford explaining the implication of the site on the plan of their house.

possible solutions to the problem (Mallion, 2014). Parallel to the Passivhaus implication of the site, the initial idea of the clients for their home was a very traditional one that was very representative of a typical terraced house, including a traditional pitched roof and a barn structure. However, the site constraints did not allow such flexibility in the design and, in addition, the Swale Borough council discouraged the traditional approach and pushed for modernising the design (Ford & Tarrant, 2013). Nevertheless, one of the traditional features that did carry through to the developmental stages was the categorical division of spaces in the plan with the idea of a central corridor on the north-south axis to try and filter daylight into the deeper ends of the building.

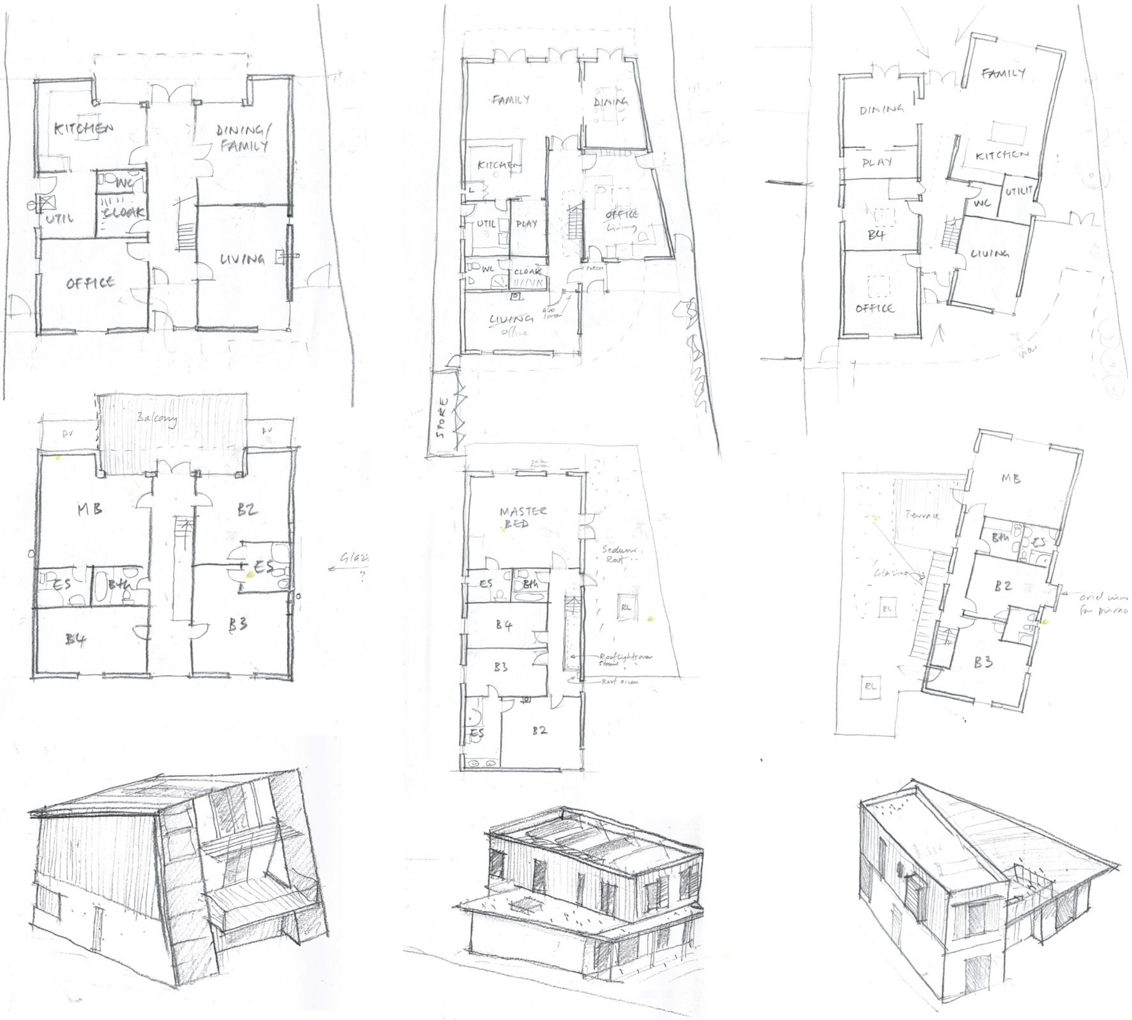


Figure 3: Developmental sketches by Paul Mallion, progression from left to right.

Figure 5 illustrates several of the architect's drawings through the design stage and how the design evolved taking into account the project objectives, parameters of the site and a functional plan to the client's satisfaction. The first drawing on the left shows what the clients had discussed with Paul Mallion of what their ideas were for their home in combination with a very simple compact plan with a corridor binding the space on a north-south axis. From there, Mallion started developing the plan by dividing the building into two parts to allow for more sunlight to enter the building, while maintaining a reasonable form factor. The drawing on the right explores the idea that Mallion had illustrated in his initial sketches with the clients (Figure 4), of opening up the south elevation to create a 'v-shaped' layout, while maintaining the subdivision of spaces. This development started to become too complicated, with too many junctions being created requiring a lot of detailing, and also drifted away from the compact shape that he initially intended to have. It was at this point that the idea of the central atrium emerged, enabling the design to maximise from solar gains and daylight while retaining an efficient enough form factor (Mallion, 2014).

This idea resulted into a simple floor plan that Mallion was satisfied with and started using the PHPP to start fine tuning the design. Figure 6 illustrates the earlier sketches that resemble the final plan and aesthetics, where Mallion had identified some implications of the geometry and addressed them through small interventions. As most of the building is east and west elevations, the south side being the smallest, Mallion used the curves on the north elevation to retain efficiency. Throughout the previous developments, Mallion did not work with PHPP because he was conscious of the basic parameters and principles of Passivhaus and confident enough not to seek reassurance from the program. His basic approach to designing is to concentrate firstly on a functional plan that takes into account form factor and orientation and then to start bringing in his background ideas of what the design might look like on the basis of his plan. This method of thinking allows him to use PHPP much later in the process as a tool to fine tune his design on a more technical level, rather than using the program as a guiding tool throughout the whole design stage, since he is already fully aware of the fundamentals behind Passivhaus (Mallion, 2014).

Together with Justin Ford, Mallion started doing the PHPP calculation using the design, shown in Figure 6, which showed them that their form factor required u-values for the wall, roof and ground floor to be around 0.1 to 0.11W/m2K, which goes beyond the minimum 0.15W/m2K and meant that the thickness of the walls had be increased. According to Paul Mallion, it becomes a balancing act to try and find the ideal point where the U-values, treatable floor area and wall thickness are all uncompromising in a way, as thicker walls meant a loss in space in a spatially limited area (Mallion, 2014). They managed to find a balance by stretching the ground floor plan to compensate for the loss of space caused by the thicker walls with the U-values for the wall at 0.108W/m2K with a thickness of 0.414m; for the roof, 0.104W/m2K at 0.447m and the concrete beam and block floor, 0.087W/m2K at 0.55m (Ford & Mallion, 2009).

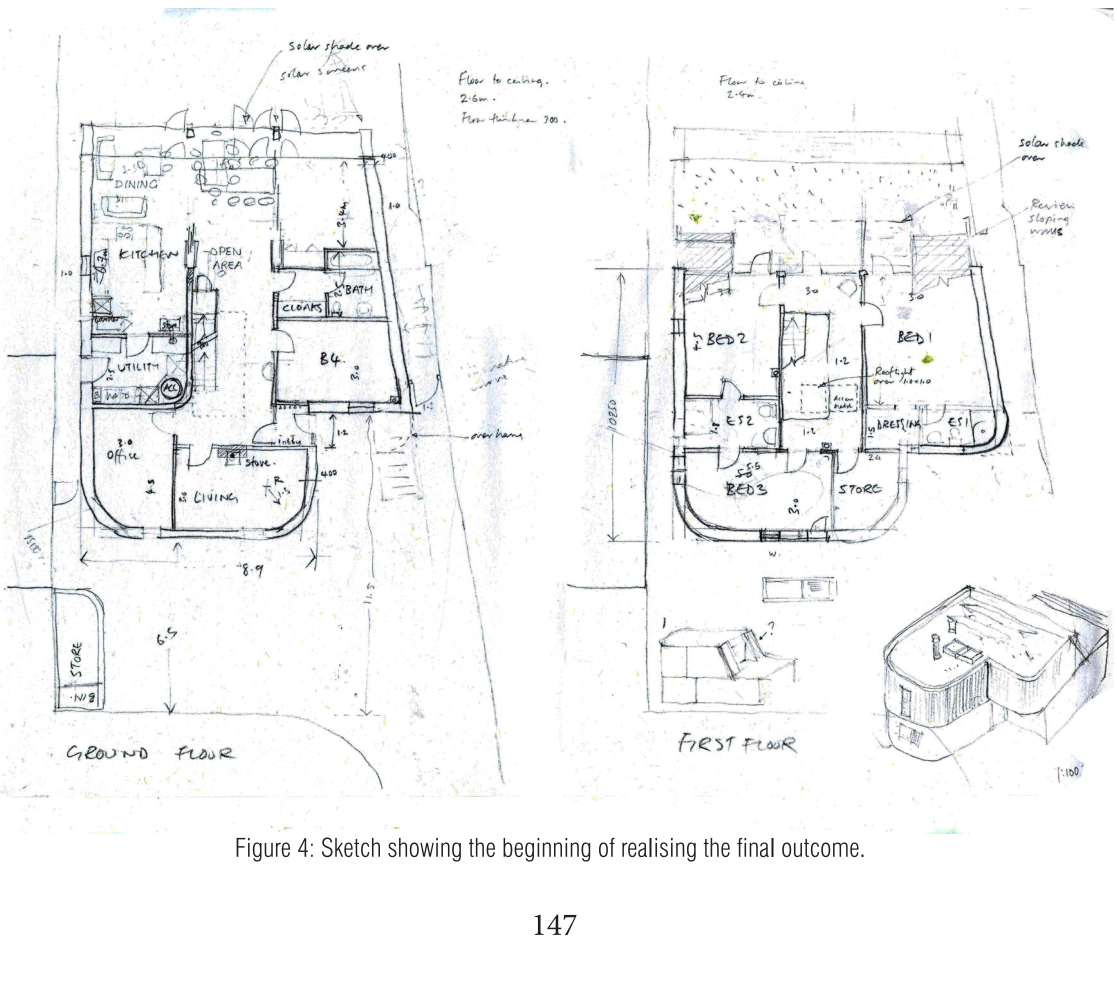


Figure 4: Sketch showing the beginning of realising the final outcome.

As the UK finds itself with a lack of experience among building companies to construct to Passivhaus standard, it becomes ever more vital for the architect to detail the junctions accordingly to eliminate the potential of thermal bridging and air leakages arising on the construction site because of contractors' unfamiliarity with Passivhaus. This transfer of knowledge between architect and contractor is easily overshadowed in the current building industry with low skilled labour providing low standards. In Mallion's experience, there is a certain ignorance in the implications of constructing at the current standard, making it difficult to convince contractors and builders about the benefits associated with airtightness. With this premise, he avoids cavity wall construction, saying:

"I try and avoid cavity walls, they are a known disaster area, and builders have been doing them badly for years. When you want them to do it really well, you almost have to be there all day every day to make sure it's built properly and you can't do that on £120 an hour. It's not cost effective so I try and avoid them."

Mallion resorted to using timber construction in Grey Lyn detailing every junction in order to evade problems later on in the construction process (Mallion, 2014). However, the use of cavity wall construction has been shown to be successful with Passivhaus, as in the Denby Dale scheme. Mallion also used a cavity wall plinth (refer to Figure 7) to resolve the junction between the wall and ground floor. Thermal bridging in this detail is eliminated through the use of foam glass, which connects the insulation gap of the polyurethane insulation through the structural load path. The tie used in the cavity is a special low conducting (u-value of around 0.7) composition of materials, including pultruded basalt fibres in an epoxy resin. Moreover the Steico I-joist is sandwiched between two layers of wood fibre insulation. These details, created by Conkers Conservation, to put into context, are of a much higher calibre than the Enhanced Details promoted by Code for Sustainable Homes (CSH) as a construction guide for its agenda. Paul Mallion expresses that those details target property developers that employ a low-skill force who can comply and carry them forth but are miles behind the quality of Passivhaus detailing (Mallion, 2014)

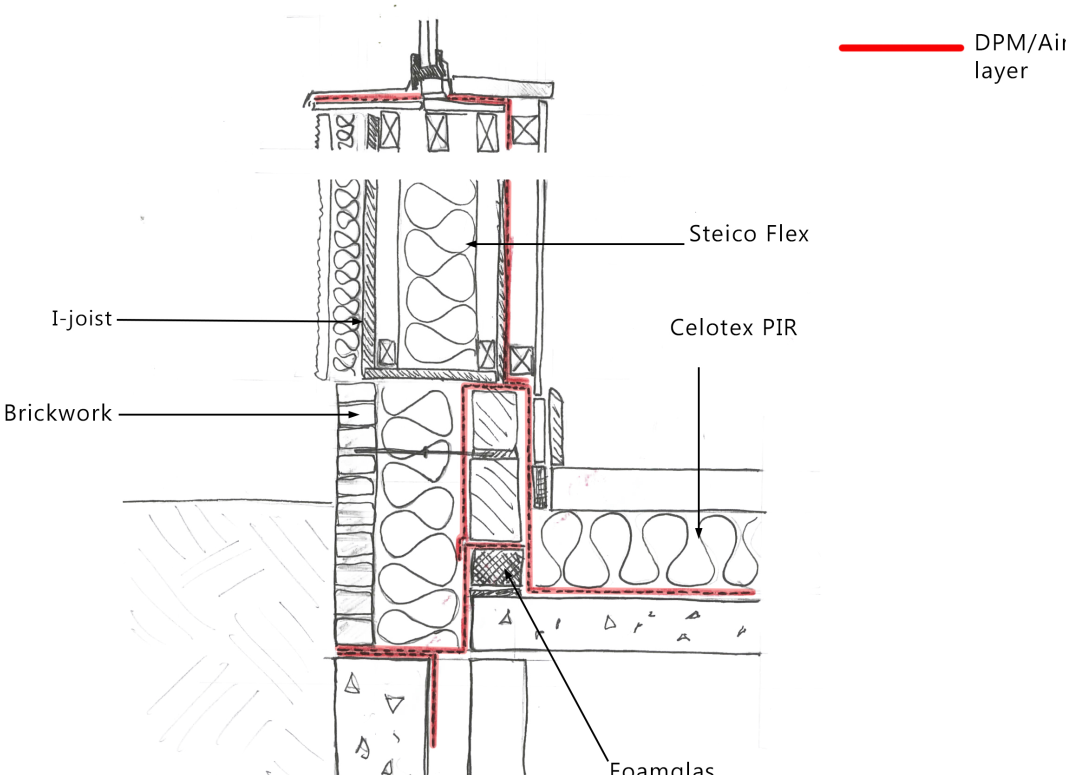


Figure 5: Unscaled detail drawing of floor to wall junction

Renewable Technologies

The clients, being owners of Invicta Clean Energy, had the opportunity to explore their repertoire of expertise and apply them to their new built, as well as their ambition and excitement to achieve the best possible outcome. The use of renewables is not required for achieving Passivhaus certification but can act as a compatible add-on, which can potentially cover a significant part of the primary energy consumption of 120kWh/m2 per annum and the maximum 15kWh/m2 needed for space heating, if not all of it. Grey Lyn incorporates the latest technologies as part of its design, helping it off-set carbon emissions incurred through operational energy consumption with renewable clean energy, using solar thermal panels, photovoltaic panels and an efficient wood stove. These technologies are integrated with a 600 litre thermal tank, which has two capacities other than outputting hot water: one, to input heat into the MVHR, through an air to water exchange; two, to supply optional heat to towel radiators in each of the bathrooms. This arrangement combined in a Passivhaus focuses primarily on covering the hot water demand of the family, as high levels of insulation and airtightness with a MVHR unit, allow the house to be passively heated by radiation from the sun, people and appliances. When a heating deficit occurs, most likely in winter, the loss can be replaced by the woodstove.

The integration of the different technologies in the design is straightforward with two solar thermal panels mounted at a 67° incline on either side of the upper storey glazing, to maximize their output during the low suns of winters and minimise their performance during summer in order to avoid potential overheating. Their counterparts, the photovoltaic panels, are positioned on the flat roof in a total array of 16 that can be flexibly positioned to take advantage of the sun during the year. It was estimated that only about 30% of the electricity will be used onsite, with the remainder going back into the grid qualifying themselves for the feed-in-tariff scheme. However, the recent installation of a photovoltaic immersion switch has allowed them to convert their surplus electricity generation into heat, which is fed into the upper half of the thermal tank. This arrangement is illustrated in diagrammatical fashion in Figure 5, where all the technologies, apart from the wood stove, are automated through the use of temperature sensors to essentially allow the system to run itself (Tarrant, 2014). In the planning application, the Fords propose to limit their potable water use to less than 80 litres per person, compared to the national average of 150 litres of water per person. This reduction will be driven by recycling rainwater through the rainwater tank on the roof that will be used to flush the guest toilet and irrigate the landscape, as well as flow-reduction shower and tap fittings (Ford, 2009).

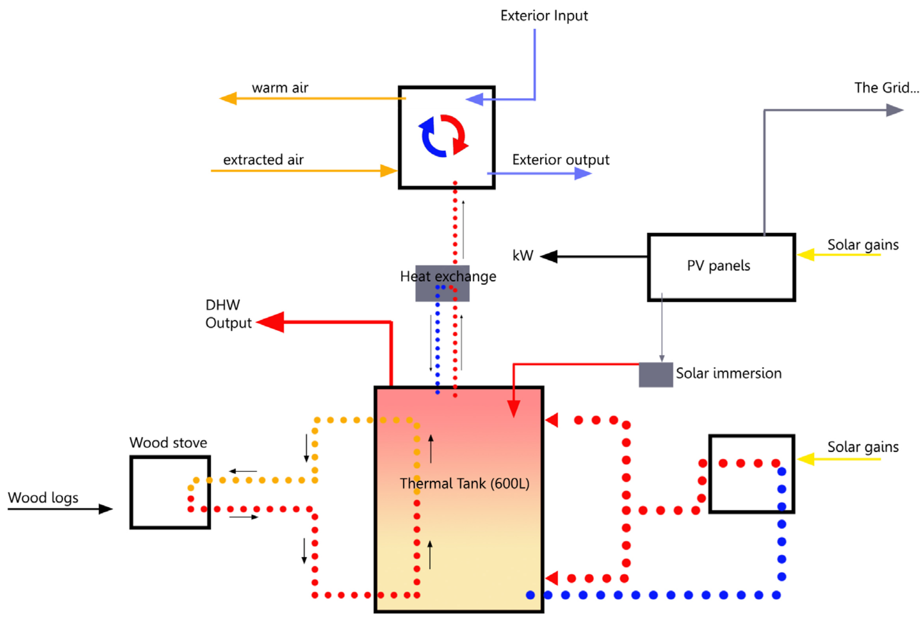


Figure 6: Diagrammatical representation of the arrangement of renewable energy technologies.

Construction Process

Grey Lyn was project managed by Trudy Tarrant, coordinating between different subcontractors and contractors to accomplish the build to the standard of the fully Passivhaus-certified detailed drawings of Conkers Conservation (Ford & Tarrant, 2013). The closest thing to a main contractor in the construction process was Ecolibrium Solutions, one of the leading building companies in the area specialising in sustainable construction since 2001. In Grey Lyn, they were in charge of the timber frame, insulation, airtight layer, chalk walls and Passivhaus certified components, including windows and doors. The other aspects, such as the foundations, plinth cavity wall and roofing were done by smaller contracting companies, excluding the servicing of the building, which was done by Justin Ford himself, who covered everything from the ventilation system to plumbing. With this in mind, this section will cover the challenges that occurred with respect to Passivhaus and other issues specific to this project.

The construction started with the ground works in November of 2010, taking nearly three years to build due to delays in several key phases. Ecolibrium were employed to deliver their part from November 2011, starting with the assembly of the timber frame structure on the plinth. A swift assembly of the frame was enabled by joists arriving onsite cut and ready. Before the insulation and airtight layer could be added, the structure had to be completed with the ramming of the chalk walls, which took until April of 2012 to go up. (Ford & Tarrant, 2013).

Placement of the airtight layer proved to be a challenge during the construction process, even with an experienced contractor, problems still occurred. The membrane on the upper storey was incorrectly placed on the cantilevering end of the north elevation. A cantilever is a trickier geometry, which was carefully detailed by Paul Mallion, but the subsequent application lacked supervision and required each individual joist to be sealed off to make it airtight. Fortunately the mistake was caught by the manager later and they were able to redo the job properly. However, an airtight test was conducted and the result was around 1 air change per hour (ach), which is above the minimum 0.6ach, so it would not have qualified as a Passivhaus. This result disillusioned the clients and they called Paul Mallion for advice, who recognised that there was a degree of sloppiness when the initial test was done, mainly construction equipment still lying around the site. He advised them to redo the test, which requires a framed sealed device with a fan to be attached on the front door and induce a pressure difference in the house, but this time to go around the house identifying the leakages, by simply hearing them out, and mending them with tape. They realised that a large number of staples had damaged the membrane and in some areas there were tears that contributed to the poor result (Ford & Tarrant, 2013).

In their own endeavour to maximise the potential of their build, Ford and Tarrant, including a close inspection of the airtight membrane, went around with a thermal camera to look for exposures of thermal bridges. They discovered that the glazing of the sunspace area had not been mounted properly and was causing a significant thermal bridge on the upper part of the component. Internorm, the window manufacturers, sent a certified technician to fix the problem (Tarrant, 2014). It was through the client's incentive to live in a Passivhaus that ended up fixing these essential aspects of the build.

Justin Ford was in charge of all the servicing for the building, including the MVHR ducting system through the house, whose implementation started towards the end of the frame construction, taking special considerations to the areas where the ducting routes crossed I-beams. The MVHR system was designed by Greenbuilding Store in conjunction with Mallion and Ford, who designed the routes for the system in the planning phase. In practical terms, it turned out to be a challenge between the coordination of Justin and the carpenter responsible for cutting the holes in the I-beams. The holes had to be cut out prior to fixing the I-beams down with all of them aligning so that the ducting could run uninterrupted. An example of this is demonstrated in Figure 7, where the ducting is able to run in a straight path through the joists. Justin was aware of the importance of this in relation to the MVHR performance in terms of noise and fan power. Therefore, he was very demanding with the duct work and several beams had to be redone in order to ensure the quality of the ventilation unit (Ford & Tarrant, 2013). In summary, these experiences demonstrate common aspects between Grey Lyn and self-builds - which, to an extent, this project can be categorised as one of - as they both strived to achieve the best possible outcome, a characteristic in building that is not nurtured sufficiently by the government in its building industry (Cutland, 2012).

Figure 7: Top left, chalk wall testing. Top right, formwork with chalk being rammed. Buttom left: MVHR ducting crossing I-joists. Bottom right two pictures: Man ramming chalk.

Chalk is an abundant material found in the area of Kent with healthy properties when used in buildings. Initial site digs at Grey Lyn found chalk at a remarkably shallow depth making it a viable and sustainable solution to the light weight timber frame that lacked thermal mass. The chalk from the site was sent for testing to classify its compressive strength to the University of Southampton and came back with excellent results, translating into two 300mm single height and one 400mm double height wall. Figure 11 shows several snapshots of the ramming process; at first it required a trial run to ensure the chalk had the right amount of moisture and granularity that would result in a sturdy aesthetic outcome. In order to achieve a smooth finish, it was vital that the big lumps of chalk were all accumulated in the middle part of the shutter and the smaller ones on the internal part of the shutters to avoid cracks in the finish (Ford & Tarrant, 2013).

Ramming the chalk within the fully raised timber frame meant that at many parts the joists had to, if possible, be lifted if up temporally to allow the rammer accessibility. However, the clients were very pleased with the end result, especially regarding the appearance, manifesting its natural properties towards improving the internal comfort on both a visual and sensory level, shown in Figure 8. In hindsight, due to the difficulties caused by the order of operation along with the learning curve of the builders that led to increased labour costs compared to the original

Figure 8: End result of the rammed walls.

quote, the clients felt that tackling the challenges in the reverse order - in other words, putting the chalk walls up first and then the timber frame - would have been more effective (Ford & Tarrant, 2013).

Post Occupancy

Grey Lyn was designed by clients who set out to build their own home with an office to Passivhaus standard with their own added layer of expertise on renewable energy technologies. At the moment there is no quantitative data to analyse the performance of Grey Lyn. However, the implementation of all the renewable technologies in their own home offers insight into how these technologies are integrated and automated to their new lifestyle and provide a comfortable energy-aware environment. The occupants' experience can be examined in terms of their perception of the internal thermal comfort, the space heating requirements, as well as dealing with their hot water needs through renewable technologies and behavioural changes in respect to their home's infrastructure. To give some sort of notion as to how well the house performs in terms of carbon emission, it is interesting to see the Energy Performance Certificate, which rated the building's environmental impact at 105 points, above the 100 maximum, producing -0.9 tonnes CO_2 annually compared to the average 6 tonnes produced by households (Bower, 2013).

Their perception of the internal thermal comfort is good, they are very pleased with the way the house is performing and how they have adapted to it. In comparison to their previous home, the use of fewer layers of clothing is testimony to the comfortable and consistent temperatures in the house that effectively isolate them from seasonal weather conditions. In many ways this is culturally new in the UK, as people are accustomed to a colder average internal climate that is susceptible to external swings in temperature and are thus more aware of the outdoor climate (Ford & Tarrant, 2013).

As space heating requirements are passively covered, the main occupation of the network of technology is to cover hot water demands, albeit the fact that the Fords have installed systems to compensate for a failure in the building's passive strategy, such as the water-to-air heat exchanger for the MVHR and the towel radiators (Tarrant, 2014). Currently the solar thermal panels have not been working at their full potential and require modifications from the clients in conjunction with the supplier to solve this. However, since the photovoltaic immersion installation, it has contributed a significant amount during this relatively sunny winter and used in conjunction with the wood stove, it is perfectly capable of supplying sufficient hot water. In the early winter of 2013, the occupants used the wood stove daily during the evenings for around three hours to supplement heat in the thermal store, compensating for the solar thermal performance. More importantly, this has introduced the notion of water usage to their new lifestyle, which they were far from learning in their previous home thanks to their combination boiler that provided an endless source of instant hot water. Regardless of the reality that the system is perfectly equipped to provide hot water needs, the amount of water the thermal tank can provide them with is fixed and has to be reheated if it runs out, which requires a time lapse as opposed to what normal citizens are used to. This circumstance has made Justin and Trudy Tarrant aware of their water usage and they are happy with this awakening as it's a very important issue regarding modern society's perception of finite resources as limitless (Ford & Tarrant, 2013).

Since the occupant's office is run from their house, their electrical generation can cover a percentage of that, as well as any household chores that require power. Trudy now orientates household chores like dishwashing and laundry during the day to take advantage of the electrical generation, taking special consideration in using these appliances in sequence rather than all at once to avoid electricity usage from the grid; a subtle but important change in user behaviour that compliments the system. The only manual intervention to the system is the use of the woodstove only when the solar gains have not been sufficient to cover the hot water demand, which is expected to occur in winter (Tarrant, 2014).

Conclusion

Grey Lyn demonstrates qualities of a holistic view on sustainability to drastically reduce carbon emissions with Passivhaus as the key element, using principles promoted by CSH and orgainising them around the German standard's methodology as promoted by the voluntary Association of Environment Concious Buildings. CSH, despite the leap the government took to set the building industry onto a sustainable path, fails to provide the right means to follow this path, with the scope of solutions varying substantially between different developments when aiming for levels 4-6 (McManus, et al., 2010).

By investigating the different phases of Grey Lyn from conception to completion of the project, the means used have been identified and examined. These include Conker Conservations having the experience of other Passivhaus projects, developing a specific methodology that emphasizes the functionality of the plan in relation to an efficient form factor as a basis. Using sustainable construction modes suscessfully, they demonstrate the expandability of the Passivhaus standard in addressing embodied and operational energy which, with the integration of renewable technologies, lays the path towards zero-carbon buildings.

Figure 9: Green Roof and solar panel

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Acknowledgements

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Camden Passivhaus

Tim Waterson

Location Camden, London
Building Type Two storey - Single family house
Construction Type Prefabricated Timber frame
Floor area 101m^2
Completed December 2010
Year Certified April 2010
Overall Cost £813/sqm

Client Malcolm & Fiona Terry
Architects Bere:architects
Main contractors Visco (Integrity Buildings)
Council Camden
Certifier Peter Warm
Consultants and Collaborators Kauffman Zimmerai (Timber Frame Fabrication & Engineering), Dominic Danner (Air-tightness Champion), Alan Clarke (Services Engineer), Rodrigues Associates (Substructure Engineer), Green Building Store (Heat Recovery Ventilation Design), Jason Palmer (UCL, Technology Strategy Board, Lead Researcher)
Funding sources Private

Abstract

This case study will look to analyse the accomplishments and issues encountered during the Camden Passivhaus project, London's first certified Passivhaus. The study is divided into four sections, with 'Key Findings' paragraphs acting to conclude each section with a concise summary. Case specific analysis will be drawn from; the design process and its extensive use of the Passivhaus Planning Package (PHPP), the construction phase, particularly the skill and attitude required on site and the configuration of the construction team, finally reviewing the occupancy phase of the project and the Soft Landings approach used by the architects.

Camden Passivhaus
Ranulf Road, London
Bere:architects

Introduction

This chapter aims to decipher the difficulties and accomplishments encountered throughout the Camden Passivhaus project and discuss the future of the standard in the UK residential market. The research has been compiled from a number of interviews, data sets, published reports and articles. The interviews were conducted in January 2014 with; Justin Bere (Project Architect), John Seaman (Lead Contractor) and Dominic Danner (Air-tightness Champion). The following chapter has been divided into three sections, discussing the design, construction and post-occupancy phases of the project.

Figure 01 : Aerial View - Camden Passivhaus (Bing Maps, 2013)

The Camden Passivhaus by Bere:architects was completed in 2010. The detached two-storey home is located in Camden, north London and was the first Passivhaus to be certified in the city. The limited size of the site, accompanied by height restrictions and over-shadowing from adjacent houses were principal influences on the early design decisions. The house has a modern, timber-clad design and is located on a suburban street, predominantly occupied by large detached homes. A south-facing garden and two-wild flower green roofs help to situate the home within its compact site. The building is partially sunken within the ground to adhere to the height restrictions and achieve comfortable ceiling heights for a two-storey dwelling. Interlocking planks of cross-laminated timber were used to construct structural decks for the roof and floors, helping to minimise noise transmission between spaces and obtain the low-profile of the home. The superstructure of the house is a heavily insulated prefabricated timber frame from Austria, which has then been clad in European Larch. An unconventional internal layout features two bedrooms with private bathrooms on the ground floor, whilst an open-plan living, kitchen and dining area occupy the first floor.

Section One

Why Passivhaus

This project began life as an investment opportunity for the client, a developer, who owned a garage and garden, located on a small site in Camden. The client was looking for Bere:architects to design a relaxing, healthy and energy efficient house with a high quality finish. It was in fact Bere's previous low-energy 'Focus House' in Finsbury Park that attracted the client attention. When Passivhaus was first mentioned, Justin Bere gradually introduced its benefits and principles, but described the client as a little 'dismissive' (Bere, 2014) of the standard, due to the added cost being off-putting.

"Early clients came to us looking for a nicely designed building, not especially a low-energy building. So, you have to then try to introduce the idea… what if all the surfaces of your house are radiating heat for you, because they're all at the same temperature as the air." (Bere, 2014)

Figure 02 : Focus House by Bere:architects (Bere.co.uk, 2007)

Planning prospects were a concern for the project due to the nature and location of the site. Camden planners were cautious 'of establishing a precedent for houses to be built in gardens' (Palmer, 2011). The client's Passivhaus epiphany came once an article appeared in Camden's local paper, where a councillor was advocating for Passivhaus. Bere met with the councillor, who became hugely supportive due to the prospect that Camden may get London's first Passivhaus, and this helped to push the design through committee.

"So immediately the client, subtly shifted his tune from 'yeah yeah, maybe' to 'ok! Let's do Passivhaus' because it was suddenly more attractive." (Bere, 2014)

The client appreciated the wider attraction of Passivhaus, such as, increased value and workmanship, but planning acceptance, as recorded here, is being seen as a major reason for recent Passivhaus adoption in the UK (NHBC Foundation, 2012). Bere remarked, "Planners do really seem to welcome the Passivhaus approach… the integrity and ethical nature of it does help with planning, I'm quite sure of that." (Bere, 2014). As the project progressed the client became 'excited by the idea of healthy indoor air quality' (Lewis, 2010) and the purpose of the project was amended to become a home for the client's daughter, who suffers from severe asthma.

PHPP Iteration Walkthrough

For the design of the home, Bere:architects began with the typical architectural concerns you might encounter when developing on a residential road. A height restriction was the major constraint on the design as was the small footprint of the site. As the house was not allowed to go higher than the existing neighbouring garage, the decision was made to partially sink the house into the ground. These height restrictions also pushed the design to feature a flat roof and a lower ceiling height for the bedroom floor. Once these practical limitations were established, the architects used the Passivhaus Planning Package (PHPP) to incrementally hone their design by calculating each alteration's bearing on the energy performance of the building.

"After sketching, we then had a CAD model, so we had accurate dimensions which we put into the PHPP, and after that we just did free hand sketches of 'what if we try this' and then from those sketches we are able to adjust the PHPP model, windows, scale, walls etc." (Bere, 2014)

What proceeded was part architectural process and part learning exercise for Bere:architects. In this brief summary of design options, the specific heat demand from the PHPP is used to quickly demonstrate the outcomes from the main alterations as they progressed with the design for Ranulf Road.

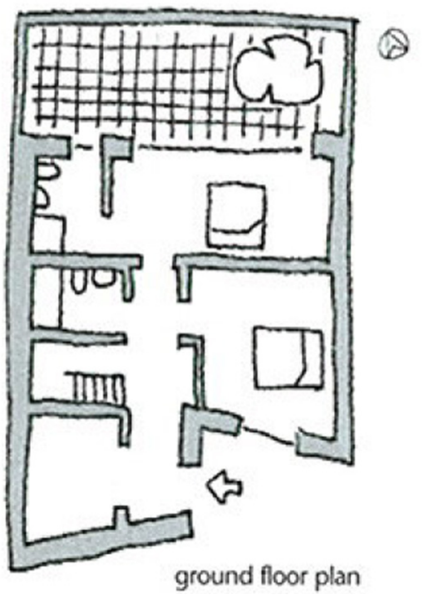

Figure 03 : First Design Iteration (Lewis, 2010)

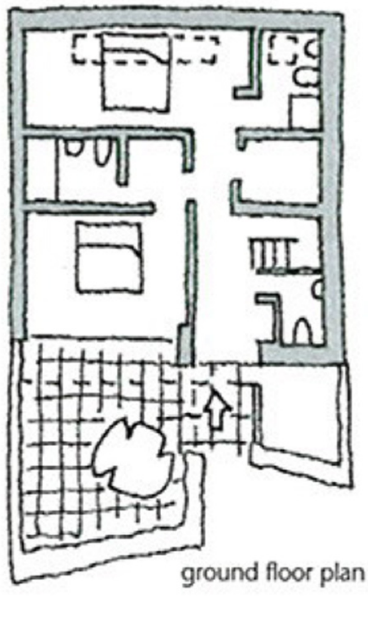

Figure 04 : Fourth Design Iteration (Lewis, 2010)

Looking at the initial scheme produced, the design featured a large amount of north glazing and had a high envelope to treated floor area (TFA) ratio. The early environmental considerations in the design resulted in a reasonable result of 21.2kWh/(m^2a). Although not near Passivhaus standards, this proved a strong starting point for Bere:architects to refine their awareness of Passivhaus principles in practice.

The second iteration, contained an open courtyard within the plan, this adjustment was to counter lighting issues, which traditionally would have been a plausible solution. However this did not address issues in the design of a large percentage of glazing either not south-facing or being heavily shaded, the envelope to TFA ratio was also too high, resulting in a slightly increased specific heat demand result of 21.9 kWh/(m^2a).

Iteration 3 - An open courtyard in the north-west corner. Moving the courtyard to the north-west meant a high percentage of glazing was not south-orientated and the TFA was again too high but the small envelope resulted in a better result of 16.7 kWh/(m^2a).

Iteration 4 - A South facing garden resulted in a high percentage of south-orientated glazing and provided a good envelope ratio as well as the specific heat demand to meet Passivhaus standards, producing an specific heat demand of 13.5kWh/(m^2a). However compromises made meant the master bedroom's only daylight came from roof lights.

Iteration 5 - The Southern garden was still featured but the bike store was moved internally, causing the results to suffer, and increased to 14.2 kWh/(m^2a).

Iteration 6 - This layout maintained the high percentage of south-facing glazing from the previous scheme but had a higher envelope to TFA ratio due to a north facing courtyard, leading to a higher result of 17.6 kWh/(m^2a).

Iteration 7 - The layout reformatted the bedrooms to have a straight wall in bedroom one, whilst also reducing the shading on those windows. This improved the ratio of envelope to TFA lowering the result to 17.0 kWh/(m²a).

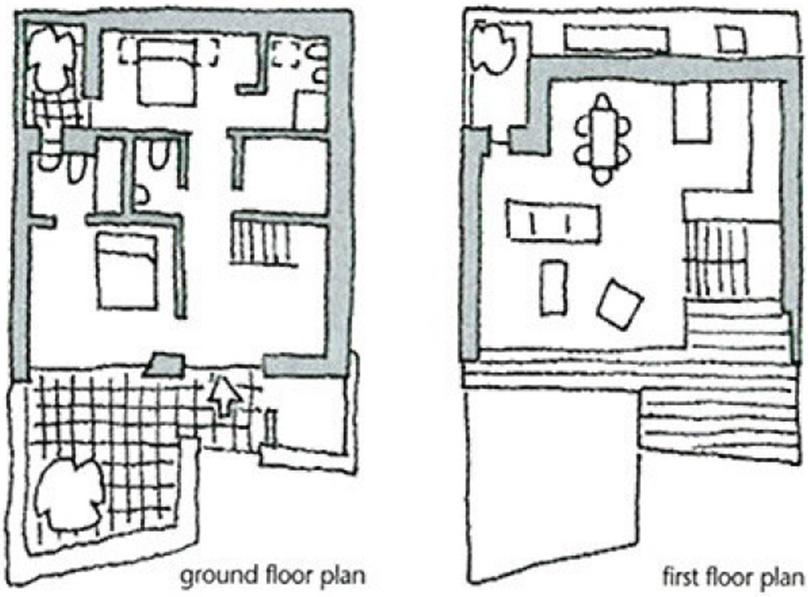

Figure 05 : Seventh Design Iteration (Lewis, 2010)

Iteration 8 - Extruding the straight wall from the ground through to the first floor helped to improve the envelope to TFA ratio, whilst also further reducing the shading to the first floor windows. These alterations lowered the result to 16.3 kWh/(m²a).

Iteration 9 – The width of the north-west courtyard was reduced from 1.5 metres to 1 metre, further improving the envelope to TFA ratio, and lowering the specific heat demand to 16.1 kWh/(m²a).

The architects were observing incremental fluctuations in the PHPP with every adaption made to the layout, by the tenth iteration a new approach to insulating was applied. Using vacuum insulation, they were able to reduce wall thickness without a reduction in U-value for the wall. The reduction in wall thickness also benefited the envelope to TFA ratio, producing a result of 15.4 kWh/(m²a), however this was a costly option for the project and was dismissed.

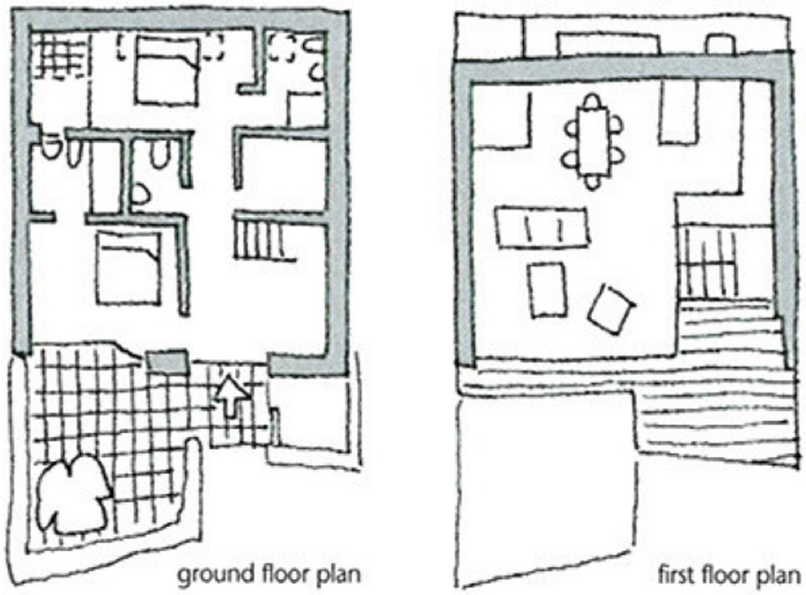

Figure 06 : Twelfth Design Iteration (Lewis, 2010)

Iteration 11 – A light scoop was introduced to bring south light into the back corner of the plan and the Northwest courtyard was now covered. This setup caused an increase in the building envelope area and led to a poor result of 17.2 kWh/(m^2a).

This was a learning process and with their iterative approach, Bere:architects could record results and learn from each design variation. For the twelfth iteration; the light scoop was reduced, along with a change of specification and increase to insulation in the roof and floor. This all led to further significant reductions to heat demand and improvement in the envelope/TFA ratio, producing a result of 15.3 kWh/(m^2a).

Iteration 13 – A one metre gap to the west side of the building was introduced to provide windows to more rooms of the house, however this reduced the ratio of south-orientated glazing on both floors, giving a higher specific heat demand result of 20.1 kWh/(m^2a).

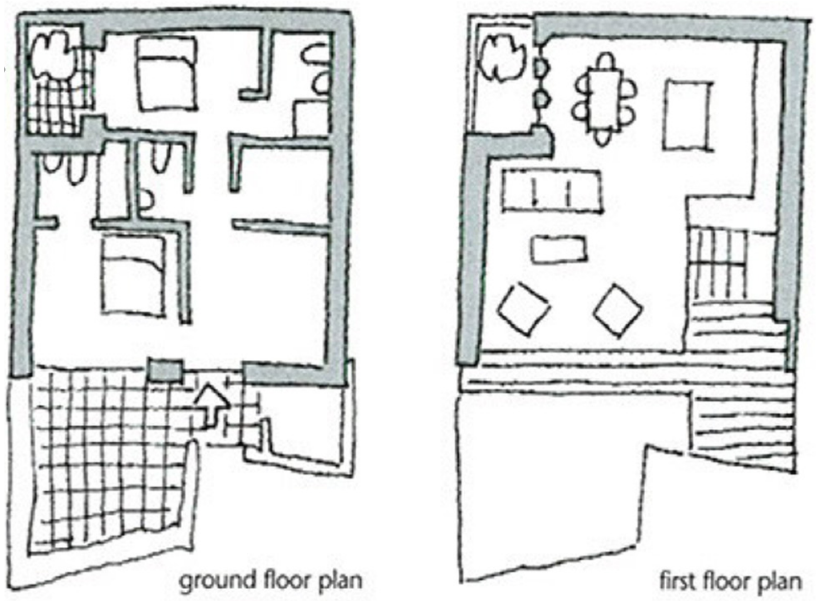

Figure 07 : Fourteenth Design Iteration (Lewis, 2010)

Final Design

The fourteenth and final iteration introduced improvements to the envelope/TFA ratio by removing the roof-lights for bedroom two and giving a straight wall to bedroom one, reducing the shading of the ground floor windows. The new plan gave bedroom two its own small private courtyard and an increase to insulation meant the predicted specific heat demand came down to 14.5 Wh/(m^2a).

The methodical use of PHPP by Bere:architects drove the earlier design to relocate from the south of the site to the north and removed the north-facing rear private courtyard, allowing for the creation of a south-facing garden enclosed at the front of the house. Bere noted that these alterations not only helped to reduce the visual impact of the home when viewed from the road, but benefited the internal layout as well, with increased natural day-lighting throughout (Lewis, 2010). A number of the iterations were seen to meet Passivhaus energy requirements, but the final design was chosen not only for its high energy efficiency but also for its financial, practical and aesthetic characteristics (Palmer, 2012).

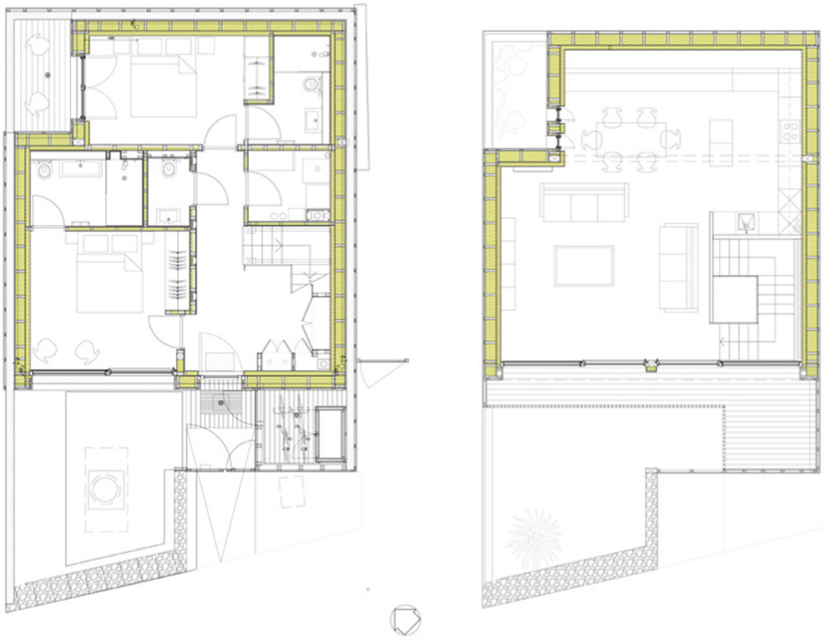

Figure 08 : Fourteenth Design Iteration - Final Drawings (Bere:architects, 2010)

Passivhaus insulation standards were achieved using 240-280mm of Rockwool Flexi between the timber studs, with 100mm of natural wood fibre insulation inside the vapour control layer. The flat roofs use 400mm of high performing rigid insulation, with a thermal conductivity of 0.026W/(mK), to maximise the thermal performance while minimising the build-up. The insulation also performs well with the green roof build-up, which was a part of the planning conditions, as was the general landscaping surrounding the home. An airtightness membrane was stapled and taped throughout, designed to achieve an air permeability of 0.6 ACH (at 50Pa). The layout tries to maximize light to the first floor living space with the large windows essential to the passive heating strategy. The use of mechanical heat recovery ventilation with fine (F8) air filters produces high air quality and the use of a solar thermal panel to supply domestic hot water with a small gas boiler to compensate benefits the overall energy efficiency (Palmer and Clarke, 2011).

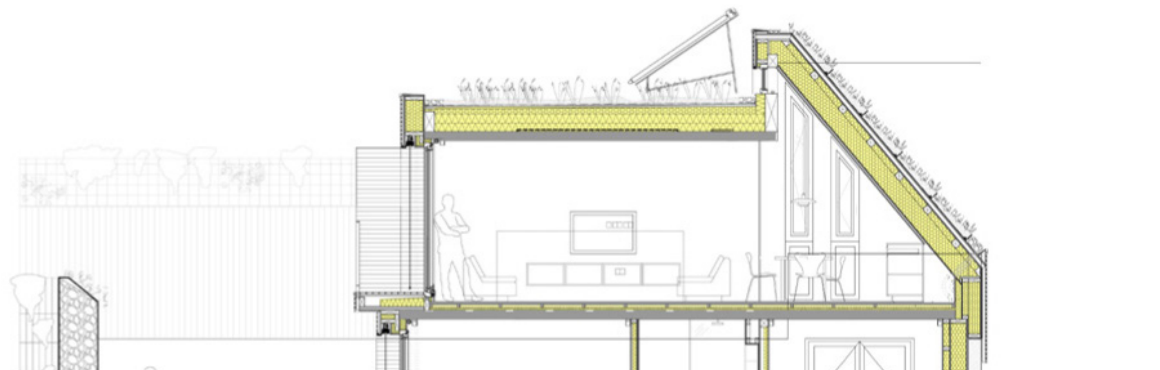

Figure 9 : Final Design - Section (Bere:architects, 2010)

PHPP Use Analysis
Justin Bere described the PHPP process for Camden as a ‘learning exercise’ for a UK practice and that they invested ‘a lot of time in looking at the subtle variations… in order to get a better feeling for the impact of various changes’ (Bere’ 2014), using PHPP to help visualise and understand the repercussions of certain design choices. Bere:architects spent ‘quite a long time’ on this part of the process but express that this needn’t be the case for every project:

“I think it was well worth investing the time to develop an intuitive feel for Passivhaus designing… once you’ve got your design worked out for planning you can put it into a model with PHPP and after that it’s just little tweaks.”
(Bere, 2014)

Whilst some may suggest that relying on analytical tools can stifle an architect’s ability to design, Bere argues that; “It’s integrated design. Anyone who regards it as an impediment doesn’t even begin to understand what it is to design using these principles. As architects we should be able to include more sophisticated techniques as part of our design process.”(Bere, 2014)


Figure 10 : Final Design - Section (Bere:architects, 2010)

When queried about the effect of PHPP on project costs and time, Bere summarises that it became ‘just part of the workload’ and they now choose to outsource the PHPP to a past employee; “That’s the way it works in Germany, they outsource to a PHPP specialist. What I’m trying to say is there should be no impediment to any architect.” (Bere, 2014)

Bere:architects have since chosen to use PHPP, instead of other tools such as SAP (Standard Assessment Procedure), on all their projects including non-Passivhaus. Praising PHPP as a more accurate and practical tool for achieving a consistent high standard of energy-efficiency. PHPP and Passivhaus have often been compared against current UK Building Regulations (Part L) and particularly the benefits in the use of PHPP over SAP as a design tool. One such study by Eirini Moutzouri at the University of Strathclyde summarised their differences, in that PHPP predicts running costs closer to reality when compared to SAP (Moutzouri. 2011). Each assessment tool addresses different concerns, with SAP at times ‘simply judging compliance, whereas Passivhaus and PHPP guide the whole design towards an efficient, low energy solution’ (Trinick. 2011).

Section One - Key findings

From the start, a client may need the benefits of Passivhaus explained to them in a relatable manner, but due to the developer based market in the UK, the benefits of Passivhaus outside of being an alternative route to gaining planning permission must be communicated (Schiano-Phan, et al., 2008). As for the design process, a UK architectural practice will need to invest extra time and understanding, to use PHPP effectively, just like any other design tool (NHBC Foundation, 2012). It has been made evident that PHPP does not need to add significant cost to a project, nor should it impede design ability. The use of PHPP was crucial to the success of the Camden Passivhaus and has since been used, due to advantages over SAP, on non-Passivhaus projects.

Section Two

Procurement

The procurement route was traditional, with selective tendering as Bere:architects wanted to maintain as much control over the design once construction began, to guarantee the air-tightness and thermal performance of the building (Palmer and Clarke, 2011). The UK contractor, Visco, was chosen to carry out the whole works on site, Jon Seaman the director of Visco (Now Integrity Buildings) along with Dominic Danner had met Justin Bere at a Passivhaus Conference in Frankfurt in 2009:

"As the only English Contractor at the conference he asked us whether we could do the foundations and civil engineering works, we priced it and about a month later they came back to us and asked if we would be the main contractor for the whole of the works." (Seaman, 2014)

Seaman and Danner had both previously worked in Germany, where they gained an awareness and appreciation for Passivhaus. At this point, UK Passivhaus had a reasonably muted presence amongst UK contractors due to it's low demand and it was not surprising that Visco were one of only a few contractors attending the conference.

For the design of the timber superstructure, Bere:architects at the time had an Austrian employed who was there for UK work experience, Matthias Kaufmann. Kaufmann's family ran a timber frame construction business in Austria, Kaufmann Zimmerai, for which Matthias was over in England gaining experience for. The rare situation afforded to Bere with Kaufmann in-house, provided a unique knowledge transfer opportunity. Matthias Kaufmann was able to begin work on the timber frame drawings at the design stage in-house at Bere:architects, then return to Austria to pre-fabricate the structure and façade cladding in the factory, and finally return again to complete construction on site. This had several clear benefits, which enabled a smooth office to site transition for the timber frame components. Any issues that arose with the timber frame could be easily resolved due to a thorough understanding of the design by all parties. Bere recalls how before construction could begin, a detailed timeline was created to organise the process with allowances for crucial Passivhaus junctions, such as the air-tightness test.

Imported Resources and Labour

Imported resources helped the Camden Project achieve its high standard of quality, with the principal form and structure of the building constructed in Austria. When asked about the locality of the materials and labour, Bere responded, "On the Camden project we were very much in learning mode and I wanted to learn from the best" (Bere, 2014). The import of the pre-fabricated superstructure and façade, were a prime example of this rationale, with both the construction technology and materials imported from Austria along with the workmen to install it on site. Other notable imports were the triple glazed Passivhaus windows, but this simply came down to a lack of viable local alternatives, that would be as efficient or cost effective.

Figure 11 : Kaufmann Zimmerai Prefabrication Factory (Bere:architects, 2010)

At the procurement stage the client was concerned about the high cost of the Austrian timber frame and requested an appraisal on alternative options. Bere recalls, "we approached British and Irish manufacturers but none of them at the time really understood the issues associated with Passivhaus. So it was clear very quickly that the skills from Austria are so far ahead of everyone else's and that when we do use a British manufacturer we need to simplify things to help them"(Bere, 2014). This noted absence of viable local alternatives and need to alter Passivhaus design to adapt to the UK market forms part of the summary in the final section of this study.

Figure 12 : Substructure Works and Superstructure Installation (Bere:architects, 2010)

After the substructure was laid, the Austrians arrived and over a two week period constructed the pre-fabricated superstructure with the incorporated façade. The benefits of the pre-fabricated system became clear on site, with the fine tolerances, reduced construction times and minimised waste immediately apparent.

Air-tightness Champion

Both Bere:architects and Visco admitted that they were concerned with air-tightness and quality of build, as this was their first Passivhaus. As one of the steps to minimise this concern, Dominic Danner of Visco who had taken the CEPH (Certified English Passivhaus Designer) course in Germany, was named as "Air-tightness Champion" for the project. This role primarily emerged from the need of a 'liaison with the German speakers' on site but developed into a more encompassing role of supervising the workers and maintaining the air-tightness barrier. Special attention was paid to on-site workers from traditional UK building backgrounds to make sure all details were constructed as designed.

"The Austrians were phenomenal, they knew exactly what they were doing and I learnt through them so much… but it was so detailed and intricate some of it that working with the trades wasn't easy… Camden was one of the first ones so a lot of people were learning and mistakes happened." (Danner, 2014)

When questioned about the benefits of the CEPH course, Danner emphasised the helpfulness of the course in grasping the concepts and an understanding of Passivhaus. Danner then went on to explain his professional opinion that the CEPH course should not be seen as an instant ticket to the title of Certified Passivhaus Designer and that major problems can occur when this is not realised:

"I'm very pessimistic about Passivhaus in the UK and the CEPH training is like passing your driving license, you do your test but its only really afterwards you learn how to drive." (Danner, 2014)

The evolution of Danner's role since Camden and the concerns raised here will be further addressed in the final section of the study.

Local Resources and Labour

UK builders supplied the labour for all aspects of the Camden Passivhaus, bar the prefabricated components installed by the Austrians. The site, which had a footprint no bigger than the building itself, could become very crowded, and carelessness sometimes led to mistakes and damage to Passivhaus features due to their exacting standards. This was a new issue for the UK team to address, as such caution and accuracy during every stage of the build was an unusual imperative. The contractor employed their own workmen, whilst the client employed his own electrician and plumber, whom he had previous experience with.

"The air-tightness role on [Camden] was, compared to other jobs that I've now done, really minimal, but one could see that the role was needed…" (Danner, 2014)

Figure 13 : Interior Construction Works (Bere:architects, 2010)

Bere and the Contractor unearthed tradesmen on site who were simply unaware of Passivhaus or reluctant to employ new techniques. Bere and Danner were often required to spend extra time on site making sure the Passivhaus standards were adhered to. Briefings and training for workers on the construction team about the importance of air-tightness and the aims of a Passivhaus were initiated throughout the construction process, with some workers more willing than others to learn (Palmer and Clarke, 2011). Frustrations arose on site between Dominic Danner and other members of the construction team, when extra care for tasks was not understood or simply ignored. This was especially disruptive with the client's own M&E contractors, whom had no contractual obligation with the architects, and openly treated the Camden build like any other development they had worked on. One such example occurred when the plumber decided to install standard large-diameter pipework instead of the small-diameter specified. The plumber's training meant he was only concerned with flow-rate performance and the energy-efficient small-diameter pipes went 'against every grain a traditional plumber from the UK has, because for [the plumber], it's performance loss' (Danner, 2014). This issue and others like it were eventually resolved through reiteration and on-site education of Passivhaus standards, but added unnecessary cost and construction time to the project, especially when certain elements needed to be reworked.

"Some of the workers really bought in to the fact that the project had to be constructed differently and to look after the air-tightness layer and some didn't last a day. Some people assured us they bought into it but you would walk around the corner and they would go back to their old ways. It just wasn't worth keeping them on site, so they very quickly disappeared." (Seaman, 2014)

Figure 14 : Exterior View of Last Stage Construction (Bere:architects, 2010)

Summarising the contractor's experience during this project clarifies the obstacles encountered. With regard to overall construction being a much more exact process requiring a 'higher quality of works and tradesmen' (Rodrigues, 2008) than originally predicted and that any design alterations during construction were particularly expensive. Minor problems were also presented when the air-tightness barrier was not always obviously visible on the drawings, Bere:architects now clearly highlight in the drawings of future projects to avoid confusion.

"At Camden when people inadvertently made a mistake, perhaps went through the air-tight barrier, they certainly were shouted at, so one or two were definitely hidden. We now praise people who come and tell us of a mistake… It makes it a much cheaper repair then and there" (Seaman, 2014)

Jon Seaman explained how issues from Camden are being resolved on future projects with; additional preparation by all parties before commencement on site, further toolbox talks, including guides for particularly detailed work and a budgeted cost specifically for inspection. Particularly relevant to UK Passivhaus progress is the attempt to alter the mentality of workers on site.

Section Two - Key Findings

During the construction phase, the Camden project encountered minor obstacles, with complications arising from the project being a learning experience for most of those involved. Local alternatives proved inadequate at the time compared to imported services due to the relative 'immaturity of the supply chain'(NHBC Foundation, 2012). However, the knowledge transfer between Bere's offices, to the Austrian factory and then onto site for construction, became an incredibly valuable asset for this build. Certain issues could have been resolved with further control over the site and the sub-contractors, with problems resulting from ignorance or clear disregard, by UK tradesmen, for the Passivhaus standards, this was principally tackled on site by educating those involved with the build. Separate reports by both the NHBC Foundation, and School of Environmental Sciences at the University of East Anglia, support the practice of providing further training to the UK industry as a sensible way to ensure the development and acceptance of the skills required for Passivhaus construction

Section Three

Implemented Design

The completed design, which began construction in September 2009, is a meticulous and well-formed piece of architecture and was certified to Passivhaus standards in April 2010 with the occupants moved in by December. Peter Warm, of WARM: Low Energy Building Practice, issued the certification. With the home achieving the results Bere:architects had predicted. A heating demand of 15 kWh/m^2, an air change rate of 0,6 ach at 50 Pascal of pressure, with the primary energy demand for standard use less than 120 kWh/ m^2. Camden's project team used the Technology Strategy Board (TSB) procedures for fabric and services testing. A building performance evaluation team carried out; a thermographic and heat flux study along with air-tightness, co-heating and service tests. The results of these tests validated the quality of the build and confirmed the 'exceptionally low heat loss' (Palmer, 2011) and expected performance of the services. Thermographic tests displayed surface temperature for the walls as comparable to the ambient air temperature, with the only significant heat loss occurring around the window frames, but still performing far beyond standard construction details.

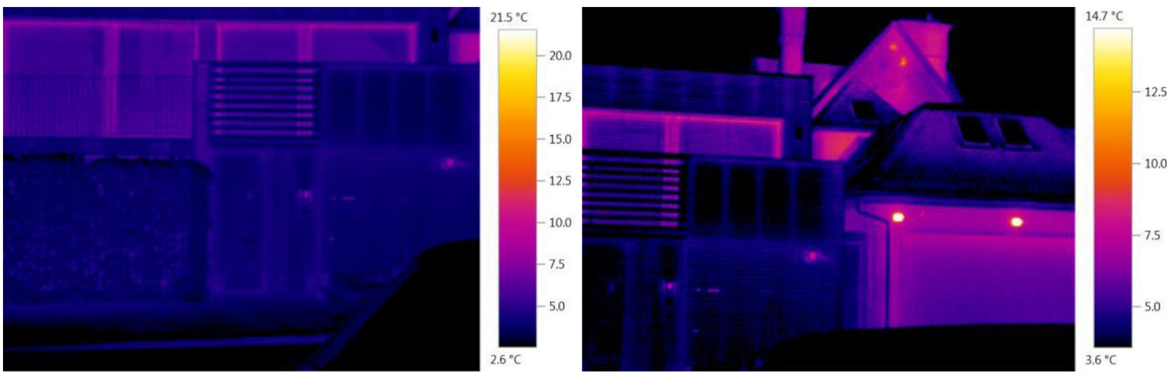

Figure 15 : Thermographic Imaging of Camden Passivhaus (UCL, 2011)

User Guide

This was a two-stage handover, with Bere providing an initial user guide for the occupants with clear information on how to run the building efficiently, and then returning after they had moved in to discuss the operation of various systems. This allowed them to further explain and clarify certain elements, such as was necessary in providing more detail to aid changing ventilation filters and further text for the ventilation boost switch (Palmer, 2011). Bere cites Bill Bordass, a key member behind the Usable Buildings Trust, as inspiration for the guide.

"A point [Bordass] has been making for a long time, is complexity in buildings that people don't understand, so they misuse them. I thought, let's try and make this mystery building as easy to understand as possible." (Bere, 2014)

The guide went through a design process, where they specifically were not after an instruction manual. A part one architecture student, whose graphic design skills had impressed Bere, put together the user guide with a clear brief for it to be, enjoyable and accessible. The success of the guide for the occupants of the Camden Passivhaus has led to Bere:architects providing one for each of their projects since.
"We dot them around buildings now and for public buildings we take extracts and put relevant parts around the place, so people get a visual connection." (Bere, 2014)

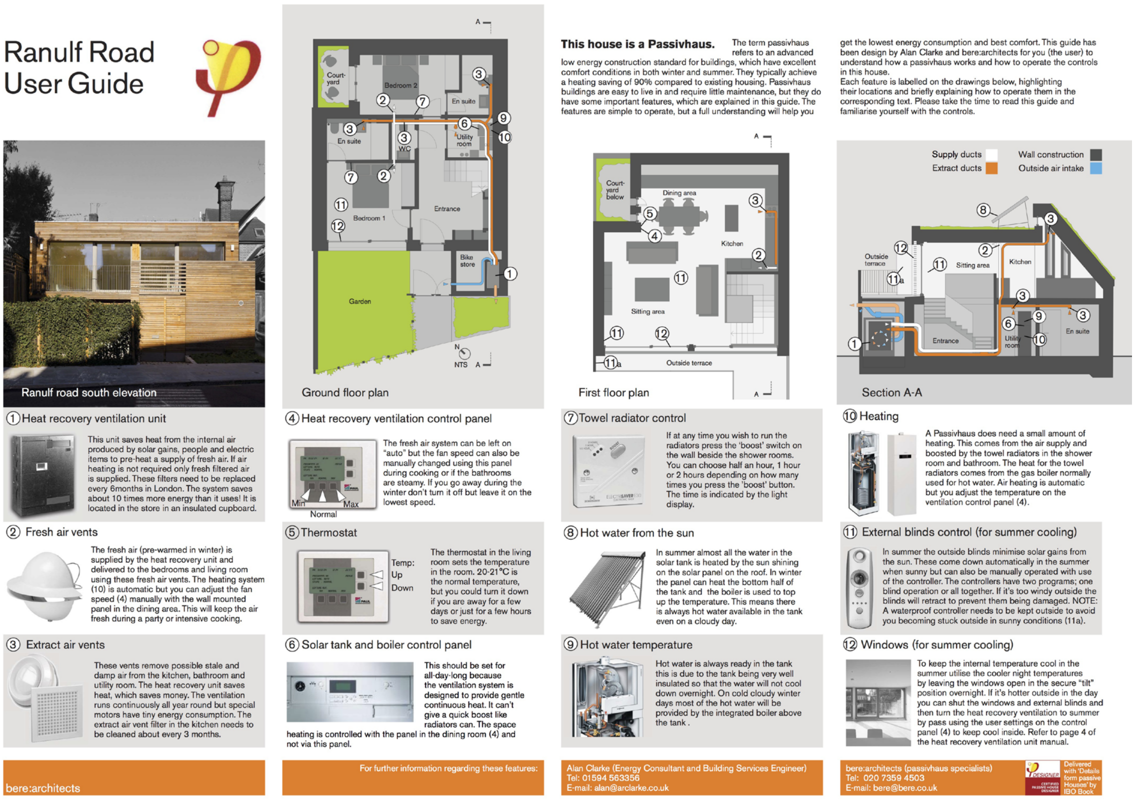

Figure 16 : Camden Passivhaus User Guide (Bere:architects, 2010)

Soft Landings & Monitoring Data

The user guide formed part of the Soft Landings methodology adopted by Bere:architects, with Camden serving as one of their first projects to follow this protocol. Bere describes the initial benefit of this approach to help align the views of the client and the team. With the ability to present further opportunities after construction to informally refine the experience of the occupants within the home. "We're building foundations with our approach, so there's no point rushing off and leaving these buildings without finding out if they're doing well" (Bere, 2014). In the case of the Camden Passivhaus, the soft landings approach was augmented by the data-monitoring conducted by the TSB.

As part of the UK government's TSB Building Performance Evaluation Programme, the house was awarded funding for two-years post-occupancy data monitoring. The study was led by Jason Palmer at the University College London (UCL) with Bere:architects reviewing the data to inform their Soft Landings protocol. To determine real fabric performance in the Camden Passivhaus and evaluate its effectiveness, a broad range of data monitors were installed. Doctor Ian Ridley form UCL specified the monitoring system and oversaw the installation by Bere:architects. Data retrieval was then carried out using Darca Plus software and downloaded remotely by UCL on a weekly basis.

Data from the first stage of monitoring (as of writing, second stage data has yet to be published) suggests the home is performing as expected even once occupied. The preliminary tables display the early results of energy use in the home, which was part of the TSB study and was also fed back to Bere for use in their soft landings procedures. Certain anomalies in the results highlighted issues within home and allowed Bere to follow up and correct them. A surprising amount of electricity was being used for the boiler/towel rail, which led to the discovery of a faulty control panel causing the solar and boiler pumps to run continuously. Whilst unexpectedly low-performance of the solar water heater revealed it was installed incorrectly, and improved once adjusted.

Occupant Observations

Once occupancy began, Bere could no longer predict the use of passive measures required for temperature regulation in the home, and found that on occasion the occupants were overriding them. The shading devices, such as the blinds in the living area were not being used during the summer days, leading to recordings of higher than expected internal temperatures, which the occupier actually preferred. However, due to privacy concerns from the large windows, the blinds were being used during winter days, negating the intended solar gains, fortunately this did not produce a discernible temperature drop within the home.

Figure 17 : Filter Changes and Blind Use Issues (Bere:architects, 2010)

The occupier explained in the Building Use Survey (BUS) that overall living in the Camden home was 'very comfortable and pleasant', scoring the house highly (UCL, 2011). However, certain aspects of design features necessary in a Passivhaus have caused a few noticeable issues for the occupants. Sound transfer between rooms on the ground floor is perceptible but currently unavoidable, as there has to be a small gap under the doors for airflow purposes. Security windows designed to open as part of a cooling strategy are unused at night as the client feels unsafe sleeping with them open, and therefore electric fans are required. However the positive notes from the BUS suggest the Passivhaus features of the home are some its greatest strengths. The occupant describes how the air quality is noticeably better than any other home she has lived in. On the whole the house is consider easy to maintain by the occupants (UCL,2011) and they understand the principles of the MVHR, with ‘no reported ventilation or humidity issues’(Palmer, 2011).

Figure 18 : Finished Living Space Interior (Crocker, 2011)

Section Three - Key Findings

The lessons learnt from monitoring are invaluable to the original project as well as for future projects. Noticeably, the requirements from the occupier cannot be too scripted into the function of the building and its systems should be flexible enough to suit varying lifestyles (Ridley et al., 2013). This reasoning was further supported in a study conducted by the University of Strathclyde on recent Scottish Passivhaus dwellings. They went on to further detail the difficulties experienced by the occupants due to lack of clear instructions on how to operate the home (Tuohy, et al., 2012), a problem successfully addressed during the Camden project with their user guide.

Conclusion

The Camden home by Bere:architects is a compact serving of sophisticated residential architecture and successful Passivhaus construction. The rigorous use of PHPP software, inclusion of experienced professionals and commitment to cultivating a knowledge of Passivhaus techniques proved essential to fulfilling the projects potential. Issues occurred due to inexperience and miscommunication, hampering progress during construction but ultimately becoming relatively insignificant towards the completion of the project. The post-occupancy monitoring and Soft Landings procedures concluded the case study analysis, and demonstrated the benefits of collecting follow-up data, clearly providing positive information for use on future UK Passivhaus projects.

The majority of parties involved with the Camden project had never worked on a Passivhaus building before, but importantly they acknowledged the process as a learning experience, and allowed themselves additional time throughout the course of the build to develop their techniques and understanding of Passivhaus. The education gained as the project progressed became instrumental towards its successful completion. The teams involved went on to use these experiences to refine their approach to Passivhaus construction in the UK. Bere alone have subsequently produced housing prototypes for an architectural study in Wales.

"With the Welsh Social Housing prototypes, we were just trying to keep the costs down, very simple buildings, optimally orientated… using smaller timber sections and so on. Then that was ideal for working with a UK manufacturer." (Bere,2014)

Whilst the economic cost accompanying a Passivhaus and it's impact on the UK market cannot be accurately measured due to the relatively small scope of completed projects. It is clear the increased costs of a UK Passivhaus are in part due to the need for imported materials and labour, as well as the construction industries current inexperience with the standard. With both of these concerns set to improve, as represented in Bere:architects Housing Prototypes, the feasibility of producing a Passivhaus in the UK should only increase.

All three of the professionals interviewed showed an optimism for the standards future. They all agreed that the UK is currently behind countries such as Germany and Austria in implementing Passivhaus technically and economically but is fully capable of producing a Passivhaus of equal quality, as demonstrated in Camden. When asked about their thoughts on the challenges ahead for UK Passivhaus adoption, the professionals expressed comparable responses but with distinctive inflections ranging from optimistic to cynical. The main concern echoed throughout this case study was the current shortage of UK Passivhaus suppliers and skilled workers, as well as a growing concern over the number of 'Passivhaus designers' in the market with insufficient knowledge or respect for the standard. Dominic Danner went further and warned of the standard becoming compromised, due to the UK construction industry being deeply influenced by speed and cost rather than quality, going on to propose 'Passivhaus is not in a bubble'.

Currently the UK Passivhaus market appears to show a steady increase in its levels of knowledge and construction, with a number of people dedicated to the standard and capable of producing a certified Passivhaus. Not only demonstrating proficiency with the tools necessary, but an ability to understand and advance Passivhaus principals to achieve a sophisticated architectural design. Critically, the construction industry would benefit from a more appreciative view of building standards, dedication to further training and respect for quality in balance with their concerns of project cost. A mindfulness of Passivhaus in certification only or 'Paper Passivhaus' should be understood. As the developer led UK market begins to grasp hold of the Passivhaus standard, the temptation will be to compromise the exacting requirements established in Germany. If Passivhaus is to thrive in the UK with it's original standards intact, then a commitment to the high quality in projects like Camden should become the rule and not the exception.

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Author Information

Tim Waterson comes from Colchester in Essex and is in his final year of Post-graduate study at the University of Kent, completeing a Masters in Architecture with the intention of becoming a qualified architect

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Denby Dale

Sam Ashdown

Location Denby Dale, West Yorkshire
Building Type Single family house
Construction Type Cavity Wall
Floor area 104.45m^2
Completed Summer 2010
Year Certified December 2010
Overall Cost £141 000 Basic build cost

Client Geoff & Kate Tunstall
Lead Consultant Green Building Store
Architects Derrie O'Sullivan
Main contractors Green Building Company
Council West Yorkshire County Council
Certifier Peter Warm, WARM Associates
Consultants and Collaborators (University department, specialist supplier or contractors, with role in brackets e.g. (airtightness specialist)
Funding sources Client funded

Abstract

Denby Dale house was completed in 2010 for the Yorkshire couple Geoff and Kate Tunstall as a retirement home (Butcher, 2009). The client was willing and actively seeking a low energy design that they saw as a 'common sense' (Tunstall, 2009) option to reduce their carbon emission and therefore their household bills, they were consequently guided to the German Passivhaus route by project Leader Green Building Stores' Bill Butcher who worked closely with project Architect Derrie O'Sullivan. What makes this project particularly interesting is that it was the first Passivhaus in the UK to use cavity wall construction.

The core themes to my chapter project will be to investigate, through this case study, the technical challenges of using cavity wall construction, looking into both the positives and negatives and costs compared to other forms of Passivhaus standard constructions systems. This study will ultimately try to establish whether or not cavity wall is a short or even medium term solution for the British building industry to start building more Passivhaus standard buildings or should it be recognised in its own right as a legitimate method of Passivhaus standard construction.

'Interrogating the technical, economic and cultural challenges of delivering the Passivhaus standard in the UK'- Denby Dale Case Study

-Through the detailed study of Denby Dale Passivhaus, located in Denby Dale, West Yorkshire, special attention will be made to the design team organisation, the design and construction phase of the project and analysis of the post occupancy performance.

What makes this a particularly interesting case study is that it was the first Passivhaus the design team had attempted, but the first certified Passivhaus in the UK to be built using cavity wall construction. As the most widely adopted approach by the UK building industry, could using this construction system become the catalyst for Passivhaus buildings to be constructed in the UK? Denby Dale highlighted a number of difficulties with adapting the cavity wall detail to Passivhaus standard and wider concerns to do with implementing Passivhaus within the UK.

The design team structure of this project has become a specific area of investigation, which includes the team organisation, roles of responsibility and the procurement route and contracts that were in place for this project. As with many Passivhaus projects, an interdisciplinary, collaborative approach was implemented at Denby Dale for a number of technical and also practical reasons and this often highlights the limitation of procurements and the RIBA work stages in regards to integrated design and collaborative/cross-disciplinary approaches (Butcher, 2013). An investigation of architect Derrie O'Sullivan's role within the project becomes a specific area of examination within this dissertation in order to scrutinize his relationship with the lead consultant, GBS's Bill Butcher. This became necessary in order to understand the roles of responsibility and the contractual systems in place at Denby Dale to be able to answer whether or not traditional team hierarchy still have a place within Passivhaus construction projects in the UK, for example, can there be one lead consultant, traditionally the architect, or does building to Passivhaus standard mean a much more collaborative approach needs to be embraced?

The nature of the construction industry will also be considered in terms of how the "notoriously slow" (Butcher, 2013) acceptance of change can be overcome and the importance of education for all team members of the design principles of Passivhaus and how its practical application can be accomplished. A detailed study of the role of the Passivhaus Planning Package (referred to as PHPP) will also be undertaken, as this was the first time all members of the design team had used the software, it is important to investigate how it may have influenced the overall design of Denby Dale. This will highlight any compromises that had to be accepted by the client and also for the design team with an over reaching ambition to understand the role PHPP within Passivhaus design, especially within the UK.

Design team organisation

From the initial secondary research, it became apparent that Denby Dale, like many Passivhaus projects within the UK does not follow the traditional procurement method. Within the UK there are three main procurement options, traditional procurement, design and build and management procurement. The traditional method has been standard practise for 150 years within the building industry, and its foremost feature is the separation of the design process from the construction process. Design and build is a system whereby the contractor is responsible for the design and construction of a project in return for a lump sum price with variations of options depending on the level of client's requirements. The management procurement route is where the overall design is the responsibility of the client's various consultants and the contractor has the responsibility of defining the work packages and then managing their implementation through a series of separate trades or works contracts. (JCT, 2011). For a project such as Denby Dale, the tradition contract would most commonly be used; an architect would produce all the information the contractor would need to build the structure. However, because Deny Dale had ambitions of becoming a Passivhaus from the outset which was not a 'traditional' performance standard that both designers and contractors aimed at achieving within the UK at the time, the procurement route had some key differences to the traditional contract route. Denby Dale's lead consultant was GBS, an interdisciplinary firm that have a track record of designing, building and retro-fitting with an in-house mentality of conceiving, designing, detailing and building all under one roof, and the architect, Derrie O'Sullivan, was brought on board by GBS to aid the design process. This shift in lead role of the architect to shared, collaborative responsibility developed into a core theme of research of this chapter, so to understand whether or not this is a more common trend with Passivhaus projects, and if so what are the wider impacts for the implantation of more Passivhaus projects in the UK.

The procurement route that takes place in central Europe is different to what we find in the UK, the model tends to be an architect will have partnerships with builders, suppliers that he will have formed strong working relationships with and a package will be presented to the client. Often the architect will be able to show to the client evidence of past work to give them security (Butcher, 2013). However, as with all methods it does have its strengths and weakness, a common issue with the European model is that it will frequently take a longer time for a building to commence on site; the planning work stages require more input. However, this is too some degree offset by the speed at which the building is constructed because of the collaborative effort from architect through to the construction team (Butcher, 2013). When considering using this method for a Passivhaus development project in the UK, Bill Butcher describes how this approach doesn't normally take place with the types of procurement routes the UK is accustom to using and that "Passivhaus can't be done in the usual hierarchical way" (Butcher, 2013). He also goes on to explain that tendering process for Passivhaus in this country at the moment can also not be done in the usual way as there is very few who are willing to take the 'risk' of constructing Passivhaus because it is about 'comfort zones' and being able to provide the client security that they will get value for money or a strong cost certainty. In relation to Denby Dale, this situation was slightly different because the client's brother is a quantity surveyor which gave the clients the security that they needed.

As mentioned previously, this was the first Passive house GBS had designed and built, so it became a big turning point with the company as well. Bill Butcher explains,

"We come from a construction background and our construction side is only say 5-7% of our turnover. Most of what we do now is, for the last twenty years is windows and doors, and nowadays MVHR design and supply. Doing these innovative type buildings, including retro-fits and now we are on with another new builds [is new for us]… so things have changed very quickly for us within four years".

Because this Passivhaus project was a big learning process for a lot of the design team, it is worth mentioning that it was also a learning moment for the local building control. This meant that much of the design work had to take a "collective approach" (Butcher, 2013) so that the designers and builders were all learning about Passivhaus sitting around the same table. This heightens the argument that the traditional procurement routes make it difficult to do this and that inter-disciplinary practices are better suited for the job until Passivhaus because more main stream and widely accepted by the UK building industry which is "notoriously conservative" (Butcher, 2013). Moreover, Green Building Store has its own construction arm which meant they reduced the number of sub-contractors they had to employ. This is a similar business structure that a number of companies offering Passivhaus or sustainable design have developed around in recent years. Interdisciplinary companies offer clients a complete package from design through to construction which avoids the problems with contractors who are either not educated about the Passivhaus standard or not willing to comply with the high levels of quality needed to achieve the criteria.

With regards to the particular procurement of Denby Dale, a contract was signed between GBS and the client and the architect Derrie O'Sullivan signed a separate contract with the client as an architect "but only as an advisory role, rather than a lead role" (Butcher, 2013).The contract that was in place for Derrie O'Sullivan was a JCT homeowner contract because the client did not want the pay for the services of an architect as the contract administrator. O'Sullivan accepts that was not a problem for him but in effect he acted as the contract administrator because he was available to oversee the project throughout all its stages and he was responsible for signing the certificate off at the end of the project.

Bill Butcher emphasises that he was lead consultant and Derrie O'Sullivan admits that he was willing to reduce the architect's role, seeing this as a personal strength and possible weakness in doing so, to work toward overall smooth completion of the project. This collaborative approach, which can use different organisations, can often form a blurred boundary between responsibilities and Derrie O'Sullivan explains that often a tussle with GBS would take place when discussing whose idea different elements originally where. The success of the Denby Dale project with this in mind can be attributed to the fact that GBS has strong working relationships with its employees; the construction side of the business is formed from many members that Bill Butcher has known since childhood so this would have an impact on the nature of workmanship and collaborative input to the project. From the interview with Bill Butcher it was understood that the architect's role was completing planning and building control drawings and GBS where responsible for the detailed drawings. However, it was unclear to what extent O'Sullivan had design input to Denby Dale so this was an area the interview with O'Sullivan was re-structured to answer. The architect explains that it was in fact done in a 'traditional' way whereby he would produce sketch designs for the client and these would go to and throw until a solution was achieved. However, he was keen to stress that it was always a three way conversation with GBS and this is where it shifts from a traditional process slightly, the technical design had to be present from the beginning because in order to achieve Passivhaus this had to be a consideration from the outset, he describes it as "and a true blurring of the roles" (O'Sullivan, 2014).

There is a wider contextual situation that the non-tradition procurement route Denby Dale has adopted can be aligned to, which is the wider concern about the Part L: Conservation of Fuel Power changes that came into force in April, 2006. These changes meant that any new build or refurbishment had to comply with 'Target Carbon Emission Rates', though not the same criteria as Passivhaus standard, but a similar systems of monitoring and predicting buildings performance during the design stages does have comparisons. Questions have been raised as to the impact these changes have had on the procurement methods and the overall impact on both the design and construction teams. The fact that these Part L changes differ from any previous regulations has meant that the 'tradition method', which suggests a design should be in theory completed before any contractor involvement has become less convenient because a more collaborative approach would be far more beneficial when designing environmentally sensitive buildings (Hamza, 2009). Another consideration of Part L is how energy performance parameters are determined which use the Standard Assessment Procedure (SAP) within the Code for Sustainable

Figure 01 : Denby Dale solar space

Homes (CSH) which has been a requirement since 1995. It's most recent iteration coming into force in October 2010 and uses the SAP calculations to predict the energy used for heating, hot water and lighting and scores results within a banding or rating system from A to G. Though the rating incorporates a variety of inputs and checks compliance of other Building Regulation requirements, it's most noteworthy for predicting carbon dioxide emissions. The predicted running costs are reflected through the Environmental Impact Rating and the predicted running costs are established from the Energy Efficiency Rating. The system uses a Target Emissions Rate (TER) based the emissions performance of a notional dwelling built in 2006 but less 25% (conditional on the fuel used which was implemented after government wanted compliant buildings to be 25% more efficient than a compliant buildings of 2006) compared with a Dwelling Emissions Rate (DER). Both measure the performance in CO^2kg/m^2.a (kilograms of CO^2 per square metre of internal floor space per annum).

Passivhaus uses its own system of performance prediction called the Passive House Planning Package (PHPP) which is a piece of software developed by the Passivhaus Institute and used by architects and Passivhaus designers to forecast its real world performance (Cotterell & Dadeby, 2012). Once an initial design has been formalised, it must be modelled and subsequently verified by PHPP and specific regional climatic data (SAP currently requires no site-specific climate data) will be used to make the predictions as accurate as possible. The software contains a number of tools aided at calculating energy balances, comfortable levels of ventilation, U-value calculations, heat and cooling loads, summer comfort calculations and many other features aimed at providing a dependable performance prediction of a Passivhaus building (BRE, 2014). Once this data had been set up in the PHPP, the software is designed to be used iteratively, whereby the designer can make changes to the design and test the effects on the building's energy performance. This process also has the benefit of allowing the design team to trim the building specification down to the desired performance standard which can save thousands of pounds during the design stage by avoiding over-engineering (Cotterell & Dadeby, 2012).

When comparing SAP with PHPP it is interesting how the two systems differ. SAP is in effect comparing the building with itself, whereby the design has to be 25% more efficient than the 2006 Part L compliant dwelling. This suggests that as a designer you are not necessary pushed towards designing a more fundamentally efficient shape, whereas PHPP compares the performance to a fixed energy use target of 15kWh/m^2.a. As a result, the designer aims at executing a more efficient provision of heat loss area to useful floor area by means of better form, orientation and amount of glazing used and its position. SAP and PHPP also employ different measuring rules with regards to fabric measurements of external walls where SAP uses internal dimensions and PHPP external dimensions are used and treated floor areas (TFA) are also measured differently (Cotterell & Dadeby, 2012). In effect the current UK SAP approach has its advantages in terms of being much more forgiving of certain errors but it is simply a tool used to judge compliance whereas PHPP is used to guide the complete design towards a low energy, efficient design (Warm, 2011). When comparing the calculations of the two performance assessment systems we can see that Denby Dale only receives a rating of B for both its SAP energy efficiency rating and environmental impact rating which when you consider the ultra-low energy performance of the building it highlights how this carbon-based assessment does not fully display the impressive energy-based performance of a Passivhaus. However when using PHPP CO_2 emission factors, Denby Dale achieved a reduction of 56% campared to Part L 2010 and its results using SAP emission factors was a 75% decrease (Corran, 2012).

The design process

It appears from the Denby Dale project that there is a certain juggling act between the client's desires, some definitive and others more open to discussion and a set of principles that the designer adopts; ultimately a compromise had to be struck. Based on what they had seen from 'The Long Wood House' which was an earlier project by GBS build on passive principles (although not Passivhaus standard), Geoff and Kate Tunstall knew they wanted a sustainable retirement home and whether that meant the use ground source heat pumps, or photovoltaic panels they had not yet decided at that initial stage. It then became the job of GBS to provide input on what they believed to be the best route for the clients to take. Bill Butcher explains the initial design process the company takes when approached by a new client;

"What happens is when you're a designer or a consultant with experience you automatically design around compactness of form or immediately think about what the building might be as soon as the client walks through the door, it's a different mind-set. So when they come and visit us here, we'll say first of all where is it? Which way is it pointing? What sort of planning restrictions? So things make things easier than others, in other words if you are facing south with no solar shading and there're no planning restrictions on its shape and form you're onto a winner, but quite often it's not like that" (Butcher, 2013).

GBS then adopted this approach and began to advise the client on which route they should take. The use of such renewables the clients where initially thinking about incorporating were said to not be necessary by GBS. They were then advised to take the fabric first approach which is essentially the Passivhaus route though at this point GBS and the client were not fully familiar with the standard. One feature the client was very keen to include at Denby Dale was a double height conservatory in the corner of the building as this was an architectural feature they has seen on many 'sustainable' buildings and would provide them space to grow their fruit and vegetables which is something the clients were very keen on. This lead to the first major compromise for the couple, the initial PHPP results of the conservatory space would not allow the buildings performance to meet the 15 kW/h criteria. This is where the role on PHPP becomes very interesting in the design process of a Passivhaus. As mentioned previously, Denby Dale was a project of firsts and this is also the case for the use of PHPP which was operated by Peter Warm of Warm Associates who was also learning how to use it at the time. As a result it was reported that there was a lot of "toing and froing [and] quite interestingly there were lots of stories about the shape and so forth" (Butcher, 2013). The initial design was for an 'L-shape' form with the mentioned conservatory in one corner. However, after this design was in-putted in the PHPP, Peter Warm came back to both design team and client and said it will not model down to the 15 kW/h that is necessary. This was ultimately because the overall form factor was wrong and the conservatory actually inhibited the g-value of the building which is the solar gains into the house. Having seen many 'sustainable homes' with such conservatories, Geoff and Kate would not compromise on the loss of this solar space. However, in order to achieve Passivhaus certification they eventual had to compromise and the answer was to bring the solar space inside the buildings envelope in the form of substantial south-west facing, double height glazed wall which contains an open plan area of the building with an internal balcony on first floor. This became the couple's compromise as a consequence of the PHPP results and "Passivhaus was able to deal with it just" (Butcher, 2013).

The fact that this was the first time using PHPP and the first time the design team were learning about it, and trying to reach Passivhaus performance standards, it ultimately meant a much longer lead time to previous non-Passivhaus projects the firm had completed. Since Denby Dale, the company perform the PHPP calculations in-house and have now fine-tuned their application to it and as more Passivhaus' become designed this process will become more efficient. This allows GBS to speed up the process and allows them to be much more confident of the final builds performance level, being able to value engineers at an earlier stage to reduce the 'buffers' they allowed for to meet the 15kW/h criteria. GBS admit that they were operating in the dark in terms of using PHPP to begin with at Denby Dale. However, an argument to this new efficiency could be at the cost of replication of designs because company's such as GBS have developed a design that meets Passivhaus standard and therefore it is commercially more viable to duplicate rather than to come up with a completely new design for a different site context.

In order to make sure that the GBS team were all fully aware of the requirements necessary to achieve Passivhaus standard, Bill Butcher gave both the designers and the construction arm of the company a Power-point presentation (which especially the construction workers and never had before) on an introduction to Passivhaus. In addition to the toing and froing of the PHPP, there were many extra drawings that needed to be completed in order to make sure everything thing went as smoothly as possible during the construction phase of the project. This links back to what is found in the European model, where there are longer lead times for the design process, but faster construction times which should allow for fewer unknowns on site with a higher degree of quality control and attention to detail from a well-informed construction team. This in theory is a positive characteristic of a Passivhaus development.

The use of cavity wall construction

So with specific attention to the detailing and construction methods at Denby Dale, why did the design team and the client decide to go down the cavity wall construction system route which in terms of central-European examples is a relative unknown?

The answer to this comes in three key points: the first is that it offers a high thermal mass inside the insulated envelope of the house. This allows for an even internal environment for both acoustic qualities and temperature. The second is the familiarity of cavity wall for both GBS and construction arm of the company and as a result means that local building merchants will stock all the necessary materials needed for the project with minimal specialist materials. The third point is the constraints that West Yorkshire Council planning depart requirement for natural Yorkshire stone façades on new buildings. The options considered by the team with this in mind were solid block, polystyrene insulation stuck to the outside and then stone slips applied as the finishing face or a timber frame with an outer bracing of stone work. The reason behind their choice to use cavity wall was decided upon because at that particular time it was seen to be the cheapest option and most easily achievable at the time. Also GBS had to factor in the knowledge they had gained from past projects such as 'The Long Wood House' which used cavity walls and how they could adapt Denby Dale's details accordingly to achieve Passivhaus standard. For example, they became aware of problems of intermediate timber floors into the masonry of the structure in terms of cold bridging at 'The Long Wood House', so the detail for Denby Dale was altered so that they were hung from the wall plate with render behind so that the air tightness layer was not compromised (apart from the bolts that held the timbers in place) (Butcher, 2013). Having already had this base of knowledge and using it to adapt to Passivhaus standard is personified by Bill Butchers description of the project, “The whole philosophy of Denby Dale was that it was as simple as possible, and using vernacular materials from literally the builders merchants around the about here in Huddersfield…[simplicity] is about cost and robustness really and that is what has attracted a lot of people to Denby Dale” (Butcher, 2013).

However, this isn’t to say that cavity wall is without its inherent problems. One of the biggest issues is achieving the 0.6 air changes per hour through leakage which unlike timber frame construction relies on lining walls with vapour barriers and can be tested early for seepages that can be patched up with relative ease. Cavity wall relies on wet plaster that can only be tested at a late stage and is far harder to fix (Butcher, 2009). Achieving a high level of air tightness through plaster massively depends on the quality of workmanship and also on the external walls when considering the need for electrical wiring chased into the block work (Elton, 2011).

Andrew Yeat of EcoArc is part of a design team for a 40-unit Lancaster Passivhaus Co-housing project. For this project, he had asked the contractor to provide quotations for seven different construction methods and to compare them for theoretical cost, buildabilty, programme and easy of construction. The contractor found that although a timber frame would have brought the programme forward by as much as 10 weeks over cavity wall due to the fast construction of the prefabricated elements on site, this method was found to be over £80 000 more expensive and would also mean that the contractor would have to out-source specialist help which contributes to the extra cost. Because cavity wall is the most dominate technique in the UK, the contractor can also provide the highest cost certainty compared to any other method, however, the Passivhaus consultant on the project found cavity wall to be the least favourable to achieve the standard for many of the technical reasons above (Elton, 2011).

Denby Dale’s cavity walls use high thermal mass concrete blocks for the inside skin of the house and three layers of 100mm Dri-Therm fiberglass insulation is positioned into the cavity with the external skin being formed with 100mm natural stone. The traditional stainless steel wall ties that would normally be used for a cavity wall could not be used at Denby Dale. When WARM associates conducted the Passivhaus Planning Package (PHPP) calculations for the traditional ties it highlighted a potential thermal bridge problem that could cause cold spots in the plaster. So instead they used Teplo ties that are made from resin and basalt. These ties give a very low reading for heat transfer in the PHPP, but the difficultly the contractor experienced was that they are rigid and therefore it became extremely important the two block work walls line up as they are built. This requires extra care from the builders on site and this inevitably has an impact on the build programme as every two courses of concrete block on the internal side had to match perfectly to three courses of stone on the external side. The below ground the cavity encases a more structural stable polystyrene solid closed-cell insulation. If there were to be any movement then this is expected to provide more support than Dri-Therm and if any ground water were to enter the cavity then this material should not have as dramatic effect on thermal conductivity (Butcher, 2009).

Figure 02: Denby Dale cavity wall detail

Figure 03: Denby Dale external facade

However, since this initially detail was written about in 2009, the detail has proven to not work quite as well as first predicted, as Bill Butcher explains,

"We hadn't realised how badly moisture affects lightweight blocks below ground…the actual polystyrene we used at Denby Dale in the cavity down to footing level also wasn't as robust to moisture as we had originally thought in theory… so we are [now] using an extruded polystyrene in that situation, and then on the thresholds at Denby Dale you will see that we used a fibreglass box section filled with polyurethane bolted onto the side of the slab as a thermal brake to the threshold. Now have another material that's called compact foam which simplifies that situation."

Extra attention was paid to the detailed design around the doors and windows and Green Building Store's technical leader Chris Herring spent time going through all the different permutations different designs would have in the PHPP software for cavity wall construction. The house uses Ecopassiv timber windows, these triple glazed units were positioned halfway between the insulation layers to improve performance and minimise thermal bridging. In order to provide structural support to the windows that are sat within the insulation, plywood boxes in which the window will sit was constructed on site and also improved the ease of achieving the required air tightness by using 'Pro Clima' tape which will permanently seal the gap between the window and the plywood. Another disadvantage of the cavity wall detail is the effect on the overall building footprint. This detail results in the external envelop being over 500mm thick which reduces the internal floor area for the occupants.

For many of the reasons highlighted, cavity wall appears to have a serious role to play within the UK in terms of more Passivhaus' being build. Both GBS and Derrie O'Sullivan have gone on to design and build passive designed cavity walled buildings since Denby Dale, while continuing to adapt and refine detailing learnt from Denby Dale. When asked how influential do they feel cavity wall construction can be on Passivhaus in the UK, O'Sullivan fully expected to see between 50-100 certified cavity wall Passivhaus because "that's what builders do, it's what they are good at, they know what to do" (O'Sullivan, 2014) and once taught about the ways of achieve the air tightness value, it could become a dominate force if the required level of workmanship is met.

Conclusion

When analysing the merit of Denby Dale, it is important to take into consideration the successfulness of the building as a home for its clients, once initial teething problems had been overcome, the building passes this fundamental function as Kate Tunstall describes,

> "We are very happy with our home and wouldn't want to ever live in a non-Passivhaus now. You can sum Passivhaus up in three words: cost-effective, comfortable and sustainable. There isn't anything about the house that we'd change. The whole thing has been a victory for common sense" (Tunstall, 2013).

In terms of Denby Dale's cavity wall construction system and its ability to act as a catalyst for bridging the divide between Passivhaus and the UK construction industry, analysis of the evidence suggests that it does have a strong future for Passivhaus construction within the UK. Both GBS and architect Derrie O'Sullivan have gone on to develop new passive designed dwelling using this system (though not all to Passivhaus standard for various reasons). To the discerning self-builder looking to develop a Passivhaus in the UK with local building firms, cavity wall offers the best solution, given the established knowledge base, control over procurement and material selection. In relation to a larger scale project scenario, a tendency to lean towards pre-panelled systems, found more commonly on the continent may be preferable. So in essence the choice of system has to be assessed on a project by project basis, there is no single solution for delivering low energy buildings in the UK, but Denby Dale proves to be a viable, working model of the cavity wall system with no more flaws than any other construction system and it can have a big impact for Passivhaus within the UK.

The argument to whether or not PHPP has had a negative impact on the aesthetic interest of designs is not conclusively answered when using Denby Dale as a case study. We have to take into consideration that Denby Dale was the first time the project team had designed to Passivhaus standards, and on a restricted site, the Passivhaus 'box' solution that has a stigma attached to Passivhaus, was a workable answer to achieving PHPP certification on this site. The PHPP did cause one particular impact of the overall look of the building which was the planned glass conservatory that the clients were originally so keen on. This had to be absorbed into the building envelope and substantially reduced in size and North facing windows also had to be reduced. The ambition of the project from the outset was to build a home that would sit within its Yorkshire village context, not a contemporary architectural extravagancy, and with this in mind it is unfair to say PHPP had any dramatic impact on its design, rather it allowed for various subtle changes in both design and detail. I feel that even if the client had not been interested in achieving Passivhaus standard then the overall appearance of the building would not be too dissimilar from what we see today. When considering the impact of PHPP on design in the UK within the wider context, the argument that it is stifling creative and inspirational architecture is unfounded. Energy performance is now another constraint architects have to allow for and PHPP should be seen as a valuable tool for testing design options. The very nature of Passivhaus being a performance standard means that an infinite variety of designs can be implemented if they achieve the performance criteria, this should ultimately stimulate creativity and innovation.

The whole ethos behind Denby Dale was simple is best and for a keen eye for quality and also to show that Passivhaus standard can be achieved from materials sourced from the local builder merchant and using= local construction firms. This in my opinion is a noble ambition, which benefits both local business and economies while providing a working model of delivering super-sustainable homes (whether to Passivhaus standards or not) with relative easy, and ultimately producing homes that should aid the effort toward meeting future carbon emissions targets government has set in place.

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Image Index

Front Cover: http://www.greenbuildnews.co.uk/images/img/articles/297_198/Articles_774_3_1360838576.jpg

Figure 01: Lee Garland

Figure 02: http://www.greenbuildingstore.co.uk/

Figure 03: Source: http://www.greenbuildingstore.co.uk/

Underhill House

Jessica Ringrose

Location Moreton-in-Marsh, Gloucestershire
Building Type Detached family house
Construction Type Poured and pre cast concrete
Floor area 375m^2
Completed 2010
Year Certified 2009
Overall Cost £575,000

Client Seymour-Smith
Architects Seymour-Smith Architects
Main contractors Various
Council Stratford-Upon-Avon
Certifier Scottish Passivhaus Trust

Abstract

This comprehensive and in depth study aims to explore the challenges associated with delivering a dwelling to the Passivhaus standard in the UK. It will do this through one primary case study, Underhill House. Investigating one central case study will allow this study to be rigorous and detailed. This report focuses on three areas; each will address a different phase of implementing Passivhaus in Underhill House. The first part will introduce the case study and explore the initial stages of design, by doing this it will aim to determine why and at what stage Passivhaus principles were adopted in the project. In order to establish what effect Passivhaus had on the final built outcome it will define and analyse the main influences on the design and specification, whether these be sustainability, planning, economic, aesthetic or cultural. This study will then seek to address the procurement and construction phase. It aims to establish the reasoning behind the construction and material choices, how and why specific techniques were used and where the main influences came from. The final section will focus on investigating if living in a Passivhaus is in line with British culture, expectations and habit. The finding of all sections will be used to evaluate any issues faced regarding Passivhaus and its adaption to Britain as this is key to forming conclusions about whether Passivhaus could be an option for improving Britain's future housing stock.

Interrogating the implications of Passivhaus in the UK through one primary case study, Underhill House.

Underhill House is England's first certified Passivhaus, completed in 2010 it was designed by Helen and Chris Seymour-Smith of Seymour-Smith Architects for them and their family. Covering 375m2 and costing £575,000 this project is of a bold, minimalistic style that is clearly displayed in the dwellings aesthetics and layout. The house pivots around a central open plan living/dining/kitchen space, with two wings containing four bedrooms, two studies, a snug, a family bathroom, garage and several utility rooms extending in an 'L' shape.

This project is remarkable not only in its design and sustainability credentials but in the fact that it exists in the first place. Located in an isolated spot deep in the hills of the Cotswolds Area of Outstanding Natural Beauty, the chances of gaining planning permission for a building on this site were slim. This coupled with a local Housing Moratorium and the presence of a three hundred year old barn made the possibility of building almost entirely unfeasible. This is where the Passivhaus standard becomes important. In order to understand how the standard was implemented later in the project it is necessary to establish why and at what point it was chosen in the first place.

It is possible that Passivhaus was selected early in the feasibility process in order to gain planning permission. Due to her expert knowledge as an architect focusing on difficult planning permissions Helen was able to exploit a little known clause in planning policy, PPS7 paragraph 11 (now NPPF para.55) (Seymour-Smith Architects, 2013) (Office of the Deputy Prime Minister. 2004: Para.11).

This clause is addressed on page seven of the Design and Access Statement submitted by Seymour-Smith Architects with their successful 2007 planning application. They state that 'the substantial benefits to the environment mentioned above are clearly provided by our 'Zero Carbon' scheme, … , it will be an exemplar Eco house'. This is reiterated in an interview with Helen and Chris in the Channel Four, Grand Designs episode that focuses on their project. Helen answers the presenters question 'How did you swing it?' referring to how they gained planning permission with 'I suspect it was partly the design, … , and partly as we are going to design this as a Passivhaus' (Talkback Thames, 2010: 2.58). In this statement Helen clearly acknowledges the role adopting Passivhaus had in gaining planning permission. This is backed up by the fact that several other 'Eco homes' such as Richard Hawkes Crossways Passivhaus in Kent, have been built under the PPS7 planning policy since Underhill house (Hawks, Richard, 2014).

If Helen and Chris did choose to design to Passivhaus standards in order to gain planning permission, it proved to be successful. When first coming up for planning in June 2007, the local Parish Councillors supported the application 11 votes to nil. Their statement was as follows:' 'Imaginative project'; 'clever design' underground; 'totally eco-friendly and will leave no carbon footprint''. Applicants visited locals to explain project in detail. 'Extremely exciting and forward looking' (Stratford-Upon-Avon, 2007).

Chris believes that the councillors were keen to be seen as forward thinking at a time when Zero Carbon was all the buzz. However, due to its contentious location, support from the Parish Council was not enough to grant permission. Underhill house was refereed to Stratford–upon-Avon District Councils Planning and Regulation committee who recommended it for refusal. The planners fought vigorously against the project. Chris made it clear that the planners did not help during the application process as they were convinced the project would not go ahead. This was challenging for Chris and Helen as they were unable to have a pre planning meeting to discuss potential designs. Interestingly, once the house was built, the local planners asked to bring a group of their students to visit the project in order to see an excellent example of a new dwelling. Since then Helen and Chris have seen a positive change in how their local planners at Stratford- upon- Avon approach advising applicants on new sustainable projects.

Although the above analysis clearly shows the influence Passivhaus had on the proposals planning application, it is not fair to say this was the sole reason for Helen and Chris' decision to build to Passivhaus standards. When interviewing Chris, his enthusiasm for innovative design was overwhelming. It is clear that they harbour a passion for sustainable design and given the opportunity wanted to try to improve on current UK examples. Chris explained that having had previous experience designing and building to standards such as the Code for Sustainable Homes, BREEM and LEED, he no longer believed that these produced houses that were truly 'sustainable'. He said, 'what we wanted to do was actually develop a house that would have a reduced carbon footprint, as 80% of the energy used in the house is in the lifecycle of it, … , we wanted to build something that would almost remove the energy cost'. It was Helen who had heard about the Passivhaus movement in Germany. Upon deciding to aim for the Passivhaus standard Helen and Chris visited a series of Passivhaus' in Freiburg, Germany. It was here they got their first hands on experience; they say 'It was interesting that our preconceived ideas of a Passivhaus, were not true.' A simple example of this is their assumption that a Passivhaus would require a lobby. However, this was not necessary. They were able to take direct influence from their experience in Germany and apply it to their project in the UK.

The most notable of the project's design features is that it is completely buried. The reasoning for this seems to come directly from the planning requirements. Several planning applications had been put forward for the site previously; all were refused. On page 5 of Underhill Houses' D&A Statement the councils' justification for the previous refusal is, 'The council consider the proposed development to have a detrimental effect upon the Cotswolds ANOB, by intensifying domestic activities, introducing domestic paraphernalia and car parking, …,' To combat this Helen states that 'by incorporating a sunken house and garage attached to the office, all car parking and other 'domestic paraphernalia'' will be kept from view'. Chris confirmed that they used the previous refused applications in order to optimise their design, he states 'We took their reasons for refusal and designed out those in our scheme'. Particularly citing, 'We put the house underground for planning and to negate the previous objections of residential building on the hill side.'. This shows that satisfying the difficult planning situation was paramount to the decision to situate the building underground, not to do with achieving Passivhaus standard.

When asked about the challenges of designing an underground Passivhaus, Chris said he felt it had little effect on their ability to achieve the standard, but burying a building, typically referred to as 'earth sheltering', is a well-established principle for Eco Homes. In Borasis' *'Sorry out of Gas: Architectures response to the 1973 oil crisis'* there is a chapter on the use of earth sheltered housing to reduce energy consumption. Borasi describes earth sheltering as 'insulating the house by pulling the earth around it like a blanket' it goes on to state that the added mass of earth slows down the temperature variations within the house (Borasi, 2009:137). Interestingly, a short section cut through Underhill House, proves to be almost identical to a theoretical section draw to explain earth sheltered housing in 1985 (Fig 1). This lets us speculate that although the building may be primarily buried to satisfy planning requirements, it also conforms to an existing principle that is known to enhance the thermal performance of a building.

The aesthetics and form of the building are highly influenced by its location underground. Chris and Helen visited several underground Eco- Homes in England whilst designing Underhill House, but they described them primarily as dark and dingy, 'like a hobbit hole'. Influenced by this experience, they were determined to bring the 'Italian catwalk to Eco houses'. They aimed to 'design out the stereotypical view of an underground house that would put off your average Brit'. Key to designing out this view is natural light.

By submerging the dwelling, the options for form become significantly reduced. Ensuring natural daylight reaches into the underground space becomes the primary design consideration. This is especially critical when aiming for Passivhaus standards as solar gain is the main form of space heating. Passivhaus principles clearly state preferred glazing ratios and positions. Ideally in the Northern Hemisphere the majority of glazing in the building would face south, with limited windows to the north, east and west (Passivhaus Trust, 2012). Underhill House conforms to this exactly. Due to the lack of surrounding buildings the dwelling could be orientated directly south. With all of the glazing on this side, the house capitalises on the solar gain available (Fig 2). In a typical square house, locating all of the glazing to one side like this enhances the issue of ensuring light reaches the back of the building. In Underhill House this problem has been solved in two ways. Firstly, the form of the building has become elongated. This allows the floor plan to be narrower; reducing the distance light has to travel from the glazing to the rear wall. The second solution involves the layout of the rooms inside the dwelling. Rooms such as bedrooms and living spaces have been located to the south of the building in order to benefit from the direct day light, whilst those that require less light/heat such as bathrooms are positioned to the north (Fig 3).

Of these two solutions, one is completely in accordance with Passivhaus principles whilst the other seems to defy them. The *'Passivhaus Primer'* published by the Passivhaus Trust in 2012 clearly states that:
'Habitable rooms such as living rooms, dining rooms, bedrooms would ideally be positioned on the south façade, where the larger windows will provide a good daylight factor' (Passivhaus Trust 2012:6)

Therefore, the location of the rooms in Underhill House described above is optimal in terms of what is suggested by the Trust. However, the first solution, adopting a long thin form appears to go against Passivhaus principles. The Passivhaus Trust has identified that a Form Factor equal to or less than 3 is beneficial for reducing heat losses through the exterior surfaces. The Form Factor is the total external surface area (A) internal treated floor area (TFA), A/TFA (Fig 4).

This proves that one of the most common misconceptions of the Passivhaus standard- that it limits the freedom of design is not true (Paulsen, 2013). Seymour-Smith Architects were able to work within the difficult planning constraints imposed by the council and the extremely high quality standards required to reach Passivhaus

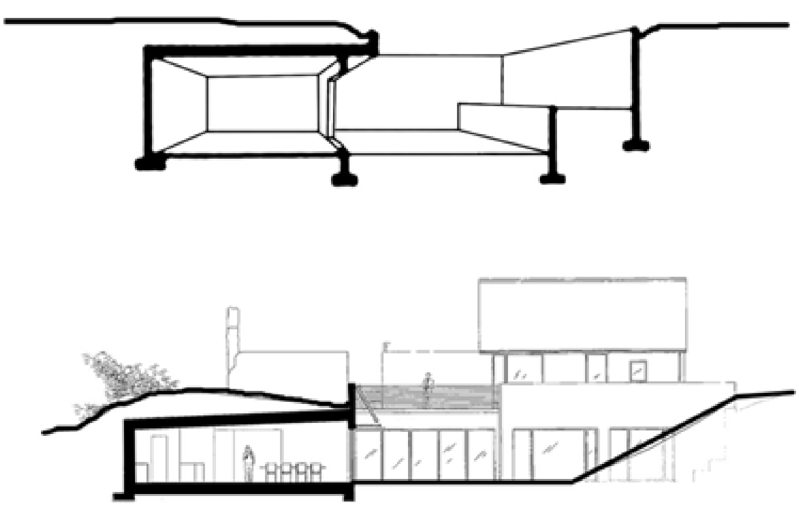

Figure 01: Theoretical section through an Earth Sheltered home 1985 (Top) Actual Section through Underhill House.

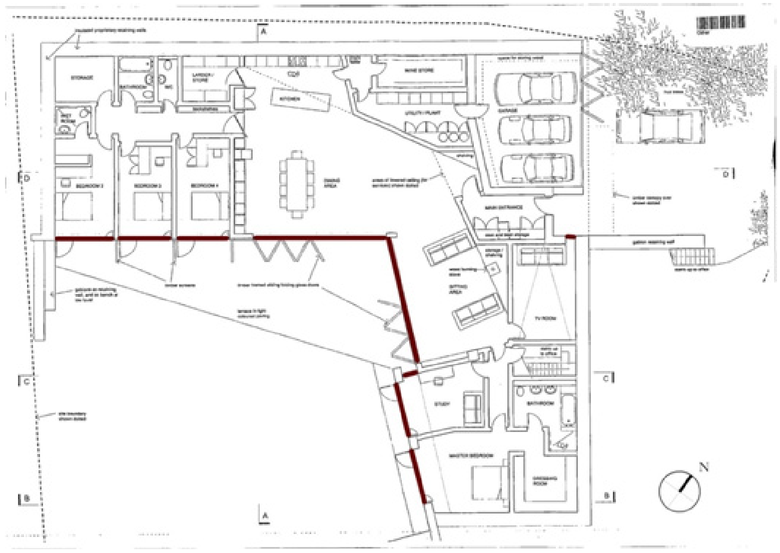

Figure 02: The areas of glazing in Underhill house are indicated in red. Primarily they face south.

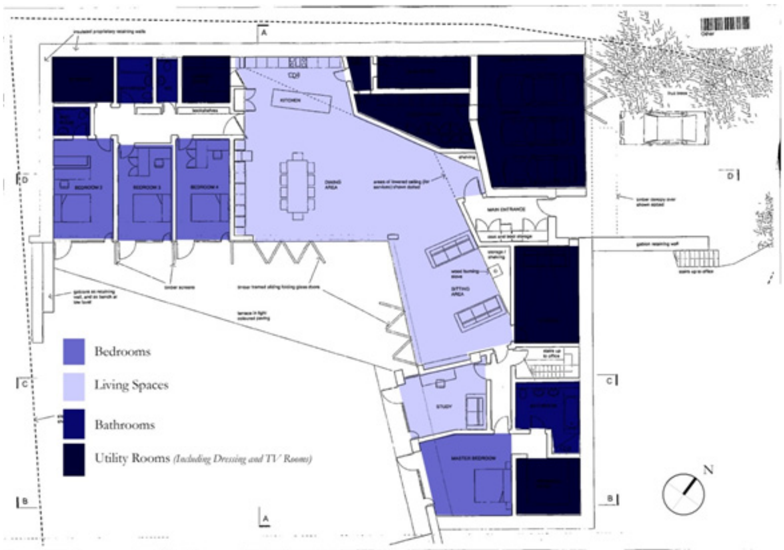

Figure 03: Internal room layout- spaces are situated depending on their day light requirements.

targets whilst still expressing individuality and design freedom. This is confirmed in a recent report published by the NHBC foundation *'Lessons from Germanys Passivhaus experience'* (2012) where it states that when done competently a Passivhaus should be able to meet almost any aesthetic requirements- such as those imposed on Underhill House by planning.

Seymour- Smith Architects have recently proved with the certification of their 2013 project at Eldorado Crescent, that Passivhaus can be achieved under the aesthetic constraints of a British Conservation Area. Eldorado Crescent, the Cotswolds, is a private detached house that responses as sympathetically to its surroundings as Underhill House, with entirely different results. Being surrounded by traditional British homes, red brick and render are used to pick up on the local materials, and the roof pitch, ridge height and overhanging eaves all reflect the design of the surrounding neighbourhood (Passive House DataBase, 2013). Chris is convinced that a good thing about Passivhaus is that it is flexible in terms of construction methods and materials making it possible to achieve a variety of aesthetics. Due to the UK strict planning and conservation rules, this flexibility could be one of the key factors that determine success.

Chris made clear that the choice of concrete for Underhill House was primarily influenced by the challenge of building underground, stating 'we are underground so it's a good idea to have something that is monolithic'. The architects acknowledge that their extensive use of concrete is foreign to the Cotswolds, but insist that it was the most suitable material. They iterate their reasons as a) it is the most practical form of underground construction b) exposed concrete gives a high level of thermal mass, and c) concrete is inherently airtight (Seymour-Smith, 2011).

The floor plate was constructed with poured in-situ concrete over insulation, a waterproofing layer and reinforcement bars (Fig 5). This floor slab was then covered with a 75mm layer of screed as the floor finish, leaving the thermal mass exposed internally. It would have been possible to build the external walls from block work. However, installing block work makes quality control during construction problematic. Issues such as excess mortar in the cavity and ties creating thermal bridges were something Helen and Chris were keen to avoid. Although they toyed with the idea, they decided that option was becoming 'overly complicated'. The answer was to build the walls from pre-cast concrete panels (Fig 6).

Precast panels may seem like an obvious choice because, as Helen and Chris say, they provide the monolithic structure required and there are fewer joins than other construction types (Seymour-Smith, 2009). However, from Aggregate Industries' point of view, projects such as Underhill House are not typical for precast as they are a one off bespoke design. Richard Wilks from AI, the technical advisor involved in Underhill House explained that Underhill required 'a large amount of different sized panels and that every time you make a panel you have to make a mould for it'. Therefore, typically precast panels are only used on jobs where there is a high level of repetition. Richard made clear that a one off house such as Underhill is difficult to do in pre cast and not particularly efficient.

The next considerable construction challenge in Underhill House was how to insulate without covering up the thermal mass. There are three main options when looking to insulate any structure, these are: internal, cavity and external. In Underhill internal insulation would have been possible but this would have covered up the thermal mass of the primary structure and potentially pose problems of thermal bridging at the wall, floor join. As precast panels have no cavity that option was not viable, this leaves a method unusual to British construction, insulating on the external face. This method is particularly crucial to Underhill Houses ability to function well as a Passivhaus as the thermal mass can be exposed internally (Fig 7).

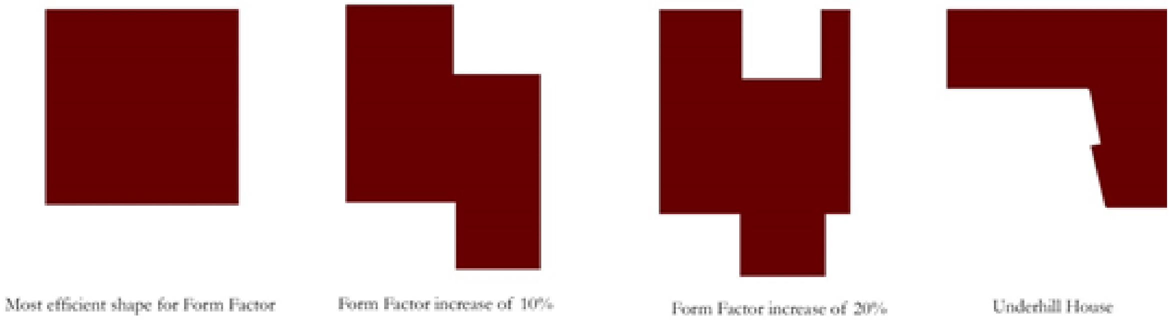

Figure 04: Form Factor analysis

Figures 05: In-situ concrete poured over insulation, waterproofing & reinforcement bars.

Figures 06: Precast concrete panels of Underhill House.

Typical sustainable insulation materials widely available in Britain such as wool, straw and newspaper are primarily used internally, therefore they are not expected to withstand the compression forces or moister that will be prevalent on the external face. It was absolutely essential that a resilient, durable material was chosen for the job as any problems once installed would be near impossible to fix. It is in this situation, one would expect the architects to look to Europe where external insulation is more common. However, they were successful in finding a company, Dow that produces a STYROFOAM™ insulation in Kings Lynn, Norfolk. Specially design to sit underneath a concrete floor slab the material is water resistant, has a high compression strength and a U-value of 0.1 W/m2K, which allows Underhill house to achieve the required Passivhaus insulation standard with 250mm of insulation under the floor slab, 310mm on the walls and 360mm on the roof (Fig 8) (Dow Chemical Company, 2011).

Installing the material on site was relatively simple. 250mm of STYROFOAM™ was laid in two layers of 125mm sheets below the floor slab (Fig 9). By doing it in two layers it as possible to over lay the join, reducing the chances of gaps. The boards were glued and tapes together in the same way as it would be on any scheme, the only difference is the thickness of sheet used. Insulating the walls and roof was carried out in the same way. Chris reported no major issues with installing the insulation, this could be attributed to thorough design in the initial stages and the fact that STYROFOAMTM was installed on Underhill House in the same manor it is used on any project.

Although according to Chris, the construction of Underhill House did not suffer from any skills shortages, the 2013 UK government report entitled *'UK CONSTRUCTION: An economic analysis of the sector'* highlights a lack of skills in the construction industry as a primary cause restricting growth (Department for business innovation and skills). They state, 'The changing nature of the construction market, combined with increasing demand for low carbon and energy efficient construction, means that a skilled and flexible workforce will be vital' (Department for business innovation and skills, 2013). This is particularly relevant for Passivhaus buildings as a higher level of care is needed on site. This has been highlighted in the press as a key issue for the UK adopting Passivhaus.
Whilst the literature suggests that there is a lack of skills in the industry. It is possible that Underhill House managed to avoid this issue due to the large amount of input in the design phase. Chris and Helen aimed to utilise standard technology, implemented in a slightly different way to achieve Passivhaus. This strategic planning, and their decision to use specialist contractors for the main parts of the build, may have prevented any issues with skills.

Once the fabric of the house has been examined, it is important to look at the mechanisms within the dwelling required to heat, cool and ventilate. Underhill house has a Mechanical Ventilation Heat Recovery system (MVHR). A Paul Campus 500DC was chosen, it is a Passivhaus certified unit with 83% efficiency and 0.28Wh/m3 energy consumption (EoinPassive, 2011). The use of a MVHR is standard but Underhill House also has a wood burning stove, unusual for a Passivhaus. There had been some debate about how stoves can be incorporated into a Passivhaus on the AECB forums (AECB, 2013). This is due to the stoves requirement for an air supply, outlined in the building regulations as 'Combustion appliances shall be so installed that there is an adequate supply of air...' (Building Regulations J, 2013). This can be overcome by ensuring that the stove chosen can have a direct external air supply. Underhill House has a Woodfire F12 installed, this particular stove is ideal as there is an external air kit available which supplies the primary and secondary combustion air (Stovesonline, 2014). The Woodfire is also beneficial to Underhill as it has a small output to room 1.2 KW but a large output to heating the hot water 10.8KW (Stovesonline, 2014). This prevents the house from overheating and supplies the residents with reliable hot water.

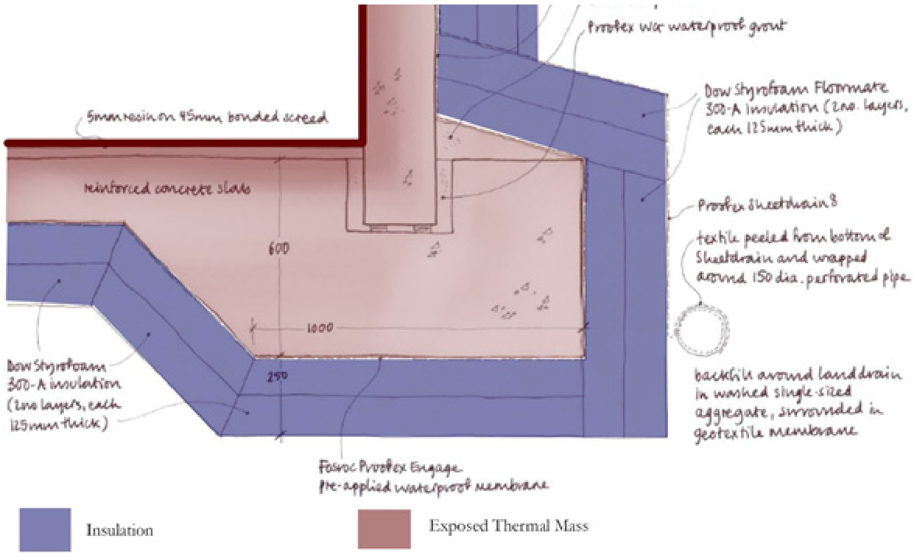

Figure 07: Detail showing thermal mass exposed internally within Underhill House.

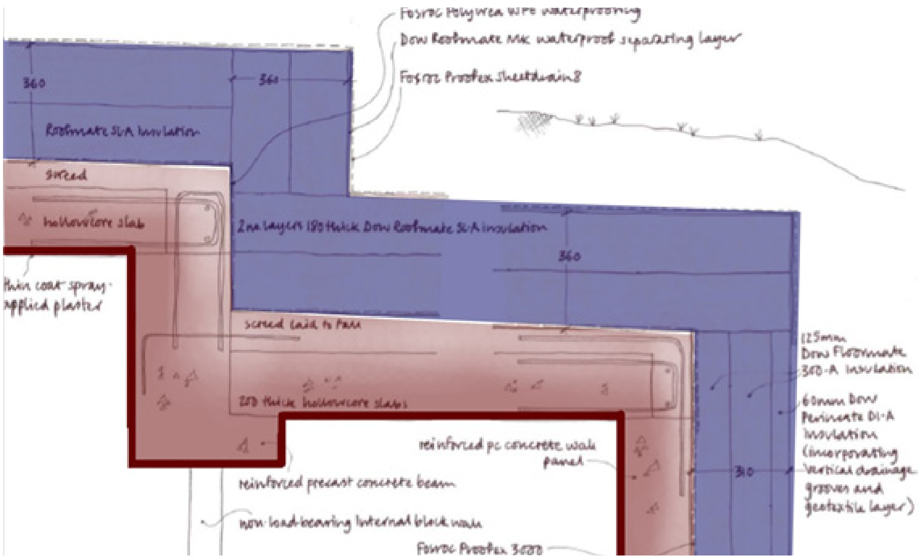

Figure 08: Roof detail illustrating location and thickness of external insulation.

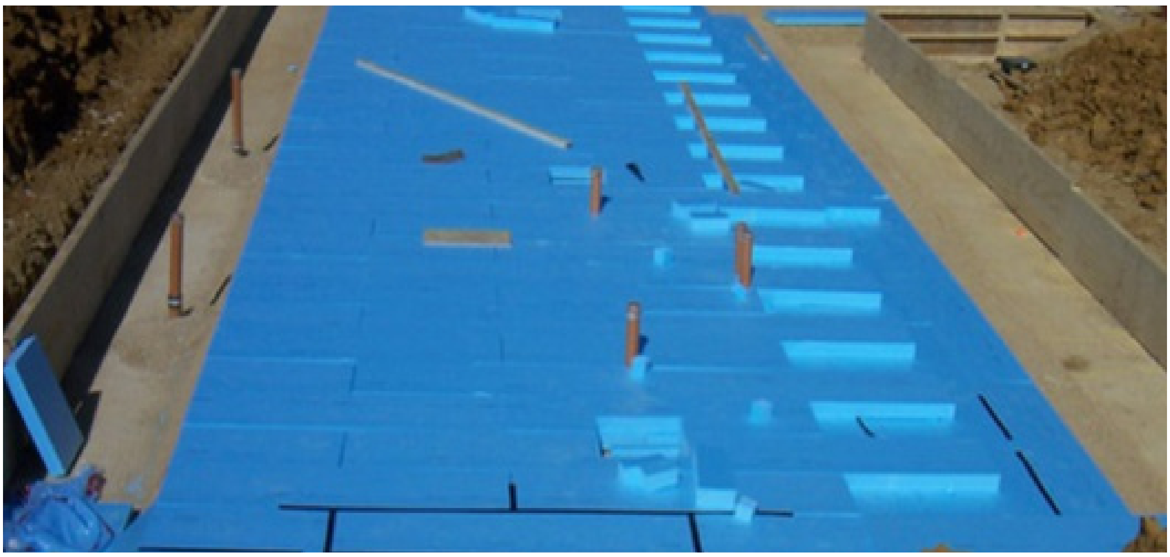

Figure 09: Laying the insulation under the floor slab.

Now this study has investigated the materials and constructions selection process and how they were implemented, it is important to look at the perception of sustainability. The current domestic sustainable guidance in the UK is the Code for Sustainable Homes, as discussed briefly in the introduction; the CSH outlines several categories of sustainability. Category one, 'Energy', covers similar aspects of a 'Fabric First' approach such as Passivhaus, but the other eight categories cover areas such as embodied energy. Embodied energy is the energy consumed by all of the processes associated with the production of a building, from the mining and processing of natural resources to manufacturing, transport and product delivery (Designing Buildings Ltd, 2014). This factor is obviously deemed of importance in British society or it wouldn't have been included in the CSH. Its value is understandable as in the UK today the construction industry is the largest consumer of resources, totalling around 400 million tonnes of material a year (Langdon, 2009). This consumption of material itself accounts for around 10% of UK carbon emissions (ENVEST, 2013). Therefore surely it is crucial that this factor is tackled as the UK aims for 2050.

Although no calculations have been done it is likely due to the material selection in Underhill House, that the embodied energy is high. Materials such as concretes, steel, and plastics are the most energy intense whereas natural grown materials such as wood and straw are less so (IPCC, 2007). When queried about embodied energy, Chris made it clear that the priority was ensuring the envelope performed exceptionally well in order to reduce operational energy. Mike Eliason of Brute Force Collaborative covers this issue in his article 'Operational energy trumps embodied energy unless efficiency is achieved' (2011). Eliason agrees with prioritising operational energy. He says that over a lifetime of CO2 emissions, operation energy will dwarf the embodied energy of construction. He insists that whilst reducing embodied energy can make a building seem more sustainable, it fails to address the critical issue (Eliason, 2011). It is only when the operation energy of a building is significantly reduced that embodied energy becomes a large enough percentage of the CO2 of a buildings lifecycle to become a priority.
In terms of post occupancy, determining how successful a project is can be done in several ways; the first is quantitative data, something that can be measured like numerical performance. The second is qualitative data, something that cannot be measured, such as personal opinion (Abawi, Dr. Karim, 2014). Although design stage PHPP data exists for Underhill house, Helen and Chris were unsuccessful in their bid to have Underhill fully monitored by an educational organisation. Therefor no detailed performance data is available. For this study it is more important to focus on how Underhill House stands up in terms of user satisfaction.

Chris, Helen and their small son moved into Underhill House in August 2010. They repeat that the house is 'fantastic' and that it was 'a lovely place to be in'. When asked if they had to adapt any aspect of their lifestyle to fit in with the house, Chris laughed saying 'No!! You see that's the problem, the average person thinks you have to change the way you live to live in a Passivhaus but that is not the case! If you have to do that the Passivhaus has failed.'. He made it clear that part of their initial brief was that the house had to be liveable.

In a 2012 report entitled *'Sensitivity analysis of the effect of occupant behaviour on the energy consumption of passive house dwellings',* Coley and Thomas investigate the effect the user has on the energy consumption of Passivhaus. They say that there is a history of low energy design failing to translate into low measured consumption in domestic buildings and that 'In part this failure can be attributed to occupant behaviour and household variation' (Coley, Thomas, 2012). As Helen and Chris designed Underhill house to suit their personal needs, it is potentially of more interest to look at the experience of the new occupants of Underhill.

The new occupants, Glenn Jones, his wife and son, moved in August 2012. In an interview with Glenn Jones he was keen to tell me about his experiences. Anticipating him to be something of an eco-warrior it came as a

pleasant surprise to find him to be a novice. Having come from a typical modern executive 1997 home, Glenn was free in admitting that when looking to buy a home it was not eco credentials they were looking for. They were attracted to Underhill purely for its location and exceptional architectural quality, they had not heard of Passivhaus. Knowing now that Underhill was not bought for its Passivhaus status, it is import to establish if this status gave the Jones any reservations. Glenn said that the idea of no heating system was difficult, but they were heavily reassured by the estate agent that it actually worked. Any persisting doubts they had were eliminated by the degree of comfort in knowing that the previous owners were the designers and that they were moving just down the road. Chris will be pleased to hear that Glenn reported that he and his family have not had to make any adjustments to their lifestyles to adapt to the house. Glenn said the only difference is they now have a fire to light in the winter rather that automated central heating, but this was no great issue, in fact it was rather pleasant. He made a small note about the air quality, saying that he thought it was dryer than normal, but that this was not a problem. The second thing he mentioned was using the gym in the house. He said he finds that whilst exercising, the room heats up quite quickly. After living in the house for a month or so, neither of these things were noticeable.
Both Glenn and Chris reported extremely low energy bills, Glenn said that their expenditure on electricity is nil, due to the solar panels on the roof. Other than that the only cost is £300 a year on logs for the fire and a new filter for the MVHR every six months. In a time of rising fuel costs Glenn remarked, ‘I am feeling phenomenally snug’. It seems that although they did not set out to buy a Passivhaus, Glenn and his family are still pleased with the benefits of living in one.

This study set out to establish the key challenges involved in delivering the Passivhaus standard in the UK through one primary case study. The scope of this investigation does not allow general conclusions to be drawn about whether the German Passivhaus standard is a viable option for creating sustainable new homes as Britain aims to achieve its Carbon reduction targets. However, it does give a crucial insight into how Passivhaus can be implemented in the UK and the decisions and challenges involved. This in turn allows speculation into the main barriers facing Passivhaus in the UK and how they can be overcome. The findings suggest that several key British ideas about Passivhaus are not as prevalent as expected.

For example, the detailed analysis of the planning and design development process in Part I highlighted the influence the British planning system had on the success of Passivhaus in Underhill. Stratford- Upon-Avon council were keen to been seen as forward thinking. Interested in having the first UK Passivhaus on their ground, they were supportive of Underhill House from the start. This could be attributed to the potential publicity it would have for the council but also due to the expected high quality of a Passivhaus project, setting the standard for future new homes in the area. When a higher level of the planning system is reached at the District Council, the process became more bureaucratic and complicated as planners attempt to adhere to the many requirements of a complex National Planning Policy. However, as Seymour-Smith Architects have proved in the case of Underhill House, due to it being performance based, Passivhaus was flexible enough in terms of design and materiality to allow a satisfying design solution to be reached for local planning requirements whilst still following Passivhaus principles. This case study proves that innovative sustainable design can be welcome at a local level especially when the community’s needs, such as the protection of a AONBs’ views in the case of Underhill house or the sympathetic materiality use in Eldorado, are clearly reflected in the final design. As Passivhaus becomes more wide spread in Britain, it is likely that local councils could be an ally, encouraging innovative design and opening doors for Passivhaus developments.

The second topic of this study, materials and construction methods has clearly shown that Underhill House owes much of its success to the architects’ ability to plan well. There are many different ways to construct an envelope to Passivhaus standards and it is crucial to select the correct materials and construction methods for the specific design. Deciding these early on allows the architect to ensure a more integrated approach to design and construction. Working with the two together increased Helen and Chris' ability to identify and design out foreseeable issues such as thermal bridging and air gaps- crucial to achieving Passivhaus

One of the key issues the background research showed was a lack of skills and knowledge regarding Passivhaus in the industry. However, Chris and Helen didn't report any major issues with skills amongst the work force. This could be due to Helen being on site throughout to closely supervise the construction. These slightly exceptional circumstances would have allowed her to oversee the build more rigorously, ensuring problems did not arise due to contractors reverting to old ways or not following drawings correctly. This lack of supervision has created problems during the construction for other UK Passivhaus such as the Camden Passivhaus by Bere architects. However, the lack of issues on site for Underhill could also be attributed to their decision to sub contract individual aspects of the build to specialist contractors, ensuring they had the right men for the job. Also as most of the suppliers and contractors on this site were engaged in some kind of PR deal with Helen and Chris, some increase in attention could be attributed to the mutual benefit of the project being a success.

One of the clear factors influencing the success of Passivhaus in the UK is our ability to live in the finished house. This study has questioned the common myth that living in a Passivhaus requires some level of lifestyle change. Both residents of Underhill House have found that no major changes had to be made to the way they usually live. The testimony of Glenn Jones in this study is particularly valuable as his unbiased opinion is rare because many current UK Passivhaus are occupied by their creators. His regard for the outstanding design of Underhill House outweighed the small reserves he had about the lack of heating system, and his only comment was about the MVHR system. He thought that it made the air slightly drier, something he and his family got used to within a few days. His statements reflect similar findings in other UK Passivhaus projects such as the Camden Passivhaus. This suggests that a Passivhaus like Underhill can be suitable for any member of the British public and that no major adapting is required.

It is possible to conclude from this that although achieving a successful Passivhaus such as Underhill in the UK has many difficult areas. If the design phase is particularly rigorous many of the issues that seem to be holding the UK back from the widespread use of Passivhaus can be designed out. Passivhaus has also proved to be flexible enough in terms of design aesthetics and construction methods to work within the UKs tightly controlled planning system. The finding of this study into Underhill House suggests that the German Passivhaus standard could be a viable option for creating sustainable new homes in future Britain. To advance this study the next step would be too look into how the first wave of Passivhaus projects, Underhill, Crossways, Camden etc. are influencing the next generation of Passivhaus in the UK. Is the industry adapting to work better with Passivhaus and is public opinion towards the idea of a Passivhaus changing now several of them are proving to be a success.

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Author Information

I am a final year Masters of Architecture student at the University of Kent, Canterbury. After completing my BA(Hons) in 2011 I secured an Architectural Assistant position with a local sole practitioner. Focusing primarily on small one off dwellings, it was during this time I became interested in the idea of sustainable housing and developments for the future. At the time we were building to reach Code for Sustainable Homes level 4, this experience with the Code led me to investigate it in detail during my 4th year technical work. This investigation through up several issues with the Code which then inspired me to investigate Passivhaus as a more viable option as Britain heads towards Zero Carbon Homes 2014.

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This study would have been impossible without the assistance of Helen and Chris Seymour- Smith. I would like to thank them for their time, co-operation, invaluable insight and willingness to share their experience. I am also grateful to Richard Wilks of Aggregate Industries, Matthew Dyke of Dow Chemical Company and the current occupant, Glenn Jones for their contributions to this study.

Wimbish Passivhaus

Natasha Gandhi

Figure 01 : Exterior view (Own Photograph)

Figure 02: Site Plan (Wimbish report, 2013)

Location Wimbish, Saffron Walden, Essex CB10 2XE
Building Type Affordable Housing
Construction Type Aircrete Blocks with Neopor rendered insulation
Floor area
One bedroom flat (6 units) internal floor area $52m^2$ (planned occupancy 2)
Two bedroom house (2 units) internal floor area $76m^2$ (planned occupancy 3)
Two bedroom house (3 units) internal floor area $76m^2$ (planned occupancy 4)
Three bedroom house (3units) internal floor area $88m^2$ (planned occupancy 5)

Completed Summer 2011
Year Certified 14/12/11
Overall Cost £1,650/sqm

Client Hastoe Housing Association
Architects Parsons & Whittley Architects
Main contractors Bramall Construction
Council Uttlesford District Council
Certifier Inbuilt
Consultants and Collaborators Davis Langdon and Richard Jackson & Robinson Engineers provided M&E consultancy
Funding sources Hastoe Housing Association and Uttlesford District Council

Abstract
This case study will focus on the Wimbish Passivhaus development, near Saffron Walden, which became the UK's first certified affordable Passivhaus scheme. The main themes will examine the process of building wide scale, affordable Passivhaus homewws and to observe the performance of the scheme by analysing the post occupancy results. We will develop an understanding of the important role of user behaviour in achieving the performance standards of Passivhaus, as well as the design itself. From this it will allow us to gain important insight into the potential merits and limitations of Passivhaus becoming the new industry standard in low cost housing across the UK.

Does this case study suggest that Passivhaus is a suitable model for affordable housing in the UK?

Before delving into the depths of the Wimbish project it is essential for us to understand why affordable homes were designed to a Passivhaus standard, rather than the average UK new build homes. The clients Hastoe Housing Association are most commonly known as the 'social landlords' across the South, East and West of England, with over 4,000 rented, shared ownership and leasehold homes. Hastoe in general tend to focus on rural schemes and have designed to sustainable standards in the past with over 200 properties being built to Code Level 4 of the Code of Sustainable Homes (CSH) (Wimbish Report, 2013).

For Hastoe, their intentions were to achieve sustainable homes and communities which provided "affordable homes" for people, as they did not want their tenants to "fall into fuel poverty as energy prices rise, and also that they remain able to afford their rents" (Wimbish Report, 2013). The solution for Hastoe therefore lay with the Passivhaus standard to meet their intentions. Hastoe aimed to examine how the standard "could be achieved in the UK and how much extra cost might be involved" (Wimbish Report, 2013). As the objective was to provide homes for local people, in particular young couples and families, the local authority, Uttlesford District Council, were in support of the scheme and assisted with the funding of the project. What is imperative for us to note, is this scheme was a first for Hastoe, and the design, construction and handover to post occupancy was a new experience for them, thus providing this case study with an interesting analysis as to how the technical, social and economic challenges were tackled.

A wide range of methodologies were used to support and inform this case study, based on the Wimbish scheme itself and wider research into Passivhaus. These included journal articles, a range of books and academic literature, surrounding various implications of Passivhaus and access to the second interim building evaluation performance report. An interview with an anonymous researcher was conducted to provide valuable data and information. The knowledge gained from this experience has been extremely insightful and has raised some interesting analysis on affordable Passivhaus homes in the UK.

The Design

The Wimbish Passivhaus, comprising of eight houses and six flats, was the first of its kind built in the UK, taking on a wide scale residential Passivhaus development. Located off Mill Road in Tye Green, Wimbish, the scheme was designed to sit in an east to west orientation, with very large south facing windows to maximise solar gain. As displayed in figure 02 the site plan expresses this new Passivhaus community, providing a pleasant addition to the area.

For the design of the scheme, Hastoe chose architects, Parsons & Whittley, specialists in Passivhaus. According to main architect Chris Parsons, the design of the fourteen dwellings, was a very "long and complex procedure, in which mechanical strategies were decided very early on" (NBS TV, 2013). Careful planning for a particularly high volume development was therefore crucial in order to achieve all requirements and gain certification. For a Passivhaus building to be certified, it was important for the architects to consistently collect "severe evidence" (NBS TV, 2013) throughout the whole design, construction and post occupancy process. This included drawings, testing results and every detail used throughout the process to en sure all areas of the Passivhaus standard were met and recorded.

At Wimbish it is interesting to note that the design primarily focused on achieving Passivhaus certification, rather than creating design considerations to encourage energy saving behaviour. The general assumption in industry is that if a Passivhaus gains certification, than that would warrant energy saving results. As this was Hastoe's first attempt at designing Passivhaus homes, they assumed and hoped that if certification was achieved than that would guarantee energy saving (Anonymous, interview 2014).

Figure 03: Wimbish Passivhaus units 7-10 (Own Photograph)

Figure 04: Terrace houses on Mill Road, near Wimbish Passivhaus (Own Photograph)

Designing to UK Affordable home standards

One of the main challenges at Wimbish was to design Passivhaus homes to the UK's 'affordable' design standards. Passivhaus homes have a much larger floor area than the average UK home. Architect, Chris Parsons, felt that designing to a particular size was a challenge, specifically designing UK affordable homes to the Passivhaus standard.

"The floor areas required for social housing in the UK affected the design by virtue of the Passivhaus, where floor areas are much larger",

Chris Parsons (NBS, TV 2013).

According to the Affordable Housing Supplementary Planning Guidance (SPG, 2002) the minimum space standards are as follows:

Property Type	Affordable homes min. floor standard (m^2)	Actual floor area at Wimbish (m^2)
One bedroom flat (2 persons)	45-50	52
Two bedroom house (3 persons)	65-70	76
Two bedroom house (4 persons)	70-75	76
Three bedroom house (5 persons)	80-85	88

Table 01: Affordable housing standard floor areas in comparison to the actual Wimbish floor areas.

The design at Wimbish appears to show a slightly higher floor area, predominately as a result of the Passivhaus requirements. The minimum space standards for affordable homes therefore show the challenge faced at Wimbish, in reducing the scale to match both requirements. According to the Passivhaus Designers guide (Passivhaus Primer, BRE Trust); the size of the building also influences the area to volume ratio. In this case the small buildings with an identical form produced a higher area to volume ratio this meant the design had to be "very compact" (Passivhaus Primer, BRE Trust).

Procurement

Before we dissect the technical design areas in more detail it is significant to identify the procurement method used. At Wimbish the Design and Build method was chosen. This meant contractors worked alongside architects until Stage F (Production Information) allowing the majority of work to be carried out at the detailed design stage. By using this method it meant the contractors and architects collaborated in all areas of concept, planning and design, providing consistent teamwork throughout these stages.

The Wimbish scheme raises the question as to whether the design and build approach is the most suitable method of procurement as it would remove the involvement of the architects post stage F. However, despite the method of procurement at Wimbish the architects still continued to monitor the project with regular visits on site to ensure detailing and airtightness was successfully achieved. Passivhaus requires a high level of detailing and therefore a strong collaboration between contractors and architects is somewhat necessary to ensure the standard is achieved with minimal problems, particularly on site.

According to Bill Butcher, Director of GBS (BD Online, 2010), regarding the 'Denby Dale Passivhaus' scheme, agreed that Passivhaus procurement needs a "connection between trades and knowledge of every stage of build". By combining both the knowledge of architects and contractors it would therefore result in continuity due to the higher level of collaboration, ensuring the Passivhaus requirements are met. This suggests that, using this procurement method in the future may be the way forward in Passivhaus design.

Technical Design

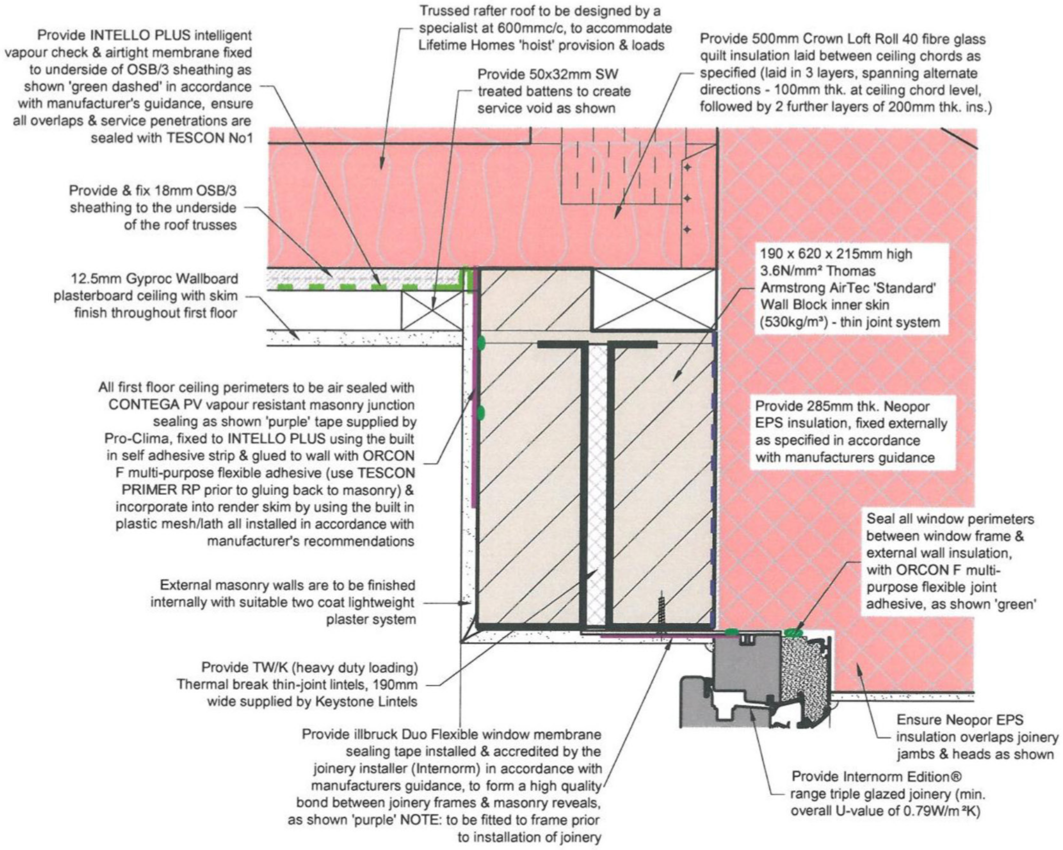
Although it appears that the design did not necessarily focus on reducing energy saving behaviour, there were a number of design considerations. Hastoe's main ambition was to adhere to the vernacular style of the surrounding areas. The Wimbish Passivhaus largely consists of strong rendered colours on plain fronted houses, under a natural slate roof (Wimbish Report, 2013), similar to the surrounding context (as shown in figure 03 and 04). Having visited the site, it is clear to see the visual attempts made in conforming to traditional aesthetics. Despite an attempt to design to the traditional housing stock there are obvious design differences such as the large south facing windows and significantly smaller north facing windows on the Wimbish homes. Even small details such as the porches portray the comparable differences between both styles. In Passivhaus, the design has to avoid any penetrations into the building to reduce thermal bridging. At Wimbish we see a separate porch, letter box and meter boxes, unlike traditional homes. Consequently the combinations of the varied design features result in two juxtaposed styles.

In terms of heating the building, solar gain was used and achieved in various ways. As mentioned the floor plan was based on an east to west orientation to maximise solar gain. The windows were triple glazed (Internorm Edition range) with wood and aluminium framing and thermal foam insulation with a total u-value of 0.86W/(m^2K). Complete with the large south facing windows, smaller north facing windows were also implemented in the design to maximise and reduce solar gain. IES software was installed in each dwelling to show any loss and gain in the performance of these windows. To avoid overheating a number of solar shading techniques were also implemented. A Brise-Soleil on the ground floor, external blinds on the first floor and a large roof overhang, ensured the building would not overheat. (Wimbish Report, 2013).

Most of the solar shading techniques used, are already familiar in UK design, however the challenge with Passivhaus is the expense of tripled glazed windows. These high performance windows provide an additional £130m^2 cost (Homebuilding, 2014), making 'affordable' homes quite expensive to achieve. However, the consequent result of energy savings once the building is complete does provide affordable maintenance.

In line with heating the building the hardest challenge in the design at Wimbish was to ensure airtightness and no thermal bridging. Chris Parsons (NBS TV, 2013) explained that "achieving 0.6 air changes per hour was very challenging, especially compared to the national building regulations which only require 10 air changes per hour" a highly significant difference! Although wet plaster and suitable tapes were able to deal with 95% of the issues, the 'use of timber floor joists caused significant difficulties in forming continuity between ground and floor' (Wimbish report, 2013), however the report failed to mention how these difficulties were overcome, if at all. Nevertheless figures 06-08 and 10 show examples of how Wimbish attempted to deal with the issues of airtightness.

Figure 05: Solar shading techniques at Wimbish (Own Photograph)



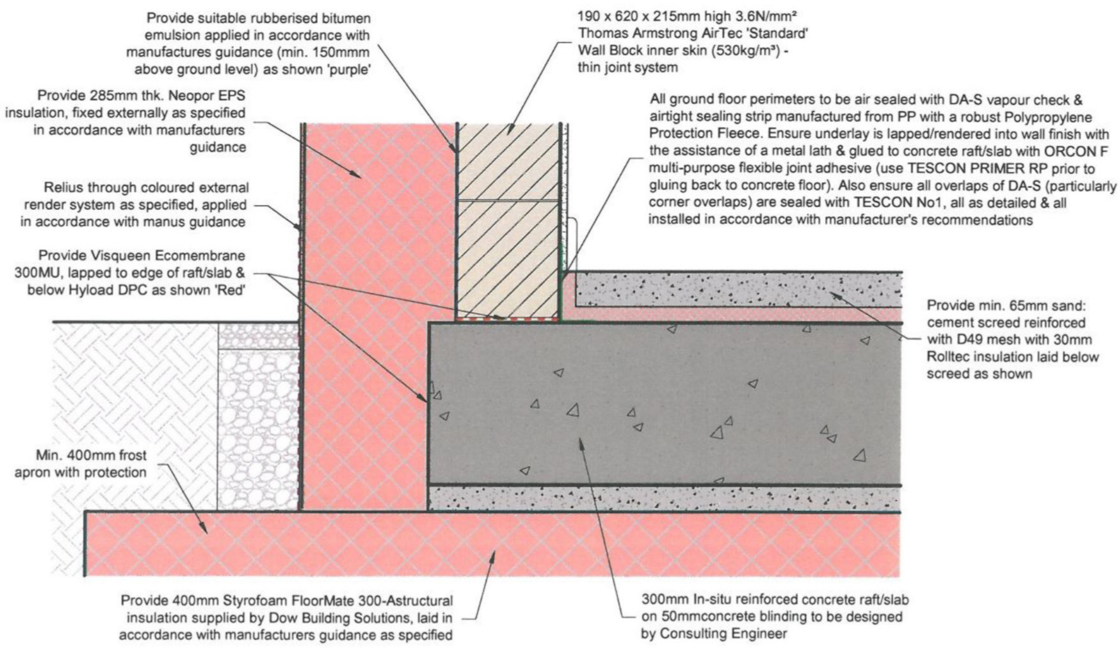


Figure 06 and 07: Airtightness detailing at window openings and ground level (Passivhaus Planner)

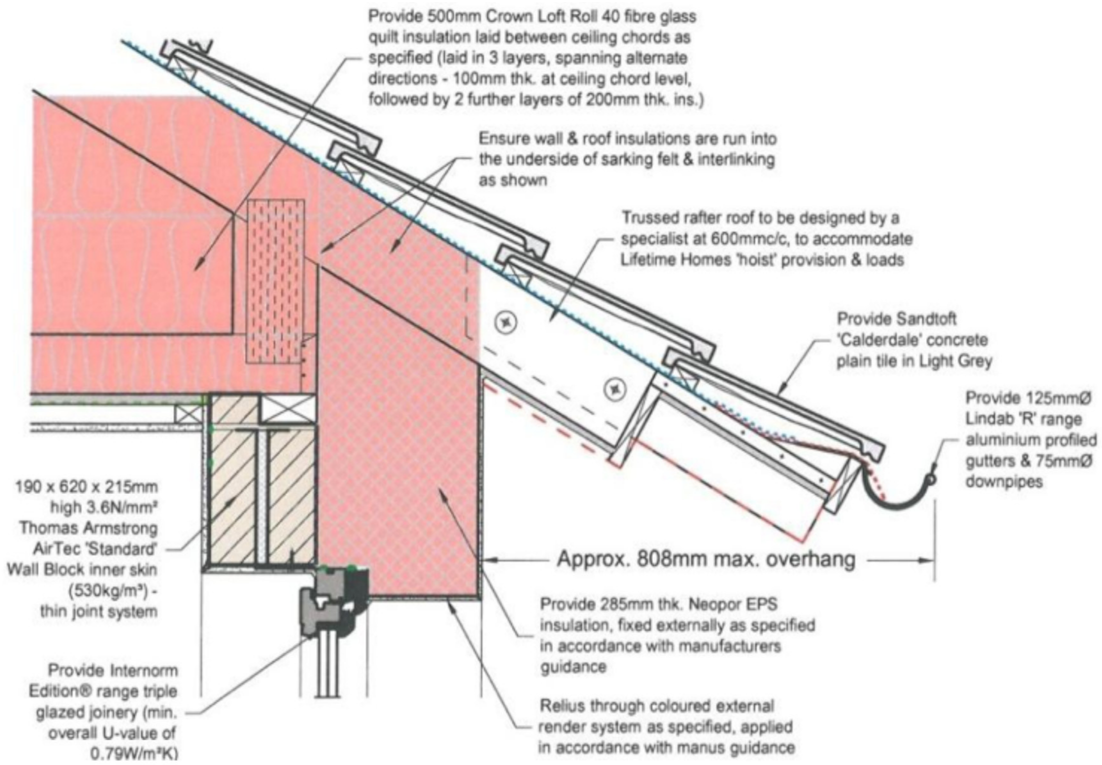


Figure 08: Eaves airtightness detailing {Passivhaus Planner)

The red areas highlight the air leakage barrier, with 400mm structural insulation below the concrete floor slab and high levels of insulation around the window openings and eaves detail. The results of airtightness will be developed further in the post occupancy review, however we can argue that achieving airtightness in these affordable homes was a great challenge and could still be in the future. The obvious solution is to provide education and training to the construction industry to insure airtightness is controlled, as this significantly affects the performance of Passivhaus.

If Passivhaus were to become the industry standard, are these design requirements "too prescriptive?" (Jefferson.N, Feb 15.2013). The level of design detail required in the case of this study, resulted in 72 drawings produced for the scheme, which suggests that the standard is quite demanding. For Parson & Whittley Architects, the average number of drawings on a Code Level 4 of CSH would normally be around 17 (Wimbish report, 2013). The significant difference in the design detailing is therefore clearly evident and this needs to be considered and recognised for future wide scale developments.

Along with passive design measures and high performance materials such as high levels of insulation and windows, the Wimbish houses each contained a mechanical ventilation system with a highly efficient heat recovery (MVHR). The MVHR was used to provide mechanically fresh air into the habitable rooms, whilst extracting warm stale air from the bathroom and kitchen, via a heat exchanger. The Paul Focus 200 MVHR Unit used in the design, claimed to be 92% efficient, resulting in 92% of the heat in the house being recycled back into the house (Wimbish report, 2013).

The use of MVHR systems however also requires the design of the homes to work in sync, to achieve the highest performance quality. The occupants therefore are required to open windows accordingly with the MVHR unit to gain the most out of the system. The MVHR leads to major debates around the effects of user behaviour on

Passivhaus design, which will be explored later. However one issue that is often linked to Passivhaus design is the provision of cat flaps; a minor part of design in an average UK home, but a large hindrance in a Passivhaus home. As some residents did own pets, windows and doors were left open regularly, more than the design assumed, and the homes at Wimbish did not reach its full potential (discussed later). Recently however, Freedom Pet Pass (Freedom Pet Pass, 2014) have introduced the “DoubleMag” airtight cat door, which could be incorporated in future Passivhaus designs, overcoming one issue surrounding airtightness.

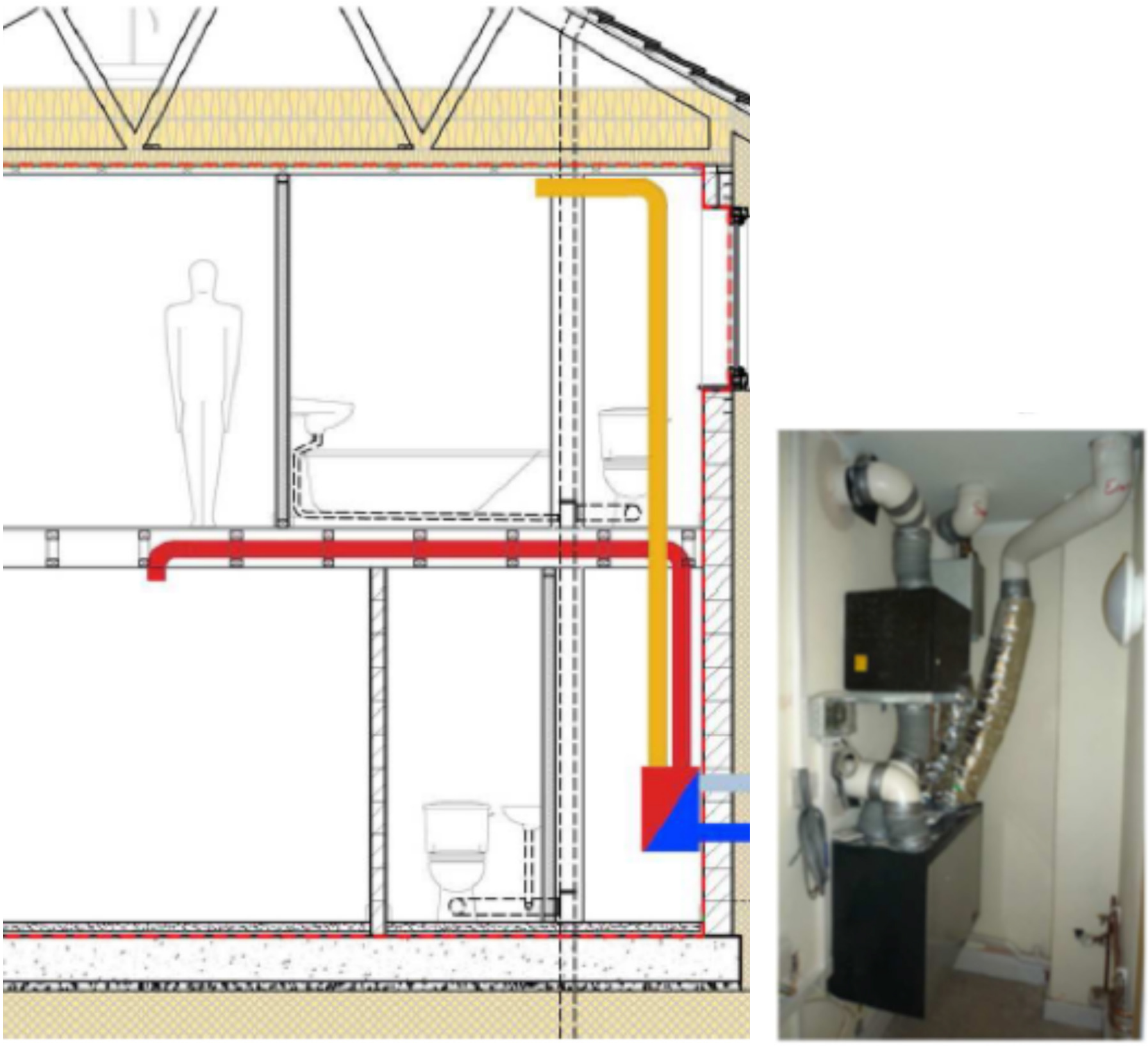


Figure 09: The MVHR system (Wimbish Report, 2013)

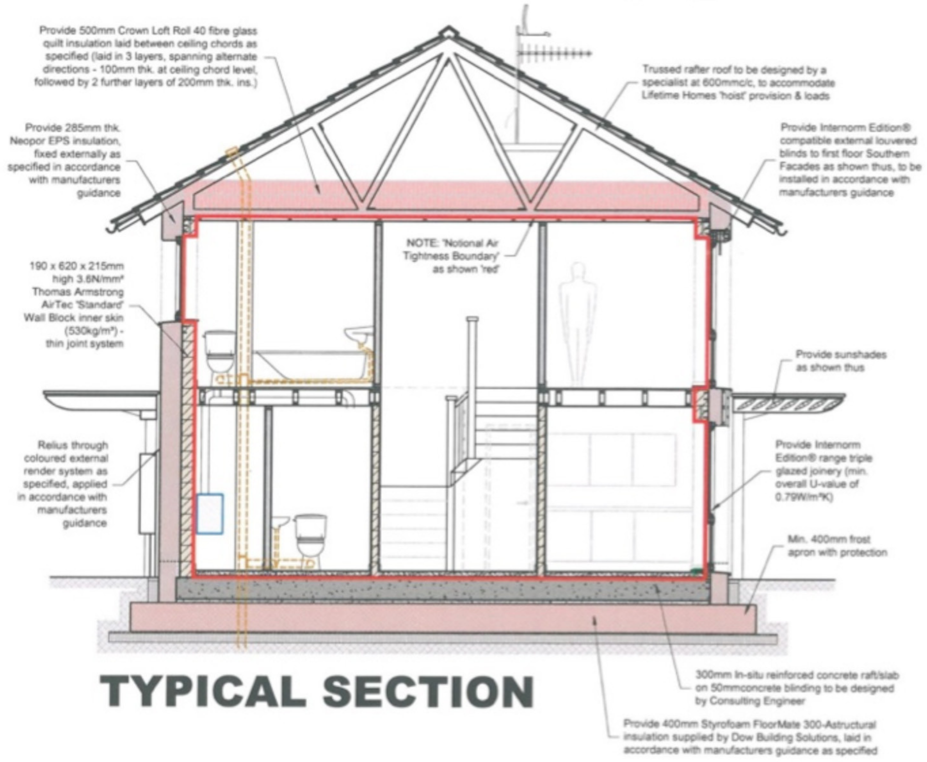


Figure 10: Typical section through Wimbish home (Wimbish report, 2013)

Construction

"Installing insulation below the slab helps to create an 'envelope' of continuous insulation which minimises heat loss, requiring a material which can maintain strength and good thermal performance even when used externally"

Chris Parsons, Parsons & Whittley Architects (NBS tv.2013)

The construction of the Wimbish Passivhaus consisted of 190mm thin join masonry with 250mm externally applied foam insulation and render. To ensure the house was completely air tight the design included high levels of insulation, using 400mm Floormate insulation, 285mm EPS on the external walls and a 500mm loft roll in the roof to create the typical Passivhaus 'tea-cosy' effect (Wimbish report, 2013). The use of externally applied insulation not only provided airtightness by forming the "tea cosy" around the building to avoid thermal bridging, it also made it highly efficient to render, consequently adhering to the existing housing stock. The construction methods chosen provided Wimbish with an economical solution to the performance requirements. It also reflected Hastoe's preferences for using local materials and available skills (Wimbish report, 2013).

In terms of the contractors used at Wimbish, Bramall Construction, were specifically chosen as specialists in Passivhaus design. They worked alongside the architects as part of the design and build procurement method. Kevin Hartnett, Business Development Director of Hastoe, reviewed the experience of choosing the contractors as "an exhaustive process" (HCA, 2013). The choice of contractors is fundamental in Passivhaus design, particularly in a scheme as large as Wimbish. It is essential that both the architects and contractors have the same level of understanding, regarding Passivhaus demands, in order to achieve certification. Often arguments between Bramall, whom were in charge of making the building as airtight as possible, were faced with others that worked as they always did and did not necessarily want to adapt to the Passivhaus way. It is important that all members of the design team work to the same understanding, for Passivhaus to become a success in the UK

Cost

Having analysed the construction and design of Wimbish, critical issues of cost have been highlighted as a potential problem in future housing developments. One of the main objectives by Hastoe was to determine how much extra cost would be involved in designing a Passivhaus development. The initial cost was said to be relatively high at £1650 per sqm, compared to a Code level 4 scheme at £1375 per sqm. Private developers appear to show a cost of £1,100 per sqm, showing a significant difference of cost (NBS TV. 2013). Hastoe's engineers calculated that the Wimbish scheme cost around 12% more than a Code level 4 CSH. However, Hastoe believed that as Wimbish was their first attempt at Passivhaus, they "confidently expected the margin to be reduced as skill sets and the supply chain mature". If we look in hindsight, the next Passivhaus development for Hastoe, which was also a 14 dwelling proposal (the Ditchingham Passivhaus), totalled £1454 per sqm, (Passivhaus Trust, 2012) still high, yet showing a decrease in cost.

At Wimbish, the scheme was lucky to receive the support and funding of £830,000 from the Homes and Communities Agency, for the total project cost of £1,675,000 (Passivhaus planner, 2014), whilst the remainder was invested by Hastoe (Wimbish Report, 2013). Would it be feasibly however to build affordable homes to such a wide volume in the future given the additional costs?

One of the main challenges in delivering Passivhaus in the UK is based on economic issues as it does require a higher standard of technologies that unfortunately come at an expensive cost. For example, a triple glazed Passivhaus window will cost 'around £350/m2', whilst a double glazed window will cost around '£220/m2' (Home building, 2014). Passivhaus doors are also estimated to cost '60% more than conventional doors' (Home building, 2014). Currently the UK lacks in its supply chain, and thus importing technologies from abroad does at to the cost. According to Wolfgang Feist, he argues that "the greatest challenges facing the UK will be to build a supply chain of Passivhaus compliant materials"; by doing so this would lower the costs of importing. Despite the obvious expense from technologies, there are also additional costs in training and education for contractors, society and perhaps architects in how to design, build and live in a Passivhaus home. Hidden costs are also found in testing, the Passivhaus Planning Package (PHPP) and the certification and processing data. Home building (Home building, 2014) estimate the hidden costs to be around £2,000 for certification, with an additional £4,000 for testing.

Hastoe however attempted to make economic considerations by using locally sourced materials, as well as local skills to build the Passivhaus homes, which is an important factor when considering its suitability in the UK. According to Sustainable Homes (Sustainable Homes, 2010), doors, windows, boilers and other equipment used in Passivhaus is set to be "manufactured by UK companies" thus making the installations of technologies cost effective by providing the country with its own supply chain.

The director of Archetype also promises to deliver Passivhaus homes to the same cost as average UK homes (Anonymous interview, 2014), showing that perhaps Passivhaus is an affordable option, thus providing hope of a potential shift away from this economical problem.

"These properties can deliver savings of more than 90% in heating bills compared to a modern conventional build. And at the same time they should be affordable to many of the younger generation seeking to make their home in the village near their parents and families".

Sue Chalkley, CEO, Hastoe Housing Association (Passivhaus Trust 2013)

Despite the costs however we must look at the long term affects the Passivhaus scheme has had on the occupants. The homes were designed to become more affordable to the residents, and their bills have been significantly reduced. Despite an unsuccessful achievement in electrical consumption, the residents have noticed a significant difference, thus making their homes much more affordable. Therefore Hastoe's aim to provide affordable homes for their tenants has been achieved.

Hastoe found that despite the reduced energy bills, the current energy tariffs means residents are not gaining the full benefits of the Passivhaus home. They claim that the current design tariffs are "unfriendly to low usage consumers, and they either have a standing charge, or tiered approach with a higher price for the first few thousand kWh per year (Wimbish Report, 2013). For future development could the service companies reward low usage to benefit society? If so, residents would then see the full potential Passivhaus has to offer.

Overall however, what we can gather through the scheme at Ditchingham and the proposals of further wide scale Passivhaus developments is that Hastoe clearly see wide scale Passivhaus schemes as an investment and therefore provides a positive outlook for the Passivhaus future in the UK.

Post Occupancy Review

The most important factor of this study would have to finish on the post occupancy review of Wimbish. To determine any future of affordable Passivhaus housing schemes in the UK, we must not only use the analysis on technologies and the design, but also user behaviour and the performance of the buildings, post occupancy.

User behaviour in sustainable homes such as Passivhaus, initiates an interesting political debate in the industry. The general assumption is that if technologies are in place then that would be enough to guarantee the high performance standard, and that user behaviour would have minimal impact (Anonymous, interview 2014). However, it is fair to argue that the success of the technologies works in unity with user behaviour, as both depend on each other, consequently affecting the performance levels of these buildings. That is not to say that all blame is put onto the residents, but to emphasise that the Passivhaus standard is very different to average UK build homes, thus education of society (including political and building groups) is key to determine a successful Passivhaus future. In a study into the impact of user behaviour in high performance buildings, the report concluded that behaviour does have a "major impact on actual versus expected energy consumption in low energy buildings" (Roth.K, 2010). Using the data found in the interim building performance evaluation report (Wimbish report, 2013) we can analyse just how far user behaviour affects the performance of Passivhaus. The report provides us with an overview of how Wimbish has performed to date and consequently highlights the merits and limitations of the scheme as a suitable model for affordable Passivhaus homes.

It is interesting how we can perceive this data provided by Hastoe. In some ways we can view the Wimbish Passivhaus scheme as being successful as it achieved certification and therefore has met all the requirements and performance demands needed to meet Passivhaus. However, how much do we accept these methods used in determining certification? What was interesting to discover is that only three units were fully tested, therefore it was assumed that the assessment for those three were representative of all others (Anonymous interview, 2014). Certification was provided using the Passivhaus Planning Package (PHPP) system, which bases the calculations on a number of assumptions about thermal comfort, use of energy efficient appliances and appropriate occupant behaviour (Wimbish Report, 2013). If the assumptions are not met, the performance is underachieved, but how much do we accept these assumptions used as an accurate representation? By breaking down the data into two sections, user behaviour and heating demand; and electrical consumption, we can begin to thoroughly conclude whether Wimbish suggests Passivhaus is a suitable model and whether the results show a fair representation of all units.

User behaviour and heating demand

Although most units passed airtightness with a substantial margin, some took a great deal of effort to achieve a pass. The performance report implies that the quality of the process to pass was not consistently applied and perhaps not fully understood by all tradespeople. It could also mean that some seals were 'short term expedients' (Wimbish report, 2013).

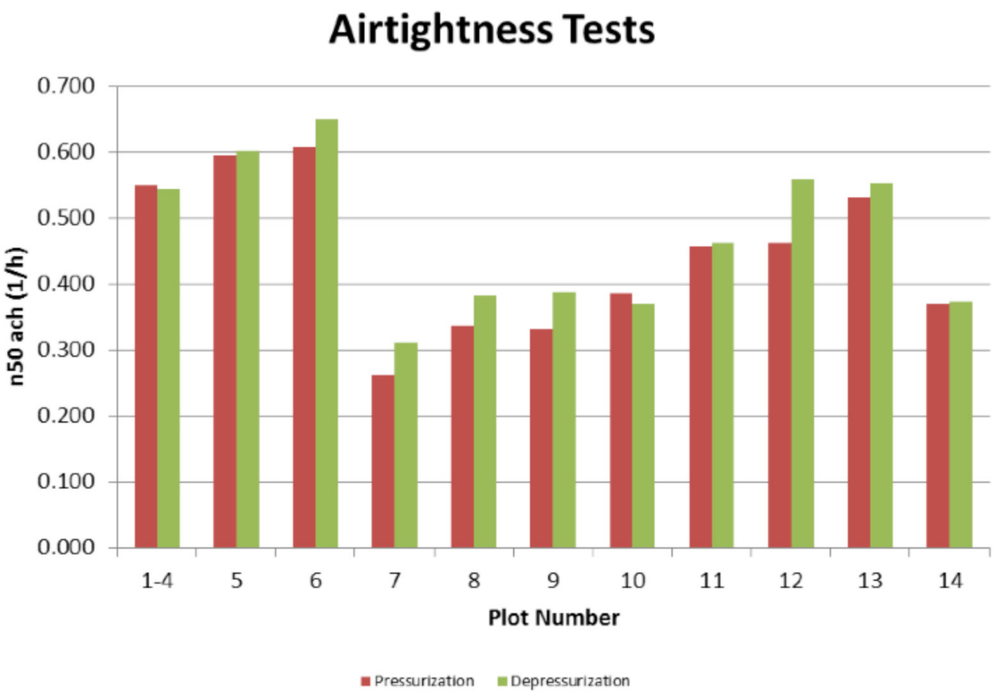
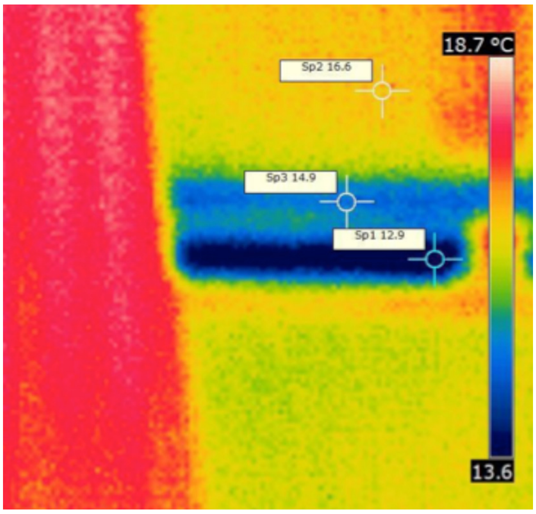


Figure 11: Airtightness test results (Wimbish report, 2013)



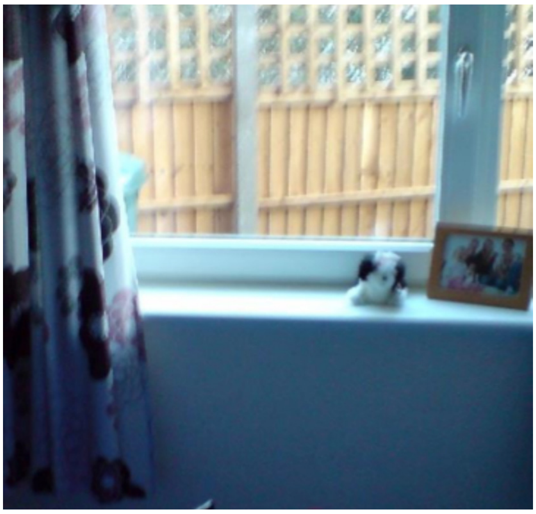


Figure 12 and 13: Thermographic imaging showing heat loss at window sill (Wimbish report, 2013)

The location for in-situ testing was also a difficult challenge at Wimbish as locality to windows needed to be avoided to gain a more accurate result. As units were designed to maximise daylight from large south facing windows, the north wall became "populated with bathrooms, services, cupboards, stairs etc." (Wimbish report, 2013). This leads to the conclusion that although this does not mean the internal layout should be re-designed, but that Passivhaus requires a "pre-allocated" space that will work when testing the building, post completion. The whole house heat loss test was also not undertaken as it can only be tested in the winter months, with a vacant property; unfortunately Wimbish was already occupied, so through heat loss tests could not be done. (Wimbish report, 2013)

At Wimbish thermal modelling in IES software was carried out to show that no room would exceed the 25C threshold more than 5% of the time. (Wimbish report, 2013). The warmest room in the house were said to have been the sitting rooms and only three rooms were "predicted to exceed more than 26C more than 1% of the time" (Wimbish Report, 2013). But these results were still based on a number of assumptions, all of which we can challenge. The programme assumed that once the room temperature exceeds 24C then windows should be opened. However, if occupants are out most of the day, windows are unlikely to be left open. The report showed that the assumptions could also factor in for windows to be left open at night, however in reality, "too many insects" (Wimbish Report, 2013) prevented this from happening. Does this indicate that the modelling assumptions used in Passivhaus, need reconsidering? In the case of Wimbish, the answer is perhaps yes, as the assumptions need to consider occupant behaviour to gain a more accurate representation.

The post occupancy review also shows challenges when opening and closing windows in the Passivhaus homes. As mentioned previously, some residents left doors open to allow pets outdoors, consequently losing heat. Furthermore one resident opted to turn the MVHR system off and open the windows in a hope that it would save them money (Anonymous, interview 2014). However by doing so, resulted in more energy used to heat up the building. Here, we see an example of user behaviour affecting the performance of Passivhaus. The strict methods surrounding when to use passive measures of ventilation in a Passivhaus is a different concept in comparison to average UK homes. When a house is hot, or in need of ventilation an immediate reaction is to open windows. In Passivhaus however, the MVHR and solar shading techniques are in place to cool the building. In order for Passivhaus to work therefore, knowledge of how to control temperature is therefore vital in the handover process.

Reactions to MVHR caused problems with heating demand, especially as it is a new concept for most people in the

UK. Often residents applied previous knowledge to old boiler systems onto their new MVHR system. Researcher Chris Foulds talks about the wider debate of how this confusion is created when society apply knowledge on existing models and attempt to place them onto new technologies in his paper Practices and technological change: The unintended consequences of low energy dwelling design (Chris Foulds, 2014).

It can be argued that the struggle between user behaviour and heating demand lies in the handover period. The MVHR system was not fully explained to the occupants until moving day. Initially residents were given a first introduction into Passivhaus, but no depth into the technologies. Residents were then taken on a tour of the construction site, where the MVHR was introduced but residents were pre-occupied with measuring rooms for carpets and furniture rather than the technologies. On moving in day, a contractor from Bramall, whom had a contractual agreement with Hastoe, gave individual talks to an adult from each household explaining the MVHR system, complete with a laminated MVHR guide. However, the timing by Hastoe and Bramall was unfortunately unsuitable. The residents were more eager to move into their new homes as they had just received their keys, rather than learning about MVHR. As a consequence this resulted in almost all residents losing their laminated guides and mould growth as the homes were not being ventilated efficiently using the Passivhaus systems in place. Within the first few months Hastoe and Bramall, were on call to the site to help guide the residents into how they were to live in their new Passivhaus home.

Providing appropriate guidance therefore is essential for residents to maintain comfort and get the most, at least cost, from the systems provided. The way Hastoe tackled the handover was recognised as a problem and in hindsight they have now changed their strategies. It is fair to also state that this was a Passivhaus first for Hastoe and they too were learning by experience. In the building performance evaluation they also recognised that they should not have informed residents it would take up to two years to learn how to live in a Passivhaus (Wimbish report, 2013). Perhaps this also needs to be encouraged, if society is constantly reminded at how ‘difficult’ a Passivhaus is to maintain then they would be discouraged to live in a Passivhaus home in the future.
Now the residents have lived in the property for over two years, they have learnt more by experience, which provides us with confidence for future housing schemes. Furthermore ‘Soft landings’ a recent development, assists with the handover issue. The Building Services Research and Information Association (BSRIA) provide support services which mean designers and contractors stay involved with buildings beyond practical completion (BSRIA, 2014). It ensure occupiers understand how to control and best use their buildings, which is an ideal introduction, if low energy schemes such as Passivhaus were to take off in the UK (even in the case of CSH). The Passivhaus trust similarly recently announced a “new occupant \guidance book”, which provides guidance for the industry in producing “effective user guidance for Passivhaus buildings” (Passivhaus Trust, 2014), all of which provide the future with a positive outlook for post occupancy in Passivhaus homes.

User behaviour and Electrical consumption

The comparisons in heating demand and electrical consumption data show a significant difference in meeting the Passivhaus predictions however overall the scheme did meet the Passivhaus benchmarks with a specific heating demand of 15kwh(m2a), a heating load of 11w/m2 and the specific primary energy at 104kwh(m2a). (See PHPP data sheet in appendix). In terms of the predictions however, figure 15 shows one house failed to meet Hastoe’s benchmark in gas consumption, however, this is still only a ‘quarter more than the national average household’ (Wimbish report, 2013). The results of this somewhat agree with the industry belief that user behaviour would not affect the technologies put in place in Passivhaus (ref. chapter 4). However, the results of electrical consumption create a alternate argument.

From figure 13 we can see results of electrical consumption at Wimbish, which was higher than the predicted 33.5kWh/m2 at around 45kWh/m2, perhaps "due to insufficient use by the occupants and household appliances" (Wimbish report, 2013).Nonetheless these results still achieved the same as an average UK home. User behaviour particularly around appliances is fundamental in this topic of debate. Even though technologies show they are often un-affected by user behaviour, examples such as the electrical consumption at Wimbish, shows that behaviours can also impact the performance levels.

If there is a future of affordable homes in the UK it would be beneficial for the social housing groups to provide or encourage the purchase of more energy efficient appliances. The houses at Wimbish were designed assuming efficient appliances were to be efficiently used, however in reality this was not the case. According to the performance report (Wimbish report, 2013) Hastoe did not select the residents as being "eco-minded" and they were also unable to provide white goods. However could there have been more emphasis on energy saving?

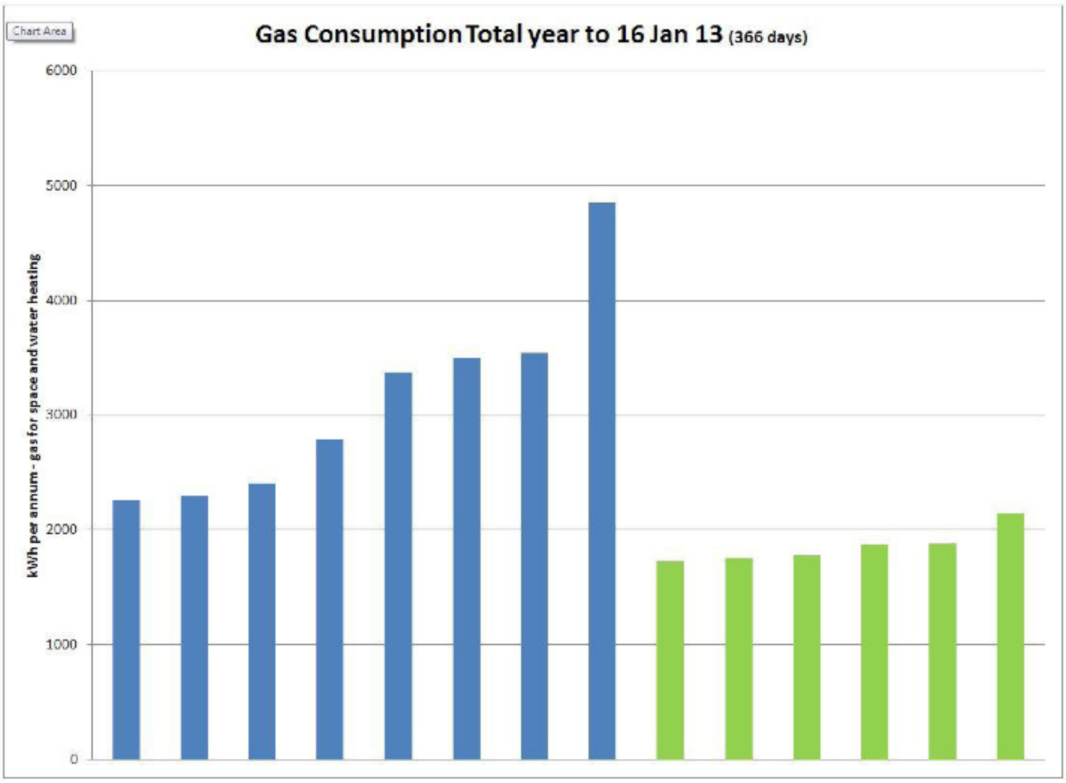


Figure 14: Gas consumption from 16.01.12- 16.01.13 (Wimbish Report, 2013)

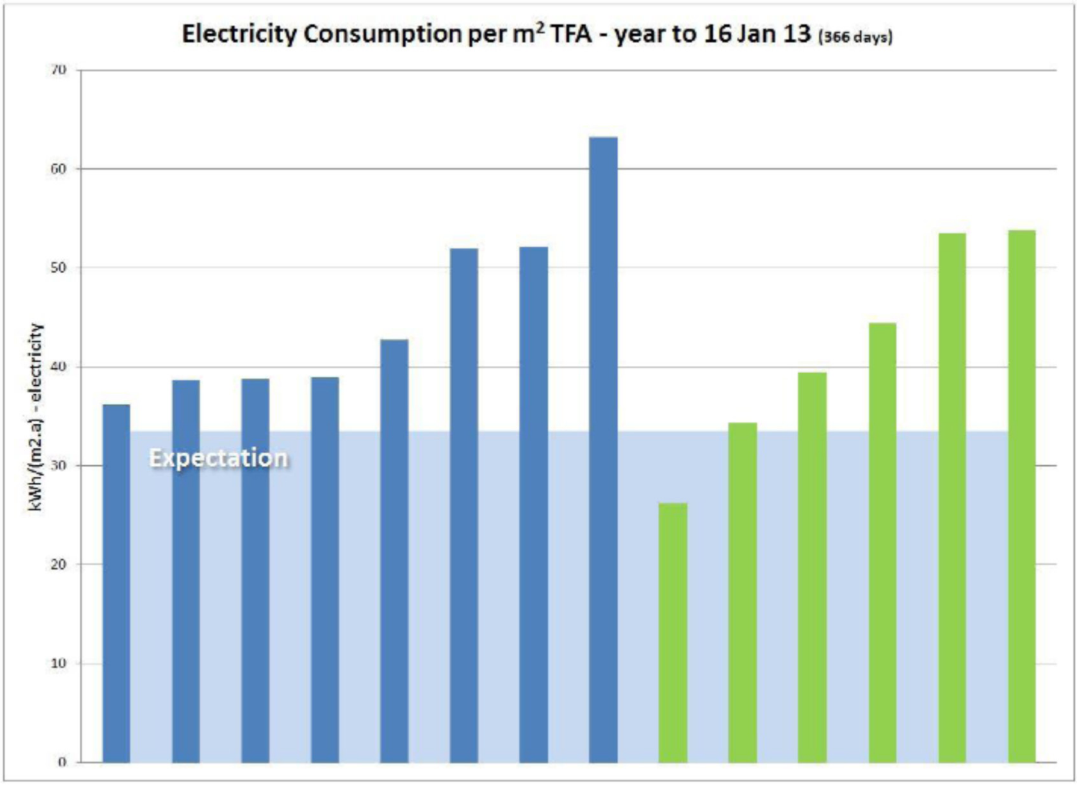


Figure 15: Electricity consumption from 16.01.12- 16.01.13 (Wimbish Report, 2013)
NB: Blue represents houses and green represents the flat units

The Wimbish residents were given a handover guide which "vaguely discussed using energy efficient appliances" (Anonymous, interview 2014); however a higher emphasis should have been put onto the residents. As most had moved from previous social housing they brought in old appliances, thus using the same energy they used in their old homes. Wider research states that perhaps in the long term it does not provide as much of a difference as we may think. In a report into Energy Savings in practice (ECEEE Report, 2010) they claim that "lifetime costs for using the most energy efficient appliances on the market may be no more than if buying current products". However, there are still differences, and particularly in the case of Passivhaus, buying energy efficient appliances is crucial, and part of the assumptions when calculating the performance standard.

What is interesting is that although residents at Wimbish opted to stick to old appliances, they have since brought or considered buying higher energy efficient appliances purely on thermal comfort, rather than for energy saving or cost reasons (Anonymous, interview 2014), so the importance of energy efficient appliances has various advantages. Although Hastoe did not quite achieve the expected electrical consumption, the overall reactions to Passivhaus from the users themselves, show a positive social impact. Residents appear to be happy and mostly comfortable with their affordable Passivhaus homes, and the bills, (despite not reaching Hastoe's and Passivhaus expectations) are still beneficial to the residents.

"We put aside £50 a month to cover heating bills, and when they only came to £30 (total) for the first six months our children had a better than expected Christmas"

Mrs N. Martin, Resident (Wimbish Report. 2013)

From initial findings (Wimbish report, 2013) the results of a 'typical three bedroom house at Wimbish used 2500kwh with a total gas bill of £150 for the year'. For a flat, the results were significantly cheaper with a use of '1000kwh with a total gas bill of £57'. A staggering reduction in most typical gas bills. UK Power (UK Power, 2014), claim that for a medium to large house the annual energy bill is around £1,416. With such a vast difference in price, it is encouraging to see how Passivhaus is an ideal solution to affordable living.

Conclusion

The positive reviews from the residents at Wimbish provide us with confidence in arguing that society could accept Passivhaus as the new industry standard for affordable homes in the future. Like any new concept however, there are still obvious challenges surrounding the technical, social and economic areas that need to be resolved before any changes are made to the existing housing stock. However, the merits and limitations as discussed in this study does not rule out a potential future for wide scale Passivhaus developments in the UK. The main themes of the study strongly emphasise the need for education of various social groups including residents, the government and the building industry; which would develop a stronger social attitude towards Passivhaus.

Despite the obvious Passivhaus merits, such as the significant energy saving results and affordable maintenance we must conclude by highlighting the main limitations this case study has recognised. Through this analysis it is arguable that perhaps a more rigorous approach is required when testing the volume housing schemes to avoid any shortfalls in the individual units. With such a wide scale development, it is imperative to ensure all units are working to the same efficiency to maintain continuity across the whole scheme.

Another concern highlighted is the fundamental need to encourage energy saving behaviours before the post occupancy period, to ensure the homes are used to their full Passivhaus potential. As already recognised the key moment would be during the handover period to ensure that the efforts taken to achieve the Passivhaus standard are consequently continued during post occupancy, as that is the fundamental moment the residents benefit from Passivhaus affordability.

Nevertheless, we must remember that this was a Passivhaus first for Hastoe, and their approaches, in particular the economical construction solutions, should be highly recognised and subsequently shows the progression of Passivhaus in the UK. A general technical challenge of Passivhaus is the comparatively different construction methods used to average UK build homes. With Wimbish however, traditional methods have been combined with the Passivhaus standard to remove some of the technical challenges. Furthermore the choice of design and build also ensured the technical detailing had a strong collaboration between all parties, consequently resulting in certification.

In terms of a universal scale director and founder of the Passivhaus Institute himself, Wolfgang Heist, believes that the UK could lead the way with Passivhaus and accepts "there is a capability of building to the standards" (Wilding.M, Feb 8 2013). The results at Wimbish does emphasis this and in recent news published by the Passivhaus Trust in late January 2014, social media "hailed" the Wimbish Passivhaus "as the model for eco-home future" (Passivhaus Trust, 2014). Providing us with a strong assurance that Passivhaus could lead the way in the UK.

Proposals for plans announced for 2014 by Hastoe also lead us to the answer that Passivhaus does have a place in the future. The proposed schemes include:

-Hatfield Heath, Essex (13 homes for rent)

-Horseheath, Cambridgeshire (3 rental units)

-Burnham Overy Staithe, Norfolk (5 rental units and open market dwelling)

-Outwell, Norfolk- (13 rental units, 2 shared ownership)

-(There is also the construction of Circle Housing's all-affordable Passivhaus certified housing development, which has got under way in Rainham, Essex. (Passivhaus Trust News, 2013)

With these planned volume housing projects and the Ditchingham scheme, which was completed shortly after Wimbish, it does provide an optimistic outlook for the UK. Indeed, work is yet to be done to resolve the limitations but the possibility cannot be ruled out. Despite the shortfalls in some areas, the increasing number of Passivhaus schemes in the UK sets a strong foundation for the future.

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Tables:
Table 1: Affordable housing standard floor areas, in comparison to the actual Wimbish floor areas creating using [Wimbish Report, 2013] and Affordable Homes (SPG) [Online] Available at: http://www.wychavon.gov.uk/cms/pdf/wdc-planning-spg-affordable-housing.pdf [Accessed March 2014]

Images:
Image 1: Wimbish units 11-14 [Own Photograph] taken November 2013

Image 2: Wimbish site plan (Wimbish Report, 2013) [Online] Available at: http://www.wimbishpassivhaus.com/datasheets.html [Accessed August 2013]

Image 3: Wimbish Passivhaus, [Own Photograph] taken: November 2013

Image 4: Terrace houses on Mill Lane, Near Saffron Walden [Own Photograph] taken: November 2013

Image 5: Solar shading techniques at Wimbish, [Own Photograph] taken: November 2013

Image 6: Airtightness around the windows [Online] Available at: http://www.passivhausplaner.eu/upload/passivhaus_Parsons_Wimbish.pdf [Accessed April 2014]

Image 7: Airtightness on ground level Available at: http://www.passivhausplaner.eu/upload/passivhaus_Parsons_Wimbish.pdf [Accessed April 2014]

Image 8: Airtightness at eaves detail Available at: http://www.passivhausplaner.eu/upload/passivhaus_Parsons_Wimbish.pdf [Accessed April 2014]

Image 9: MVHR system (Wimbish Report, 2013) [Online] Available at: http://www.wimbishpassivhaus.com/datasheets.html [Accessed August 2013]

Image 10: Typical section (Wimbish Report, 2013) [Online] Available at: http://www.wimbishpassivhaus.com/datasheets.html [Accessed August 2013]

Image 11: Airtightness results (Wimbish Report, 2013) [Online] Available at: http://www.wimbishpassivhaus.com/datasheets.html [Accessed August 2013]

Image 12: Thermo graphic imaging of window: (Wimbish Report, 2013) Available [Online] Available at: http://www.wimbishpassivhaus.com/datasheets.html [Accessed August 2013]

Image 13: Image of window used for thermo graphic imaging (Wimbish Report, 2013) [Online] Available at: http://www.wimbishpassivhaus.com/datasheets.html [Accessed August 2013]

Image 14: Gas Consumption results (Wimbish Report, 2013) [Online] Available at: http://www.wimbish-passivhaus.com/datasheets.html [Accessed August 2013]

Image 15: Electricity Consumption results (Wimbish Report, 2013) [Online] Available at: http://www.wimbish-passivhaus.com/datasheets.html [Accessed August 2013]

Howe Park Passivhaus

Cordelia Hill

Location Milton Keynes
Building Type Family Dwelling
Construction Type Timber frame
Floor Area 182m^2
Completed Summer 2012
Year Certified July 2012
Overall Cost £2000/sqm
Airtightness Value 0.065 h-1 @ 50 Pa

The Parks Trust, Milton Keynes
Eco Design Consultants
Parkway Construction MK Ltd
Milton Keynes Council
Touchwood Homes (timber frame construction and airtightness specialists)

Abstract
Howe Park Passivhaus is a five bedroom family home that stands alone in the rural setting of Howe Park Wood. As a high performance Passivhaus, it provides an excellent quality of air and thermal comfort with minimal fuel bills. It uses timber frame construction with Kebony cladding to ensure an aesthetically pleasing exterior as well as a highly sustainable structure. The insulation, triple glazing and innovative details ensure this house to be very high performance with air changes as low as 0.065 ach per hour. Due to this exceptional attention to detail, the house is able to gain heat from solar energy and use heat from the MVHR system with minimal heat loss through the fabric of the building. Direct electric heating is available as a backup system but the cost of this is offset by electricity produced from other renewables, such as photovoltaic panels and solar panels.

This chapter addresses the underlying problems in designing, constructing and living in a Passivhaus. Thorough background research and primary investigation into the design and construction of Howe Park Passivhaus, such as interviews with the architects, have provided vital information for the acquisition of an in-depth knowledge and understanding of Howe Park Passivhaus and the Passivhaus standard in general. The design procurement and architectural objectives, the processes involved and the collaborative construction, and the post occupancy aspects have been identified as areas unique to this case and will be discussed in depth in this dissertation. It refers to the adoption of the Passivhaus standard on a much larger scale and how the combination of materials, technology and a highly competent design team, can make for a design that is efficient in both design and function.

Howe Park Passivhaus - ‘Architecture That Doesn’t Cost the Earth’

Part 1 – Outline

Howe Park Passivhaus, completed in summer 2012, was designed by Eco Design Consultants, a company whose knowledge of Passivhaus was relatively limited at that time. The Howe Park project had the role of introducing the architects to the Passivhaus construction method and acted as a catalyst in educating the design team, therefore improving the speed and quality to which subsequent projects were designed. This building chapter describes, analyses and evaluates important aspects of Passivhaus design with relation to Howe Park Passivhaus. It introduces a set of core themes concerning the architectural design objectives, the different processes involved throughout design and construction and how the occupants fare with this change of lifestyle resulting in living at lower cost and in a healthier environment in terms of air and thermal comfort (Bre, 2013).

Howe Park is built in a rural setting on the outskirts of Howe Park Wood, Milton Keynes. Eco Design Consultants were commissioned by The Parks Trust to build a sustainable dwelling in this conservation area, their design being the most sustainable and sensitive to the context and environmental principles of The Parks Trust. The site was presented as an investment opportunity to generate an income for maintenancei of the green spaces of Milton Keynes (Budden, A., 2013). The land was leased to The Parks Trust by the Homes and Community Agency for one hundred years, meaning they could not sell the derelict house originally built on the site. Having little experience with sustainable housing design such as the Passivhaus standard, The Parks Trust looked for a company passionate about sustainable design and chose Eco Design Consultants’ design, who were the sole practice to submit a design encompassing Passivhaus principles. The scheme of Eco Design Consultants was chosen above other competitors for its environmental ingenuity and appeared the best choice to generate a good financial return for The Parks Trust (Budden, A., 2013). Eco Design Consultants firmly adhere to their mission statement, building sustainable homes with an unconventional design and exceptional attention to detail.

> “Champion great architecture that creates exceptional, fun places to live, work and play without detriment to others or the planet.” (Eco Design Consultants, 2012)

Eco Design Consultants have metamorphosed into a practice that specialises in sustainable design and all their schemes meet the requirements for either Passivhaus or the Code for Sustainable Homes. They believe that architects play a key role in encouraging the world to live more sustainably, hence helping to achieve the targets laid down in the Climate Change Act of 2008. An instructive client-architect relationship is essential to support the use of Passivhaus principles over traditional construction techniques, the modus operandi of a Passivhaus build and the post occupancy rewards and benefits. Alan Budden, the principal architect for Eco Design Consultants, was formerly employed as a Code For Sustainable Homes assessor. Because of this, he was aware of what building a sustainable dwelling entails and the targets that needed to be met. With this background knowledge and through learning about Passivhaus certified components, for example, how to use the PHPP and how to perform a blower door test, this was the perfect project for Alan to undertake to develop his skills to become a certified Passivhaus designer.

Eco Design Consultants used the PHPP to optimise the design and determine whether the proposed scheme would reach Passivhaus standard at the conceptual design stage. This design tool is an essential aspect of the quality assurance process and is used to balance the practical building constraints against the design's energy performance. It highlights obvious design flaws in the early stages, thus avoiding reworking of the design. Lord Kelvin stated, 'you cannot manage what you cannot measure,' (Siddall, M., 2012) which reiterates the importance of efficiently designing using facts and figures to result in a specific, high quality outcome; where theory and reality are considered simultaneously (Siddall, M., 2012). Additionally, when attempting to deliver low energy housing in the UK such as Passivhaus, it establishes a datum point where one Passivhaus can be compared to another (Siddall, M., 2012). Using the PHPP, predictions made to meet the Passivhaus requirement values for Howe Park Passivhaus were accurate and reasonable (Budden, A., 2013). Having based their ideas on previously built Passivhäuse, the architects had a good idea of how much the house would cost which they estimated at around £1650/m2. In reality, the house cost £2000/m2 to build owing to human error and open-book contractors after the design stages (Budden, A., 2013). With current, traditional construction, the national average build cost is below £1000/m2 and £2000/m2 is the norm for a Passivhaus build (Rollason, T., 2011). This larger initial outlay is not an appealing factor for the public when considering undertaking a project using Passivhaus principles. However, higher short-term outlay may be offset by long term returns if the owner is prepared to keep the building for a period of time.

Collaboration and constantly open lines of communication are key in reaching optimum agreement between aesthetics, structural integrity and efficiency as a Passivhaus, especially as pooled expertise from different areas could reduce the complexity of the design while having minimal effect on aesthetics and performance. Eco Design Consultants worked with other companies to encompass expertise in different areas. Touchwood Homes had the role of designing the timber frame to the architect's specification, calculating sizes of timber required and structural load paths and recognising the opportunities to reduce cold bridging within the structure (Wilkinson, R., 2013). Further, they approached the architects with methods of optimising the design, allowing Eco Design Consultants to accept or reject these suggestions. An example of this in Howe Park is the decision made on the airtight layer between the two parties, which is discussed later. Looking at the different inputs in the design stage will help people to understand the challenge of taking on a Passivhaus project and realise and solve potential problems during planning rather than after construction, the more expensive route.

With sustainability and energy efficiency becoming increasingly important stimuli for building design today, the design of a Passivhaus is fundamentally about the combination of different materials, technologies and construction techniques to create an architecturally intelligent building. However, with the strong environmental factors dictated by the site at Howe Park, application of the Passivhaus standard could have resulted in a simple, compact form rather than something more intricate and complex, perhaps at the loss of some interesting design features.

Part 2 - Design

The application of the Passivhaus standard drove the design from the beginning. Eco Design Consultants considered no other certification schemes, but their mission statement inferred their design would be sustainable nevertheless. This mission statement along with the Passivhaus certification route gave them a strong project to present to The Parks Trust. As this was the first Passivhaus Eco Design Consultants designed, they were reluctant to take risks with the form and structure of the building (Budden, A., 2013). Diving into something challenging and unfamiliar was rewarding for them but they decided on safer options for construction. The build was fully influenced by form factor and efficiency, as dictated by Passivhaus standards so the fabric of the building was not intended to be complex. According to Alan Budden, designing to the Passivhaus standard posed no further design constraints. The five bedroom, three storey, family home replaced a derelict house. The aim was to construct a high performance, aesthetically pleasing and environmentally sustainable dwelling, intelligent in design and operation resulting in a more energy efficient lifestyle (Eco Design Consultants, 2012). The house was built over the footprint of the previous dwelling, rotated slightly to maximise solar orientation.

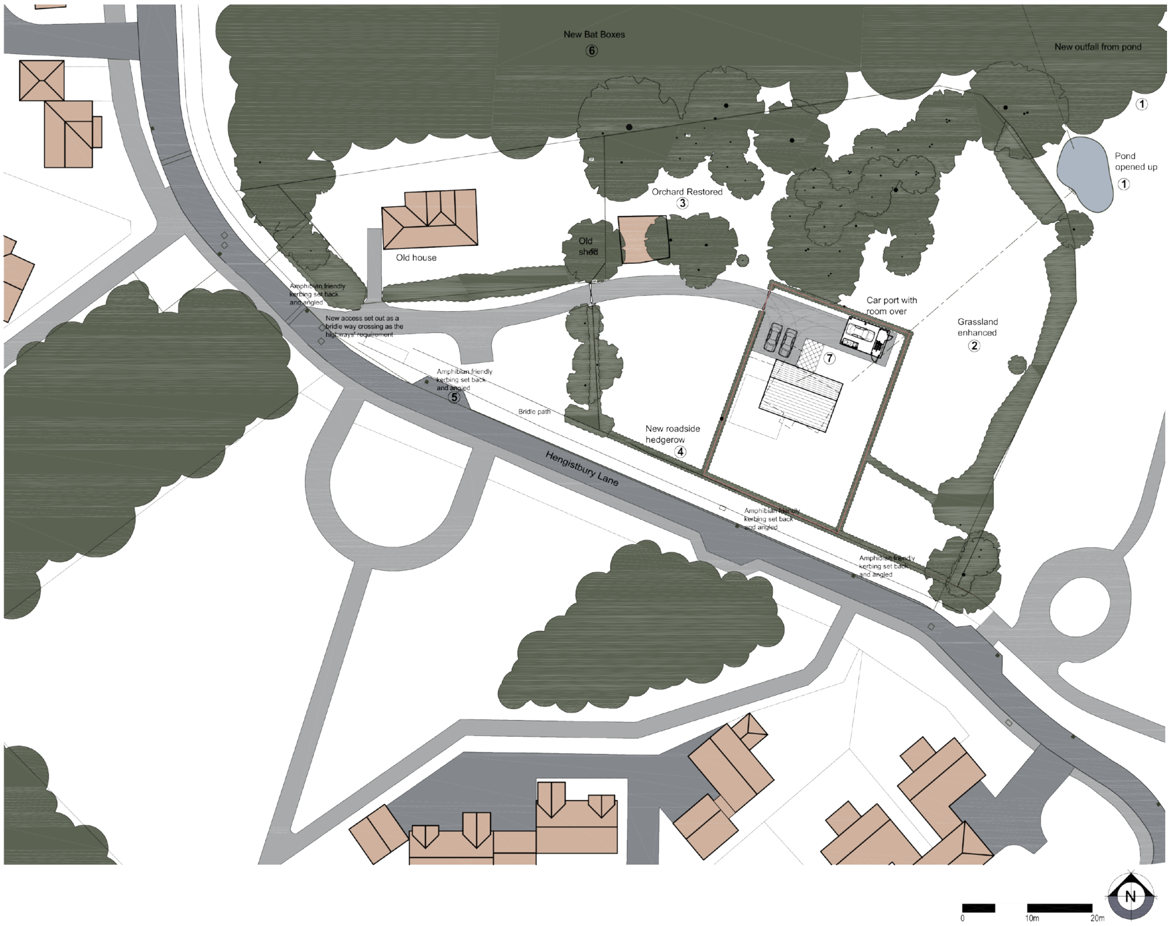

Figure 1 – Location Plan

In a rural setting such as Howe Park, the site also placed restrictions on the design owing to the conservation area and limitations on possible, alternative schemes that may not have been sympathetic to the area. Despite this, the architects found that the site did not impede the choice of materials or how the building was constructed. This is because being in a secluded plot away from other buildings, responding to the context of other buildings on site was not an issue, so they only had to design to consider the environment. Planning permission was granted on the condition that existing wildlife, fauna and flora were protected and encouraged (Eco Design Consultants, 2012).

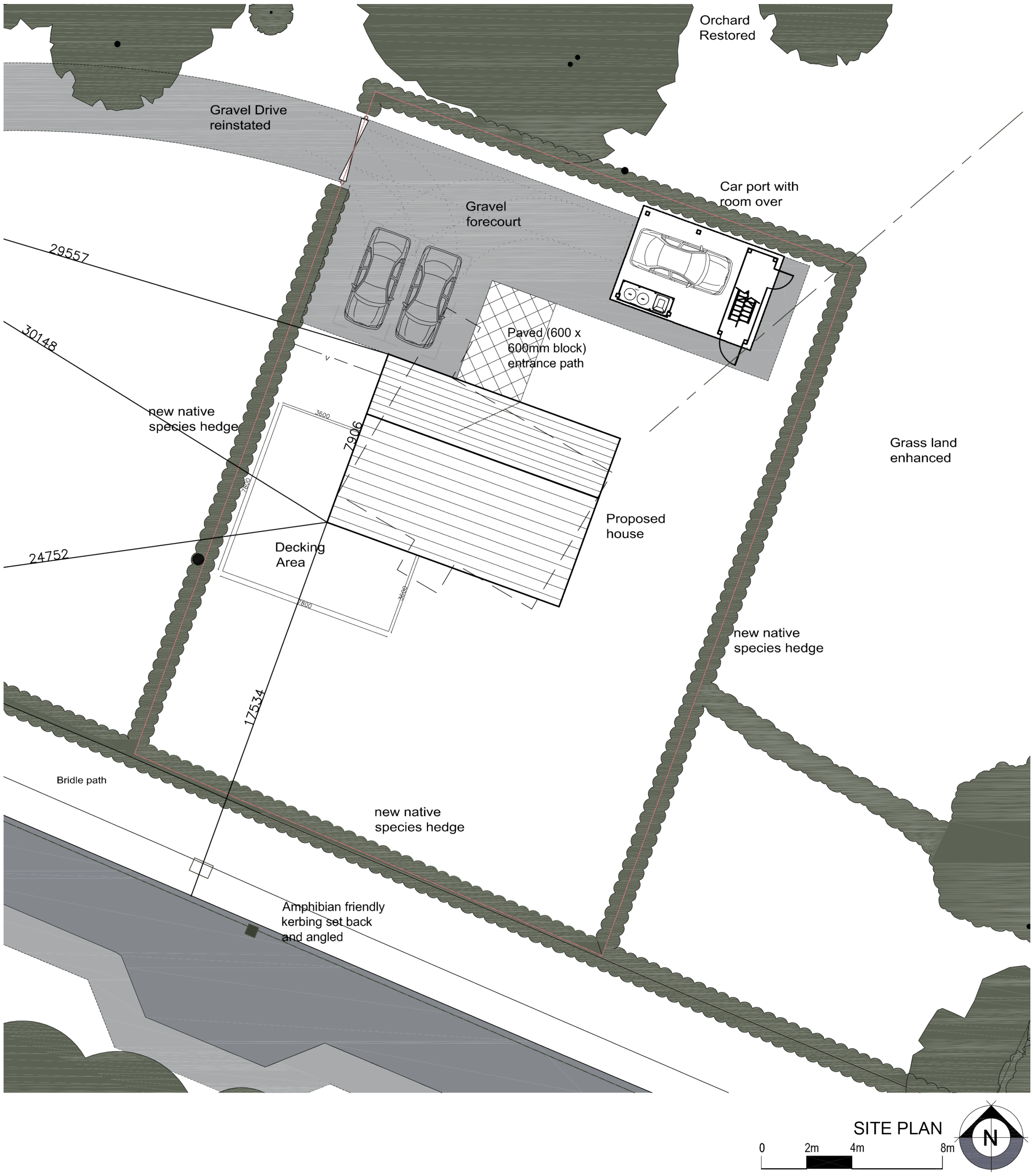

Figure 2 – Site Plan

The building is a timber frame construction with a range of innovative construction techniques to make it high performance. Originally, the architects were considering using rendered blockwork for the exterior but the clients preferred it to be timber clad to suit the environment, so a frame comprising engineered timber I-beams was used. Following this, it also turned out that this was the most efficient method of attaching the cladding to the building with minimal cold bridging (Budden, A., 2013). A range of materials was selected for the building's exterior to enhance the aesthetics. A combination of Kebony wood boards, Eternit roof tiles and Rockpanel broke up the elevations (Chadha, S., 2012) to make them look less stark. Another aesthetic consideration was the substantial height due to the three storeys accommodating the generous bedrooms (Chadha, S., 2012). The plan of the building responded to the site to maximise solar potential so certain rooms such as the living spaces would benefit from solar gain. Arranging spaces with this orientation was challenging as compromises

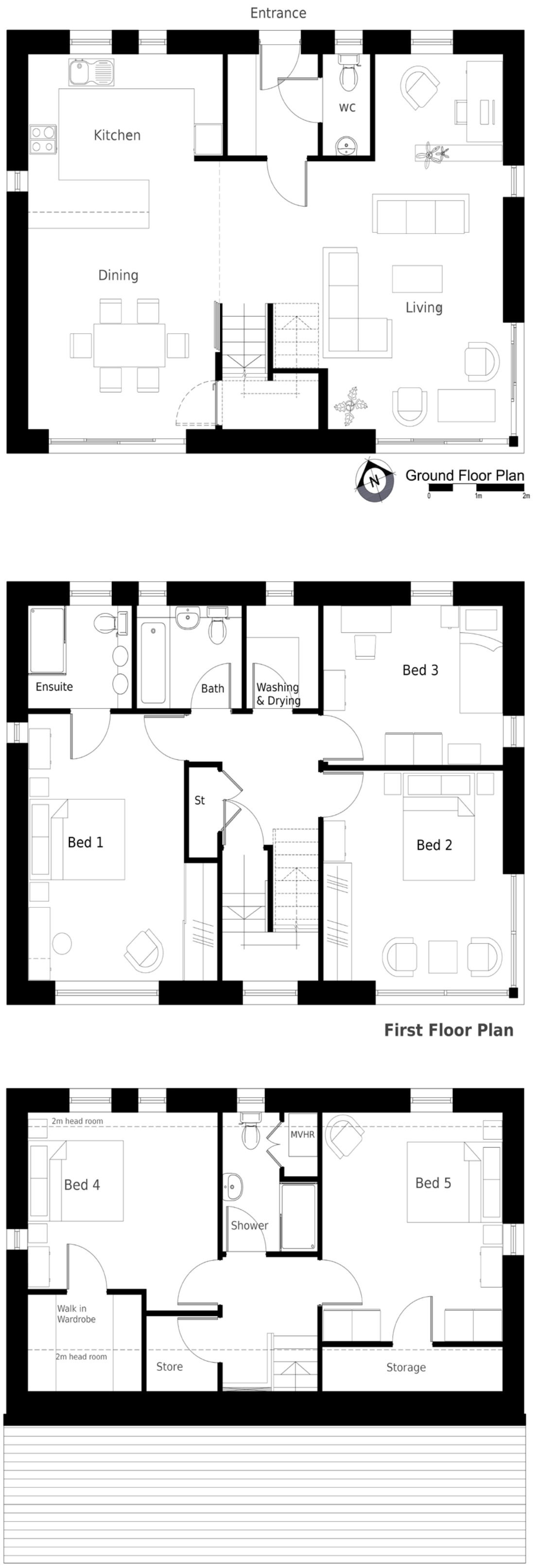

Figure 3- Howe Park Passivhaus Plans

were made regarding the area of glazing on the north faces of the building to preserve heat. However, Eco Design Consultants designed the fabric of the building in such a way that heat transfer through the building envelope was minimal and so were able to place windows on all faces of the building. Assisting solar gains is the MVHR system which recovers ventilation losses by recovering heat from the outgoing air, reintroducing it into the fresh air supply, which keeps the building warm in winter. The building envelope also has an airtight layer, unlike other conventional buildings.

Although no other sustainable schemes were considered aside from Passivhaus, the architects employed the use of water butts, a drainage system to feed rainwater back into the pond, and a number of recycled or low VOC paints. In addition to pushing for efficiency using Passivhaus principles, renewables were employed to offset energy costs. Photovoltaic panels were used to help offset costs from backup systems, like direct electric heating, installed because the gas mains were too far away from the site. Solar panels were used to contribute to the demand for hot water. The PV panels and solar panels were located at almost the optimum angle on the south facing side of the roof, which coincidently had a larger surface area than the north. After interviewing Alan Budden, it was discovered that this was not to accommodate a larger area of panels but designed according to the roof angles inside the rooms and to create an optical illusion of the street frontage being two storeys instead of a three-storey dwelling. Nevertheless, these renewables were carefully considered during the design stages and were not just a last minute piece of unnecessary adornment. In Howe Park Passivhaus, it is the meticulous design process, robust quality assurance and innovative construction that made it efficient, and the renewables were an added bonus. – “No matter how much decoration you add, you will never make a silk purse” (King, D., 2013).

In Howe Park Passivhaus, the rectangular footprint of the original, derelict building and its form factor generated the form of the design. This was significant in the design and was critical for the aesthetics and layout. The more com-

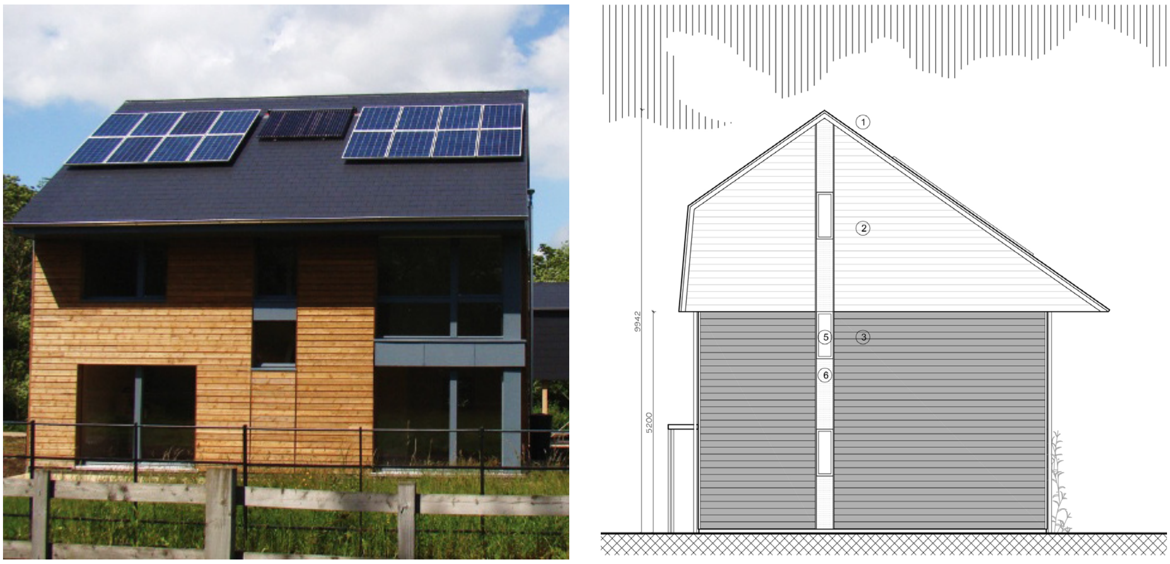

Figure 4 – Photo of south façade and west elevation showing sloping roof at 36 degrees to the south

pact the design, the easier and cheaper it is to reach the Passivhaus standard of 15kWh/m2 per annum for space heat demand. (Cotterell, J., Dadeby, A., 2012, Pg. 21). Putting this into perspective is the average annual specific space heat demand for an existing, traditionally constructed UK house, being around 200kWh/m2 per annum. Howe Park Passivhaus has a form factor of 2.77 and reflects approximations of u-values needed for the value of its form factor. Although desirable to achieve this standard with a simple yet effective design, there is a risk of having a building labelled as box like or unimaginative (Gorswift, N., 2012).

Howe Park Passivhaus used the roof pitches and a broken up elevation to disguise this compact form resulting in

FORM FACTOR	WALL/ROOF/FLOOR – APPROXIMATE RANGE OF U-VALUES NEEDED TO REACH 15kWh/m2 per year
<2	0.15W/m²K
2-3	0.10-0.15W/m²K
3-4	0.10W/m²K
<4	0.05-0.10W/m²K

Figure 5- Form Factor Table, where the lowest number provides the most efficient design in terms of complexity of the form and heat loss potential

the removal of the stereotype associated with more compact designs. With this being the first Passivhaus for Eco Design Consultants, they did not wish the design to be too experimental to ensure a high performance end product. With the Passivhaus standard and achieving a good value for form factor as the primary design objectives, the initial design concepts did not substantially develop throughout the project other than the internal room planning. The size and shape of the building were exactly the same in the planning stage as in the end product. Internal room changes, such as increasing the number of bedrooms, were undertaken only to make the property easier to rent.

The house was initially a four bedroom house designed for an occupancy of eight. However, estate agents recommended adding a fifth bedroom to put the house on a more executive level and add value. The study area and void overlooking the living space was turned into the fifth bedroom. This made the house more saleable with a suggested occupancy of 10 but the change in internal layout caused some problems. The living space (ground floor) and study area (first floor) faced south, with double height windows rising up through the space. Once the study area

Figure 6- South and north elevations showing the two-storey and three-storey frontages

was transformed into another bedroom and the void discarded, the new south facing bedroom became very hot and uncomfortable owing to the large windows. Alan Budden said ''if they had planned for this change, they obviously wouldn't have put large windows through the space'' (Budden, A., 2013). This provides an example of a problem that is unforeseen and sometimes can be hard to solve. These mistakes add to the evolution of a better model for Passivhaus.

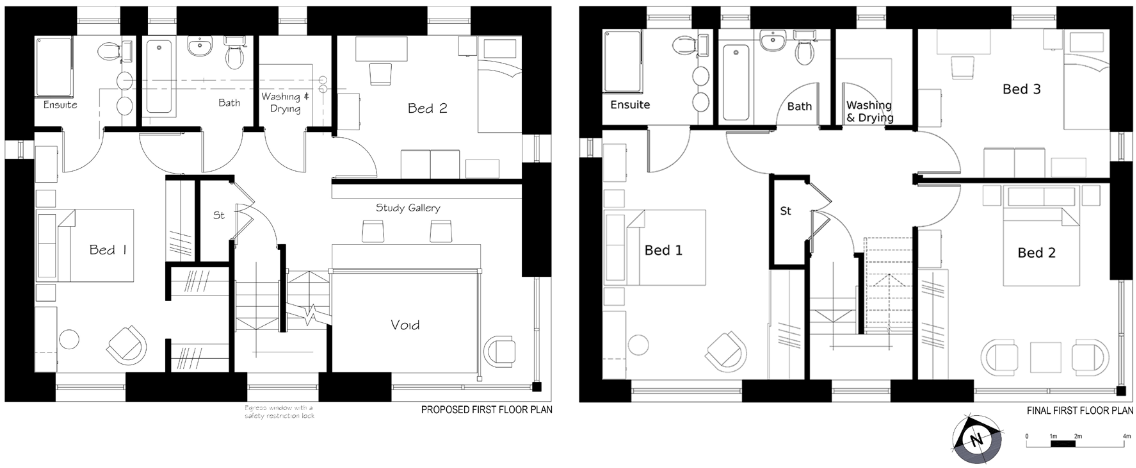

Figure 7- Proposed and final first floor plans

Part 3 – Process

Selecting the right materials is critical in how effectively the building functions. Passivhaus technology and material costs are high with Howe Park Passivhaus costing £2000 per square metre. It can be argued that assumptions can be made as to whether the extra costs for superior materials and technologies at the outset will be suitably offset by reduced energy bills throughout the lifetime of the building. In Howe Park Passivhaus, a relatively new build, this information is still being accrued by the frequent collection of post occupancy data. Within a few years, this data will provide an accurate picture of financial and energy savings acquired throughout the buildings lifetime.

Eco Design Consultants selected materials based on sustainability, embodied carbon, longevity and toxicity of the material (Eco Design Consultants, 2012). Natural and recycled materials were used where possible like low VOC and natural paints and flooring made from recycled rubber (Eco Design Consultants, 2012). It made use of specialist green porcelain tiles (McCloud, K., 2012) that use 70% less raw material than normal porcelain and utilised renewable energy sources in manufacture. These were selected for the kitchen and bathroom but were fragile and problematic to install. Due to human error, many sheets snapped during installation, resulting in wastage. The architects suggested in future fitting them using a specialist that works with fine/fragile materials rather than a builder who is used to more robust materials. The architects also used exterior mechanical blinds to shade the living space. The manufacturers claimed that sensors would make them retract when the wind blows (Budden, A., 2013). However, this did not happen so cables and fixings kept coming away from the walls and proved problematic and remain difficult to maintain.

Specific materials and construction techniques were chosen to prevent cold bridging in the building envelope, which in turn, reduces energy bills. Wrapping the structure in continuous insulation minimises thermal bridges and improves the performance of the building (Cotterell, J., Dadeby, A., 2012, Pg. 20-21). To minimise the chance of cold bridging, Eco Design Consultants used engineered timber I-beams for the frame of the building rather than solid timber beams (Chadha, S., 2012). This reduced conduction through the beam's web resulting in minimal cold bridging through the fastening of the softwood timber cladding and through the frame to the interior. Heat transfer was minimised using high performance Warmcel insulation, triple glazed windows and other insulating materials around junctions. The space between the timber I-beams was filled with 300mm of Warmcel insulation, with the cladding then directly fixed to the exterior flange of the beams. Hence, the insulation paused at intervals where the beams were present. By discarding the timber sole plate and using a horizontal timber I beam to support the vertical frame, insulation between the foundation and walls was continuous. Theoretically, there was no load being distributed on the web of the beams, just on the timber flanges and the insulation. Eco Design Consultants aim to increase the insulation layer by 200mm in other projects of this nature to reduce cold bridging further. The architects focused on making airtight connections between the different junctions of the building to reduce cold bridging, filling any areas lacking in insulation with phenolic foam, for example, around window frames. The Passivhaus requirement for airtightness is $\leq$ 0.6 air changes per hour. Demonstrating its airtight potential, Howe Park Passivhaus has 0.065 air changes per hour (Budden, A., 2013). This minimised involuntary and uncontrolled air leakage through the fabric of the building and aided the building in keeping a controlled, comfortable air supply. Eco Design consultants had to educate and familiarise themselves with air blower door tests so they could successfully identify leakages and fix them. With the combination of the airtightness layer, the insulating properties and the form factor of the building, energy wastage is minimised, benefitting the financial return in the long term.

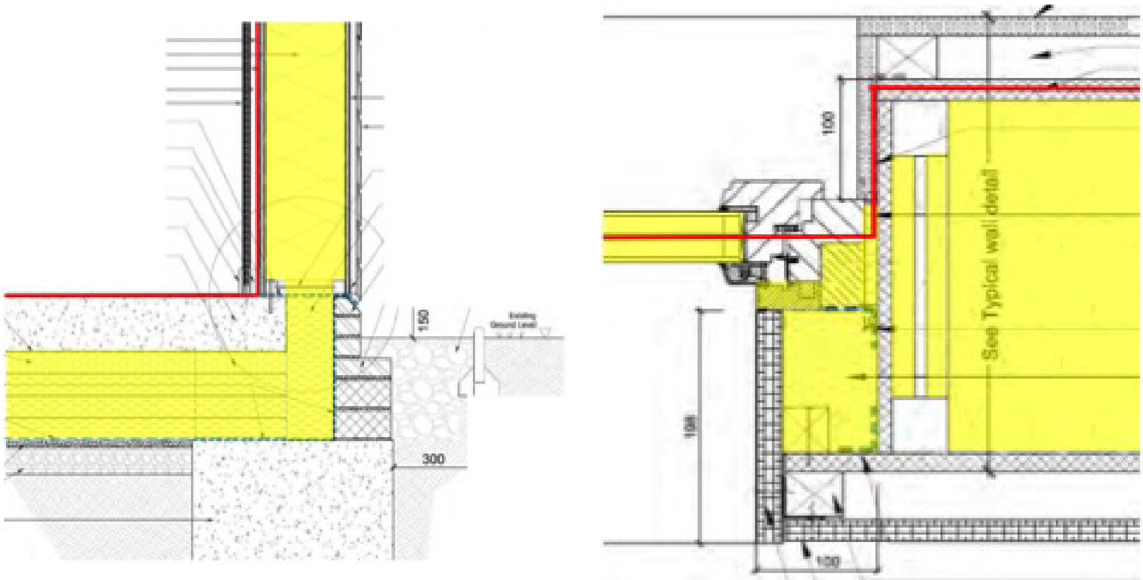

Figure 8- Howe Park Passivhaus construction details showing the principle of wrapping the building with continuous insulation (yellow)

Eco Design Consultants and Touchwood Homes worked together to design the frame and airtight layer. The methods that Touchwood Homes use in their buildings for the airtight layer usually reach 0.2 and they stated, "due to the importance of air tightness here, Eco Design Consultants went for a belt and braces approach and had an internal layer as well." (Wilkinson, R., 2013) Touchwood Homes proposed that an external layer of Agipan DWG board sealed with non-setting rubber mastic would work as the airtight layer. Eco Design Consultants challenged them, claiming there was no evidence to prove that it would work to achieve the sufficient value for airtightness they aspired to. Consequently they put their own airtight layer on the interior and called the Agipan DWG board and mastic layer a wind tight breathable membrane. The architects also had concerns about the external vapour check positioning put forward by Touchwood Homes, just in case their airtight layer did not work. Alan Budden stated ''the vapour check should always be on the inside or a least partially within the insulation layer to prevent cold bridges, condensation and mould'' (Budden, A., 2013). Eco Design Consultants used 18mm of OSB3, sealed with airtight tape as their airtight layer. Tescon Level 1 Tape was used extensively to seal intersections between components that were at risk of cold bridging. Care was taken around services to ensure nothing penetrated the airtight layer or, if it did, grommets and large amounts of insulation were used to minimise cold bridging (Budden, A., 2013). Eco Design Consultants also used a detail at the foot of the building that enabled the insulation to continuously run from the walls to the foundations, providing a sensible detailing at the damp proof course to minimise air leakage whilst simultaneously preventing moisture penetrating the structure at this level. The effectiveness of these details reflects in the energy bills and can determine the success or failure of a Passivhaus. The more airtight a building is, the harder it becomes to purge stale air (McLeod, R., 2012, Pg. 1), so having an MVHR system, as in Howe Park Passivhaus, overcame this problem, improving the internal air quality. Eco Design Consultants used the Zehnder ComfoAir 550 (Budden, A., 2013) for this building, a Passivhaus Institut accredited component (Zehnder, 2013). MVHR sometimes has a poor reputation owing to it not being installed or used properly. Alan Budden stated, "It would be very hard to achieve the Passivhaus standard in the case of Howe Park and indeed in general, without it" (Budden, A., 2013).

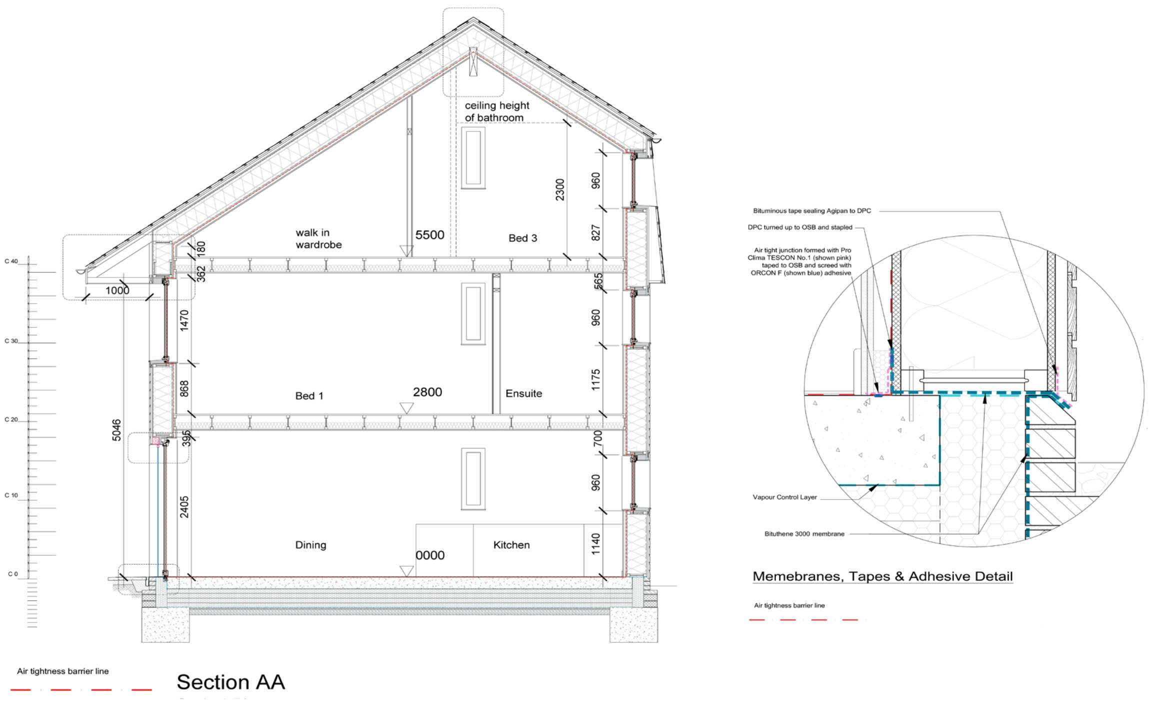

Figure 9- Howe Park Passivhaus construction detail showing the airtight damp proof course, sealed with Bituminous tape

Fig. 10 shows a 19% improvement from the minimum Passivhaus requirement for Howe Park and a 17% improvement between 0.6 and 3 ach. In Howe Park Passivhaus, air was extracted from the kitchen and bathrooms, where temperatures can be significantly higher and recycled to heat up the incoming airflow. At first the system was not set up properly and there was a distinct lack of communication between companies who installed the MVHR system as ducts were positioned in the wrong place. This led to the arduous task of rearranging the service ducts to solve the problem and make the air ducts inside the house easily accessible for maintenance. In addition to this, Alan Budden believed the ducts leading from the MVHR were too long, making the ventilation system slightly less efficient (Budden, A., 2013). This is an example of where open and frequent communication between all parties involved in a project is of paramount importance. Besides this problem and a post occupancy miscommunication issue (discussed later), there were no further communication problems. However, there are such cases where miscommunication can have a severe and costly outcome such as in the case of Camden Passivhaus, London.

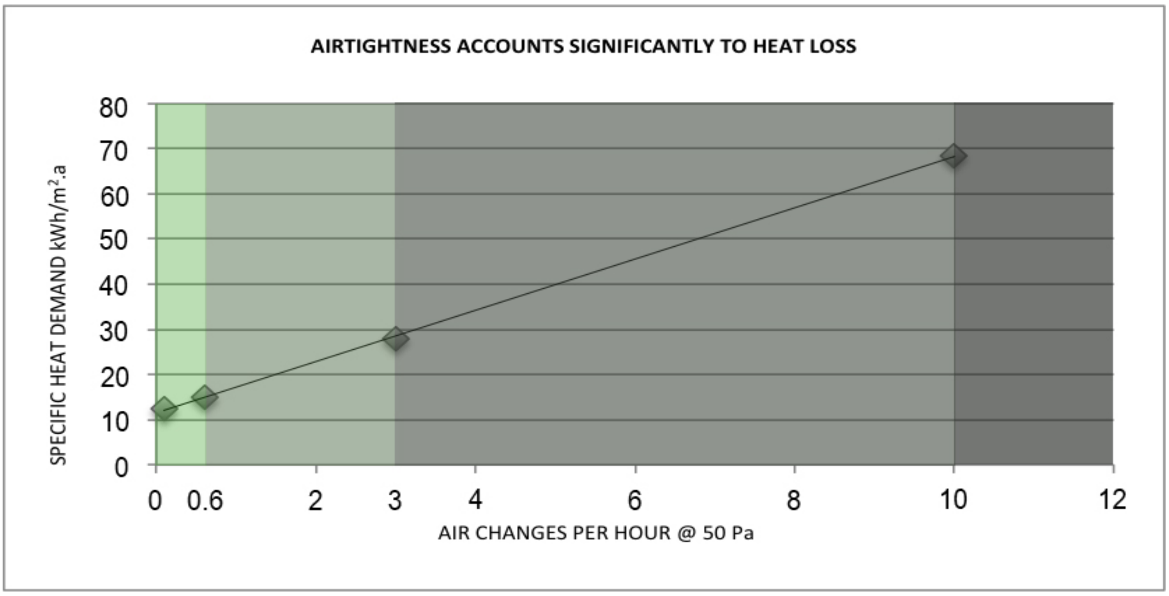

Figure 10- Line graph showing the significance of airtightness compared to heat loss

U-values form the basis of any energy or carbon reduction standard (RIBA, 2013) and help to predict the behaviour of the building after construction. Each individual material in Howe Park Passivhaus has a U-value that contributes to the total thermal resistance of the building envelope. The U-values for Howe Park Passivhaus are shown in fig. 11 and these values reflect the approximations for form factor value in fig. 5. These values were worked into the PHPP prior to construction, in the early stages of design. Because of this, Eco Design consultants were able to test the feasibility of their scheme in the earlier stages of the project so they did not have to re-work and re-design mid way through the project. However, these highly efficient materials with a low conductivity and good u-value are expensive and are not as readily available in the UK as in Europe. With an immature supply chain, around 20 years behind Germany (Priebe, K., 2013), Eco Design Consultants had problems sourcing materials, especially triple glazed windows, from distributors in the UK so had to import the majority of materials from

BUILDING ENVELOPE	U-VALUE
FLOOR SLAB	0.12W/m²K
EXTERIOR WALLS	0.14W/m²K
ROOF	0.12W/m²K
WINDOWS	0.6 & 0.7W/m²K
WINDOW FRAMES	0.97W/m²K

Figure 11 – Table containing the u-values of the building envelope components in Howe Park Passivhaus

Europe, adding to the overall embodied energy of the project. Much of the main structure was imported owing to material availability and the wider market in Europe for Passivhaus. This included the timber frame, triple glazing, Agipan board, non-setting rubber mastic and the airtight Tescon tapes. To optimise sustainability of Passivhaus in the UK, it is essential for materials and labour, where possible, to be locally sourced to develop expertise in the construction industry in the UK and provide a sustainable supply chain with readily available components.

Collaborative work is hugely important in the design of a Passivhaus. When constructing the building, strict rules must be put in place to ensure the best outcome and performance of the building. In the case of Howe Park Passivhaus, communication was vital, ensuring there was no risk of the building being less efficient and having values matching those predicted in the PHPP. Good site management and two-way dialogue between the architects and construction team ensured that Eco Design Consultants' plans were effectively applied by arranging a plan for the design and construction stages and an organised quality assurance timeline. Eco Design Consultants and Touchwood Homes worked together to design the frame and airtight layers of the building. As both companies understood the principles of Passivhaus design and specialise in environmental design and low energy products, this combination of teams tended to make for a very smooth construction, proving that teams educated in this area can work well together even though they may have varying opinions and approaches to the project. Touchwood Homes stated that there was: 'definitely a collaborative approach, which worked very well in this case' (Wilkinson, R., 2013).

Passivhaus is still in its infancy in the UK, so competent, well-educated and informed design and construction teams are mandatory. This ensures minimal problems ensue regarding reticence on the part of the builder with non-traditional methodology and scarce availability of certain elements such as triple glazing. To establish Passivhaus as a standardised building method will require educating current architects, students and all other teams involved in the construction industry to learn about Passivhaus design and construction. Eco Design Consultants provided workshops to educate their team (Budden, A., 2013) so everyone was at the same level of knowledge and understanding of how a Passivhaus is designed, constructed and functions. Driving this standard forward will present the professions in the construction industry with a fundamental skill set with regards to Passivhaus.

Part 4 - Post Occupancy

A Passivhaus is by no means a quick fix solution for housing and is definitely a long-term investment where the occupants would need to be there for a significant length of time to reap the benefits of the technologies installed. Howe Park is setting a precedent for a more energy efficient, healthier lifestyle for the occupants. As Phil Harding says, "Short term 'dash for cash' economic solutions hinder progress towards a better, more sustainable, world." (Harding, P., 2013). However, living in a Passivhaus does require educating the users to a level where they can run the house most efficiently. Eco Design Consultants provided the tenants with a handbook, explaining how the different systems in the house should be used. During post occupancy, there were a few problems due to the users' personal preference, misunderstanding and negligence regarding the instructions in the user guide, another example where miscommunication can result in an undesirable outcome. Later, the problems were overcome through reiteration by the architects of how the Passivhaus works.

Dr. Paola Sassi, faculty of technology, design and environment at Oxford Brookes University, is currently undertaking the post occupancy monitoring of Howe Park Passivhaus, providing retrospective data collected between 3rd March and 7th May 2013. The data collection covers only periods of colder weather and warming spring weather (Sassi, P., 2013). The next data collection will show how the building fares in the summer months.

It is essential to get thermal comfort right in a Passivhaus to make the internal environment comfortable and healthy. The focus is on reducing cold surfaces, condensation and draughts as well as having an established heating and cooling method all year round with sufficient ventilation (Cotterell, J., Dadeby, A., 2012, Pg. 21). The ventilation system ducts are easily accessible in Howe Park Passivhaus so filters can be maintained to ensure a good quality of clean air with minimal airborne pathogens. As an architect, it is imperative to imagine and understand the user's experience in a certain type of environment and space. Getting this particular aspect of design correct is important in any house as an uncomfortable temperature and humidity could make the user unwell and unhappy.

In Howe Park Passivhaus, the internal temperature varies. In the lower floors of the building, the temperature was comfortable but decreased towards the top of the building where the house did not benefit from solar gain, there being a decrease in temperature from ground floor to second floor of an average of 3.5 degrees Celsius. This temperature difference decreases with the seasonal change and as external temperatures increase. The occupants made adjustments to the house in the first few months of tenancy. Additional heaters were required in the bedrooms for the winter months and fans were added in the living rooms and bedrooms to help the circulation and air movement. It was also the occupant's personal preference as the family are from India and are used to a hotter climate, being accustomed to sleeping with a fan on for comfort. In addition to this, the family insisted on having an uneconomical tumble dryer rather than air-drying their clothes, which would have raised the house's relative humidity.

Despite minor temperature problems, the Passivhaus demonstrated its ability to keep internal temperatures stable compared to the peaks and troughs in external temperatures, in warming weather (April) remaining 8 degrees Celsius above the average external temperature and in colder weather (March) remaining 15 degrees Celsius above the average external temperature.

Adjustments were made to the ventilation system to increase the relative humidity in the house as in March the humidity was only 31% as opposed to the recommended humidity levels of 40-60%. The humidity increased slightly along with the change in season as the windows were kept open more often in warmer weather but to make conditions more comfortable for the occupants, a humidifier was added in the main living space. With the addition of fans and a humidifier, the dwelling was considered to be very comfortable, with a good quality of air despite the relatively low humidity and the lack of air movement. The additions were satisfactory to combat the problems with air circulation and humidity, so the occupants were very pleased with their new home (Sassi, P., 2013). Further, the problems with the ventilation and humidity were not helped because of the number of occupants. There are only three tenants but the occupancy of the house was designed for ten, meaning there were not enough occupants for the space to take full advantage of the design elements. Having more people in the house would have resulted in a higher humidity. There were also mistakes made with communication between the tenants and the architects with regard to how the MVHR system works. When the tenants felt the house was too cold they turned up the MVHR with the expectation of the cold spaces warming up. Consequently this caused over ventilation of the property resulting in the removal of hot air and a resulting rapid dehydration of existing air within the building, further demonstrating the importance of educating the occupants about new technologies such as MVHR.

With regard to natural lighting, the south facing spaces were found to provide an excellent quality of light all year round. The second floor spaces on the north, east and west sides of the building were found to be a little dull as they had much smaller windows so the building could comply with Passivhaus standards. However, the lighting conditions in these spaces are expected to improve in the warmer months after the next data collection.

All of these findings regarding the qualitative data reflect how the occupants feel in the house in relation to the quantitative aspects. It is an admirable first attempt for Eco Design Consultants, with only a few design alterations and with only 0.065 air changes per hour. Driving the Passivhaus standard forward in the UK will set a model so issues with post occupancy aspects can be rectified in the future.

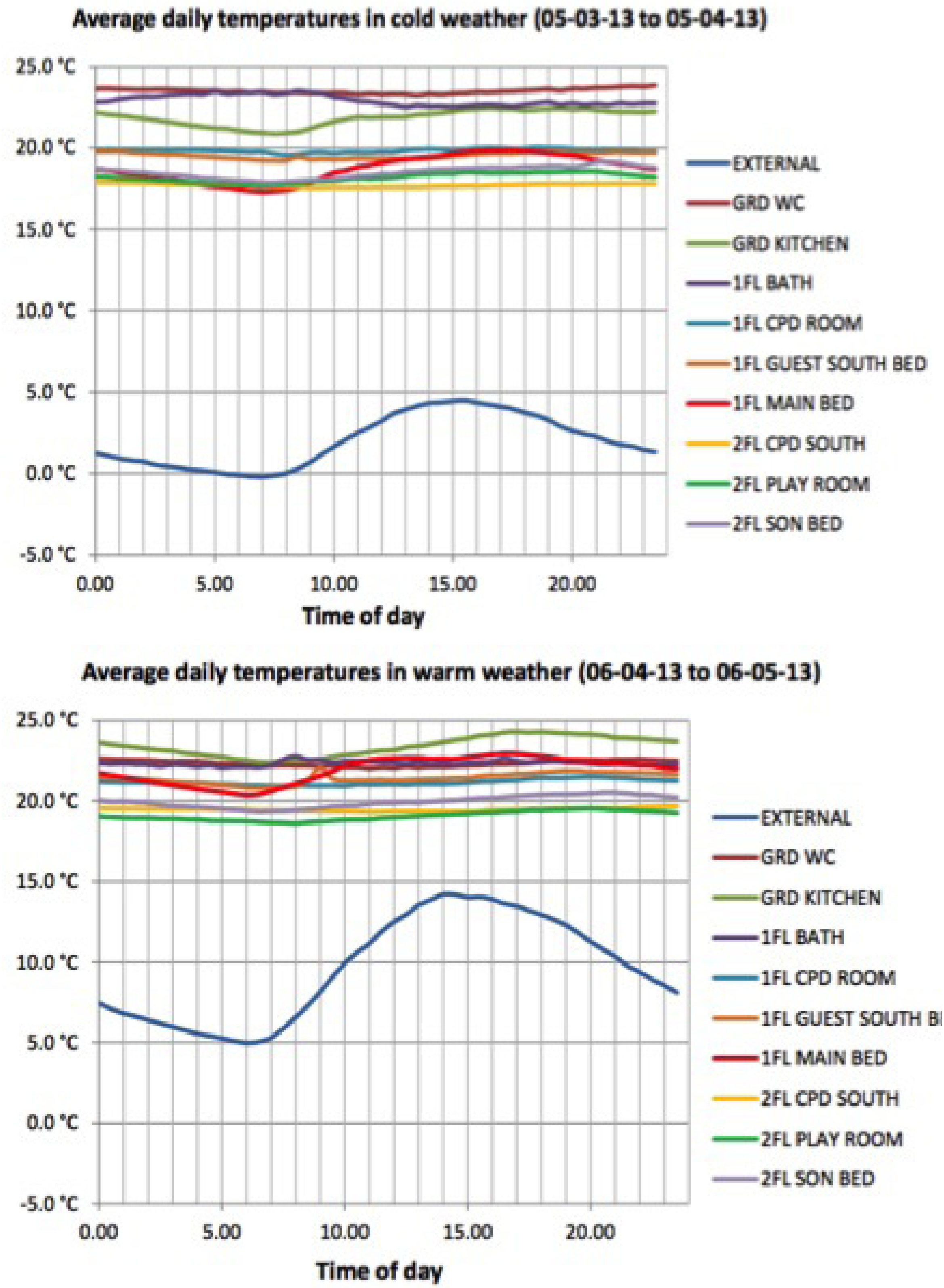

Figure 12- Temperature graphs showing how the house functions in periods of cold weather and warming spring weather

Figure 13 – Lighting conditions in the south living space (left), south bedroom (middle) and north bedroom (right)

Eco Design Consultants mentioned a number of things they would have changed, such as reducing the size of windows on the south facing corner and not relying on external blinds on the south to provide solar shading. They would also make the timber frame/walls thicker to provide extra room for insulation and use thermal imaging equipment to detect cold bridges so they could amend the detail accordingly. On the other hand, the architects have discovered some factors about this house they really like and some factors that they would modify to further improve it. An open day for Howe Park Passivhaus identified an aspect that the architects have absorbed and applied to some of their other properties. This was that small children were able to see out of the full-length windows in the bedroom, allowing them to enjoy the greenery of the outside world. In summary, mistakes were made throughout the project but have proven beneficial. In broader terms, Howe Park Passivhaus, amongst other recent Passivhaus developments, is an intermediary for improving the existing precedent for Passivhaus housing in the UK.

Conclusion

According to Alan Budden, 'the Passivhaus certification route ensures a high standard of quality control and increases the quality of workmanship' (Budden, A., 2013) and could help to deliver the Passivhaus standard in the UK. The quality assurance implemented by the PHPP and the quality control during construction by the architects and contractors, resulted in a high performance dwelling with excellent thermal comfort and air quality. At the current economic state of the housing industry, it would be appropriate to apply this high level of quality assurance on all new builds to help fulfil the legal commitments of the Climate Change Act 2008.

Howe Park Passivhaus is an example of where the Passivhaus certification route has encouraged teams to work collaboratively, with a high quality of workmanship to achieve an outcome to be proud of. Eco Design Consultants, a passionate design team, newly educated in Passivhaus construction, represent a team who have been very successful in their first project, achieving an exemplary value for airtightness. Architects such as Eco Design Consultants assist in further developing a model that leads to more sustainable design through the means of trial and error. This in turn will improve the public awareness that is impeding the widespread adoption of this construction method. To encourage sustainable living the UK must make Passivhaus principles understood, easy, desirable, rewarding and habit (Unilever, 2013).

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Crossway House

Karl Bowers

Location Staplehurst, Kent
Building Type Single family house
Construction Type Timber frame
Floor area 278 sq.m
Completed 2008
Year Certified 2010
Overall Cost £813/sqm

Client Richard Hawkes
Architects Richard Hawkes
Main contractors Ecolibrium
Council Maidstone Borough Council
Certifier Scottish Passivhaus Centre
Consultants and Collaborators Newform Energy, Cambridge University, Ecolibrium Solutions
Funding sources Private

Abstract

It is important at this point to understand that Richard 'didn't set out like many others to achieve Passivhaus status from the beginning of the project, in fact, it didn't become a factor until the technical design stage, as in his architectural career, sustainability was always a key principle to which he adhered. He and his family wanted a sustainable lifestyle, so he set out to design 'a sustainable building, with as much sustainable considerations as possible' (Hawkes) in order to encourage them all to live sustainably'.

Investigating the adaptation required throughout the design, build and Post occupancy stages of a UK Passivhaus

Design Process

This chapter will evaluate all stages of a Passivhaus project and discuss the adaptation which is required due to the Passivhaus status. By using Cross Way House as a case study, it will investigate how this bespoke Passivhaus responded to the technical, economic and cultural challenges of delivering Passivhaus standard in the UK from the point of view of the Architect, Technical/Construction team and the Client.

Crossway House is situated just outside the village of Staplehurst in the countryside of Kent. The clients for the project were Richard and Sophie (his wife) and they were looking to replace the existing run down 2 bedroom bungalow situated on the rural site with a new 3 bedroom house. Achieving planning in the Kent countryside is very difficult at the best of times, so the sustainable principles which Richard and his wife, the clients, aspired too were very positive in the eyes of the planning authorities, but in particular, the PPS7 Policy. The PPS7 policy was the government's national policy of land use in rural areas. The main principles of this policy were 'raising the quality of life and the environment in rural areas' and 'to promote more sustainable patterns of development'.

It is important at this point to understand that Richard 'didn't set out like many others to achieve Passivhaus status from the beginning of the project, in fact, it didn't become a factor until the technical design stage, although he was aware that a Zero Carbon building (zero carbon emissions) could be possible, as in his architectural career, sustainability was always a key principle to which he adhered; he and his family wanted a sustainable lifestyle.

So far during the interview, Passivhaus had not been mentioned, he still agreed that it was 'sustainable credentials' which were leading his design process. More importantly, it became apparent that as this is how he designs in practice, he was not adapting his design process at this stage to accommodate the Passivhaus standard.

"…fundamentally I wanted the house to be about the light, the materiality, the spaces; the architecture. Therefore the initial concept was about creating a sustainable house with a clever plan which took into serious consideration the rich rural context, the outstanding views and very importantly, the sunlight…"
(Richard Hawkes interview 2013)

Taken from a previous interview between Richard and myself, he goes on to say that he was adamant at the beginning of the process that the concept of the building was the 'architecture, a sustainable lifestyle and how clever technology could integrate with clever design'. He insisted that there was a rigorous approach taken towards the impact of the context surrounding the site which would begin to influence the design. He stated that the external aesthetics of the building were not an issue at this stage; the main concern was with the plan and how it would work for them.

With the aid of hand made concept models (figure 01), Richard began to extrude the plan in its simplest form to see what the building form would begin to look like. This process 'took a number of months...' As he tried to establish a Language with which he was happy; as with any design project, a design challenge needed solving and this took time as there were a number of contextual issues in which he needed to address; as Lawson advocates, 'there are an inexhaustible number of design solutions to any one problem'.

From this process, the much recognized main design feature of this four bedroom house was born; a 20 metre span vaulted arch that forms the principal element of the roof structure. The vaulting gives the house 'plenty of structural strength but obviates the need for embodied-energy intensive materials such as reinforced concrete' (Michael Ramage). It also provides the house with great thermal mass, enabling it to retain heat, and absorb fluctuations in temperature, thus reducing the need for central heating or cooling systems.

Figure 01 : Handmade models made throughout the design process

“The vaulted arch is only 120 mm thick. It has been constructed using small tiles that have been hand made from local clay; a great homage to our context”
(Richard Hawkes)

He goes on to point out that it was always in his intention to seal the archway. As one understands, one of the key principles of Passivhaus is the air tightness; at this stage, Hawkes is adamant that it was always a priority to seal the house, even with the arch way, but he did not suggest that it was Passivhaus orientated or to what level of air tightness he was trying to achieve.

After discussing the design process of the house up until the planning submission with Richard, it became apparent that any decisions made up to this point were made because of design credentials, not Passivhaus. It became apparent that sustainable techniques and interests were marrying together with his design process, but these are his professional design principles and personal interests and so were not altered.

One intriguing aspect of the design process was the orientation of the building, like any architectural process, this was considered very much at the early concept and design stage but it became a fundamental principle for Richard’s design process. Again, knowing that Passivhaus standards require very little in mechanical heating systems to lower the carbon foot print, he was arguably aware of the implications of sunlight warming the building correctly throughout the day would have on the running costs and technical process to follow. This could be suggestive as a slight adaptation, but he mentioned that it is a principle he keeps ‘throughout any design process in practice’.

All be it this is only one Passivhaus in the UK, so one must concede that every project will be different as ‘every architect works differently’ (Rowe, 1987: p51), but at this early stage, the research into Crossway House suggests that the design/concept stages of a Passivhaus do not necessarily mean that the architect needs to adapt their process in order to achieve a Passivhaus Certification Richard ensured me that his design principles of context, orientation and understanding climate did not get lost when he was designing Crossway and he claims that this is the case with the schemes he works on in practice which are also trying to achieve a Passivhaus certificate or sustainable credentials.

Figure 02 : Handmade model used during Design Process

Richard's design stayed on track and altered, as many projects do, in order to suit the needs of the client and to satisfy his design orientated mind; not to accommodate Passivhaus, but intriguingly two of the principles of Passivhaus, passive solar gains and excellent levels of air tightness, have arguably been understood and delicately adhered to at this early stage.

Planning Process

Many opinions of Staplehurst are that it is a flat landscape but what Richard discovered is that it consists of 'various levels of skyline formed by trees or something similar…' and the site for Crossway sits in a 'shallow bowl' right in the centre, allowing diverse views in all directions which he used as an argument for the proposed height for Crossway. By studying the different levels of tree lines he discovered that the building could be strategically placed so that although it is bigger than the existing bungalow, it is still not disrupting any views for opposing properties. Such site consideration sums up what the project was all about for Richard at the beginning stage.

Figure 03 : Kent Messenger Headline

The local newspaper, the Kentish Messenger ran a series of stories about the project from the planning stage all the way through to the build as Grand Designs and media interest began to grow; my intrigue however, is with the headlines during this planning stage. The banner in Figure 3 states 'futuristic home' which in many opinions point towards a futuristic home, maybe even a building which is 'space-age'?

If the branding of a 'futuristic home' was used before planning permission was granted, Richard believed that it might have been more and more difficult for the house to be granted because the locals would have been expecting an 'alien architecture with flashing gizmo's and what not…like you see in the movies' which of course, is not the case. Richard acknowledged that not everybody will know what Passivhaus means, but words like futuristic will do the standard an injustice. 'I think the term house for the future works better than futuristic; this might make people buy into it a little more'.

In the context of this chapter, the branding of the Passivhaus standard could lead to serious issues when implementing Passivhaus in the UK. One of the biggest adaptations required, in my opinion, is winning over the public. In many planning situations, they hold the power in refusing a project collectively. One must acknowledge that Crossway is a bespoke home, so not all projects will be like this but the Passivhaus 'brand' needs to be clear in order for people to understand what is actually being built, and thus, allowed to be built, as the Ecologist explains, 'it is not the exterior which makes a passivhaus, but the clever technology and construction methods used inside' which must not be forgotten.

Passivhaus is clearly well established within Germany, and for the same to happen in the UK, the public need to have a clear understanding of what the standard is, as a 'futuristic home' suggests, in my opinion, confusion and even fear for a localised UK village.

I believe it will take time for people in the UK to really comprehend that Passivhaus is all about the environmental comfort that the building offers the occupant, along with the savings in energy consumption, not necessarily particular aesthetic qualities which will obviously differ with every project. Once this becomes clear, I believe that architects will not need to adapt their planning approach, as the local people will realise that a Passivhaus is not necessarily a 'futuristic home' but more a 'house for the future', and are less likely to be put off.

Technical Design

"The first person I got on board was the eventual builder of the project during detailed design; he was on a basic £75 an hour during this stage." Richard openly admitted that he had help throughout the technical design stage of Crossway. It is essential to get across that within the context of 2007, Passivhaus principles were fairly new for architects in the UK and Richard was of no exception as even though he was interested in the topic, he sought after the help with the technical design from a builder who had experience with 'eco' (referring to a structure that is environmentally responsible and resource-efficient throughout a building's life-cycle) buildings.

Referring back to the theme of this chapter, this move by Hawkes potentially highlights an adaptation required for architects in the UK when designing and building a Passivhaus in this country. Richard acknowledged the fact that he needed help and he set a side a budget for 'consultancy' during this early stage. This is something which many other project architects may need to consider for Passivhaus against a traditional project as the level of technical knowledge requires specialist input; the learning process, which noticeably comes at a price. As stated before, Passivhaus was not specifically the target for the project but understanding and working towards the principle in excellent levels of air tightness and thus investing time and money into the design and construction of the envelope was imperative. This is where Michael Bassent of Ecolibrium solutions managed to help with the technical design. His knowledge of building airtight buildings during that year had a great influence on the detailing of the envelope.

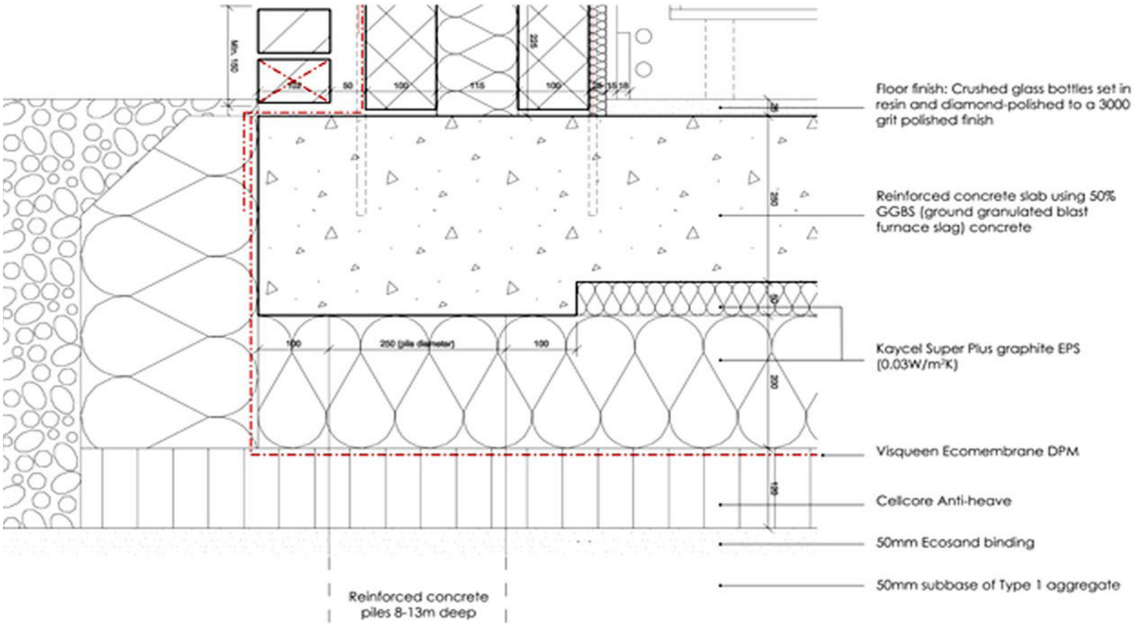

Figure 04 : Foundation Detail

When looking at a foundation detail for Crossway (figure 04) one can begin to understand the level of air tightness, thermal bridging and insulation which was implemented for the elements which sit under the archway. The intensity of insulation surrounding the concrete slab highlights this fact, with high efficiency required to reduce the impact of cold bridging. This could be considered an adaptation for technical design as Passivhaus requires a 'higher level of thermal control' (Cotterel) than that of a standard domestic house of the same size.

Initially Richard looked at rammed earth which required 15% clay and considering the local ground he was building on was much higher, he'd need to bring in 85% aggregate which didn't make sense meaning that this technique was discarded. Straw bale was discussed but the wall thickness was too thick to achieve the desired U Value results compared to other techniques and the house would have a smaller internal floor area because of the thickness so ultimately this technique was also discarded early on.

Andrew Bassant (contractor) introduced the idea of 'engineered timber beams which have recycled newspaper pumped in to the cavities' which ticked all the boxes regarding air tightness, thermal insulation and sustainable credentials. The thickness was only 300mm and the resulting U Value is 0.12w/m²K which seemed 'amazing compared to other methods' (Hawkes).. This is a prime example of where having a consultant worked well for the architect. Could this be classed as a successful adaptation for an architect trying to achieve Passivhaus in the UK? I believe so as this level of technical assistance during the technical design stage meant that there was a clear direction to head in for construction which still resulted in high technical performance.

Obviously this is only one example for Passivhaus but it worked out well for the architect and client in this occasion as the collective input of the builder and the architect resulted in positive decisions being made during the technical design process, which would ultimately lead towards an easier construction process; a factor highlighted in the Passivhaus Contractors Guide, 'success is in the forward planning'.

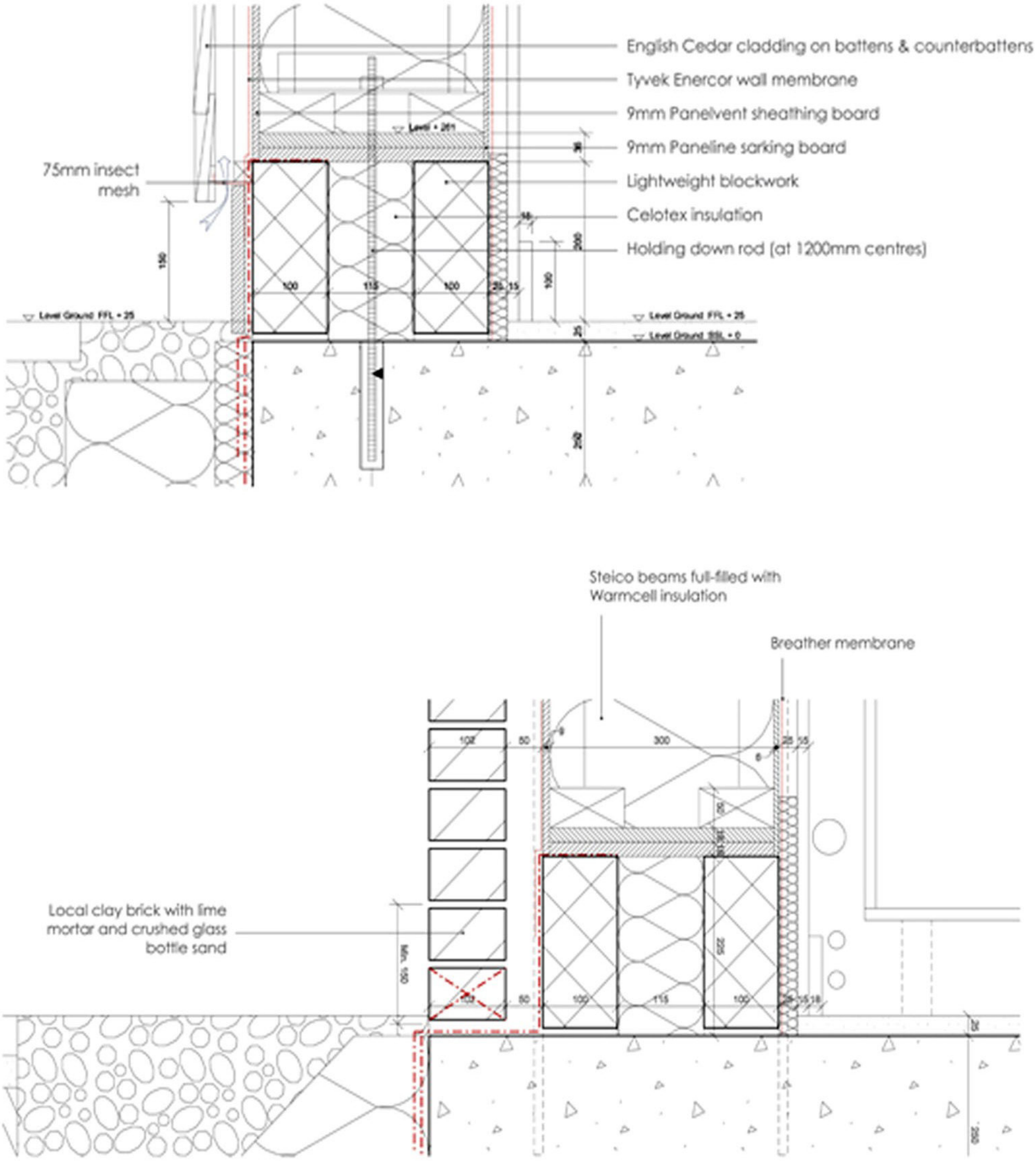

Figure 05 : Wall to Floor Details

When looking at figure 5 one can see the efficiency in the external wall detailing. The detailing illustrates this with a really compact construction with high focus on the prevention of cold bridging by including insulation within the wall construction but also in front of the internal finish. Guaranteeing the wall is as tight as possible to the concrete foundation slab is imperative to ensure air tightness is at its most effective, so 'holding down rods' at 1200mm centre's were decided upon at this stage. It was essential to understand the collaborative efforts of the two, as suggested by theorist Schön (1983), 'the reflective practitioner has an interest in understanding a situation, even if help is needed. Sometimes trust is key'. This is a reflection on what Richard said during our second interview:

“Once I knew that we (Andrew Bassant, Richard Hawkes) were on the same page and had similar ideas then I knew that we would work well together, which is key for a Passivhaus project because most of the time, it is relatively new to most people so patience and team work go hand in .
(Richard Hawkes, 2014)

He made it clear that he surrounded himself with ‘clever people’ throughout the early stages as well as the construction stages which ‘made the difference’ for the project. From Andrew Bassant to Michael Ramage who had a major input in the design and construction for the Timbrel Vault, Richard certainly knew that it was money well spent on technical help.

“I then had Michael Ramage who was brilliant. He really helped to achieve the vaulted roof and made it what it is now. Anthony Morgan and Stephen Cartwright came up with the heat store idea; they really helped me out and I’d recommend it for people who are starting out like I was…”
(Richard Hawkes, 2014)

Reflecting back to the subject of this chapter, the major adaptation during the technical design was the input of consultants. Richard conceded that it was an experiment and new at the time so having expert help at an extra cost should not be overlooked for architects in the UK as ultimately, Passivhaus is new for most architects in the UK at this time. This is echoed by the Green Building Store in their October 2010 Ecologist article titled ‘So why has the UK been so slow to catch on to PassivHaus?’ In the article, Passivhaus in the UK is heavily discussed, with the director of Green Building Store pinning it down to a number of factors; “suspicion of European ideas, the lack of a publicly funded body to promote best practice in construction in the UK since the privatisation of BRE, and the fact that the Government’s Code for Sustainable Homes has gone in a different direction (with a focus on renewables).

One must remember that U-value and air tightness is not dependent on the quality of the structural frame alone but it depends more on the detailing; membranes and insulation layers which, when well researched, improve the properties of the envelope which is the case with Crossway; DuPont Energain phase change membrane which was ‘easily installed and sealed behind the plasterboard’. The system works by absorbing ambient heat as room temperature rises (at around 22°), storing it until the temperature drops again (at around 18°), and then releasing it back into the room. The figures back up the decision to invest in this particular product, which one must comprehend was new at the time, for the envelope of the building.

“Sometimes, at night when the temperature drops low enough again, we can literally feel the walls releasing back warmth. The monitoring analysis with Cambridge University clearly shows that peak temperatures last summer were reduced by, on average, 4 degrees.”

By deciding to use this membrane during the technical design process, it allowed the construction method to ‘in theory, run smoothly’, the kind of forward thinking suggested in the Contractor Guide: ‘the sequencing of a Passivhaus build requires a detailed understanding of the assembly process as well as critical stages in the build’. This was therefore a critical adaptation, but a successful one in my opinion.

Construction Process

"This is a highly experimental project; the kind of adventure that only an architect would dare go on" (Kevin McCloud). Richard was always aware that the technical and construction characteristics of the project would be experimental but the quote by Kevin McCloud could arguably question the fact that Passivhaus at the time was a highly experimental project to see through. Crossway being one of or even the first Passivhaus in the UK at the time, this was experimental ground for all involved.

Construction began with the demolition of the existing bungalow on the site with the 'eco concrete' (50% waste material from local sources) being poured 6 weeks in. With Richard project managing the build, he wanted to ensure he was on hand to make specific decisions as any client would need to, but to also keep an eye on the build and specifically the quality as it went up. This could be seen as an adaptation in its own right, but he conceded that if 'you have a good team behind you, then when it comes to building a Passivhaus, the architect doesn't necessarily need to be on site more than any other build. I was in the obscure situation where I was client and architect so I couldn't help but be involved as much as possible."

Andrew Bassant, who's company 'Ecolibrium Solutions' specialises in sustainable buildings, insisted that the build 'was never going to be a difficult building to construct', 'each stage of the process was set out to be straight forward; the building was set out to be efficient in more ways than one…". Considering the building was seen as an experiment, cool heads and people who knew what they were doing certainly ensured a layer of quality control.

Figure 06 : Steico Timber Frame being constructed

It took 4 weeks for 3 expert carpenters to cut and construct the timber frame (figure 6) for the house. The timber frame was supplied by a German company called Steico, manufactured in Poland. An extra cost due to shipment and transport, but because of its low U-Value for only 300mm thickness, Richard knew it ‘needed to be done’ in order to stick to his principle of good air tightness:

“Basic logical principle was investing money into the building envelope”.
(Richard Hawkes 2014)

With the frame constructed, the highly expensive commissioned triple glazing arrived on site from Germany. This of course incurred extra costs, but the units ‘are not made to this quality in the UK so it was imperative that they were included in the commission for the house in order to ensure that air tightness and thermal performance were at their best. The windows ‘insulate the house more efficiently than a brick wall’ (Bassant) meaning that along with the highly air tight timber frame, the building envelope was ‘on track to achieve the results we were hoping for’ (Hawkes). All of the doors and the windows were given 3 layers of extra air tight seals to ensure that the building envelope was as tight as possible.

It is this attention to detail which one can put aside as being a definite level of adaptation required for Passivhaus. These intricate additions were researched and experienced by previous projects worked on by Ecolibrium Solutions which came about during the construction process. This shows the importance that the consultancy had not just during the design process, but also the construction. One must ensure that quality control is efficient throughout every stage.

The timbrel vault which was a feature born from the idea of needing a roof structure which would provide an open plan along with high levels of support for a green roof, was experimental in this country as it was a historic technique being built in a modern age. Even this element of the building was scrutinised to the maximum to ensure thermal performance was high. Not only was the soil and plant life envisaged to insulate the spaces within (which was deemed insufficient) so an extra layer of insulation was put between the clay and the soil to make it even more insulated. Another extra cost, but it was important to make sure the envelope was the best it could be.

The inclusion of the clay tiles as an exposed material within the building was a design feature from an architectural point of view but on a more technical issue, one must consider the properties of clay as a hydroscopic building material.

‘A building should be seen as an organism, which must breath and the walls as our third skin’. The material choice should reflect the transfer of air and moisture through the building envelope. This not only ‘helps avoid condensation in and on the building fabric but also this diffusion process helps with the necessary air exchanges for a well- ventilated room’ (vastutimes)

The use of hydroscopic material for the natural regulation of the room humidity: relative humidity of a room should not fall below 40% and not rise above 70% for the health of the occupant and of the building fabric. Hydroscopic materials like clay renders and earthen floors help reduce fluctuation in air moisture content and reduce condensation. The use of the clay tiles therefore help to work with the thermal control of Crossway because the relevant humidity within the spaces can be absorbed by the clay material helping to improve the comfort for the occupants.

Richard had mentioned on many occasions that he surrounded himself with clever people during the whole scheme, but it paid off when Newform Energy, Passive House solutions and the Carbon Free Group, allowed him to showcase the first UK appearance of PV-T technology. This combines photo-voltaics with solar thermal technology, keeping the PV cells cool using a liquid and using the extracted heat for hot water, heating etc. This helps maximise PV efficiency, reducing the amount of PV required to achieve high outputs. Like many other features of the house, this was a highly experimental piece of technology as it was the first of its kind in the UK. Whether it would work efficiently in the UK climate was a fact that had never been tested so Crossway was to be the first data source in the years to come.

After the construction process, Richard had the buildings air tightness tested, to prove the Passivhaus credentials. The result was 0.6 m3/(h.m2) @ 50 pascals, which far exceeds the building regulations requirement of 10m3/(h.m2). Another cost which comes along with achieving a Passivhaus as it is a necessity for certification, but as illustrated, it proved that the attention to detail with the air tight wall construction was worth the effort, time and extra cost.

With such efficient air tightness, managing the buildings ventilation is imperative and to ensure this was the case, an MVHR unit was installed. A system of ducts extract the warm, stale air from spaces such as the bathroom and kitchen, send this air to the recovery unit where the heat is recovered and the resulting cool fresh air is pumped back into the house. This level of technology required serious attention during the build to ensure that the system worked efficiently.

Post Occupancy

Crossway is one of a handful of Passivhaus buildings which has over 4-5 years of data and post occupancy feedback in the UK which means that the building is constantly adapting in order to be the most efficient than it can be. This is down to the fact that Cambridge University placed sensors throughout the building when it was being built which keep track of internal temperatures and the figures from the PVT panels etc.

Obviously one must acknowledge that Richard is one architect in the UK of many who have built Passivhaus' but his enthusiasm and eagerness to make the house as efficient as it can be cannot be classed as an adaptation in the case of this theoretical framework because he accepts that it hasn't 'changed the way' he lives. With that in mind, could it be that one must adjust the way they live in order to get the most out of a Passivhaus?

"To be honest, we haven't changed the way we live at all. If anything it is just a number of positive surprises. We used to always notice that during March and the beginning of Spring we were always desperate to get outside and get some fresh air as the house would feel stuffy and dull as we crept away from winter, but in Crossway, due to the constant fresh air and great southern light glazing, we haven't felt that way in the last 4-5 years that we've lived there".

It is apparent, as from the Pasivhaus Conference 2011, that 'air quality and thermal comfort' are the principle positives from the user feedback of established Passivhaus' at that time; all in accordance with the targets of implementing Passivhaus in the UK to 'improve the user quality of life in new buildings' and certainly from the client point of view, Crossway also delivers. With this in mind, surely improving the quality of life can be classed as an adaptation because the user's lifestyle is adapting to the building environment.

No matter what is written about Passivhaus, the figures of Crossway do not lie. Over 4 years of monitoring in collaboration with University of Cambridge have shown Crossway's Primary Energy consumption to be 54.59kWh/m2/annum with a heating load of 14.82kWh/m2/annum (figure 7)

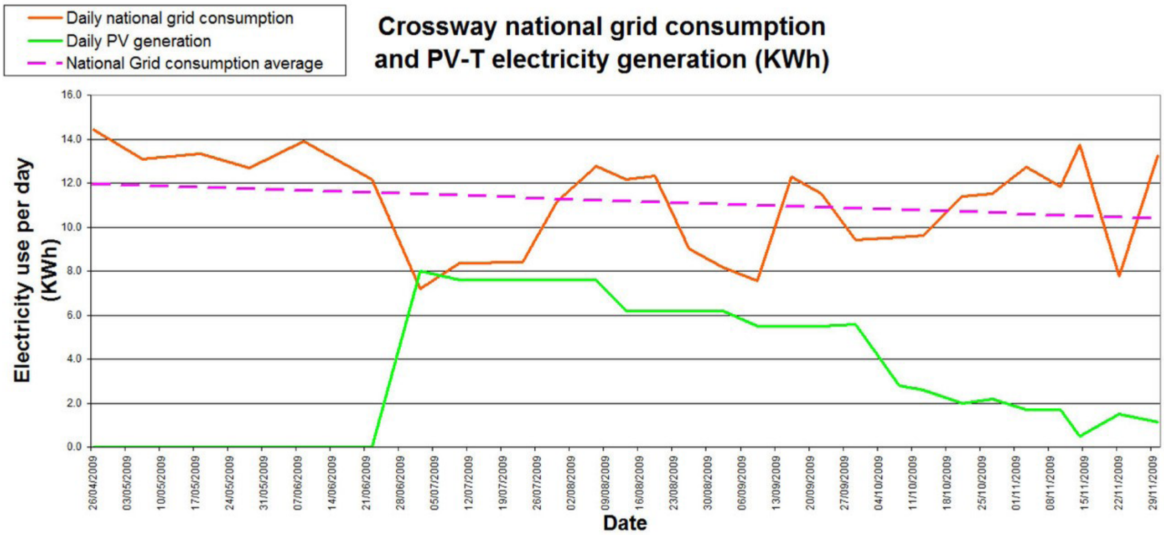

Figure 07 : Crossway National Grid Consumption

When tracking the figures for electricity use, one can begin to see the extent of how Crossway performs against its promised results. The PVT panels generate so much electricity that Crossway supplies some of this electricity to the grid and thus gets a cheque at the end of the year as payment for the electricity supplied, but this is a compliment to how well the Passivhaus credentials of Crossway are performing. The truth behind the facts is clear to see as an adaptation for any Passivhaus client. The NHS documents that "money worries and living costs are the second highest inputs for stress in the UK".

I believe this is an issue which is often over looked; of course not everybody will be able to afford a Passivhaus, but, if the feedback from users proves that the environments are calming throughout the year, 'you feel very safe during the UK storms as you are living in a well put together, qualitative envelope' (Richard Hawkes) and money can be saved by living in a building which is conscious of its energy consumption, then surely the greatest adaptation for the UK is lifestyle, even if it is not that obvious, as Richard states:

"I can see that the building provides us with a much better environment both in air quality and architectural quality. We notice the small things like when you come home from holiday and the temperature is only 1 or 2 degrees below room temperature, it helps you settle back into every day life again".
(Richard Hawkes 2014)

With all of the technologies used within the building, the user interaction is something which cannot be overlooked. One must comprehend that Richard's technical background makes him an exceptional user as he is the Architect and the client with a serious interest in sustainable technologies. As he himself researched and was there for the installation of many of the technologies, it is understandable that a plant room like his does not fase Figure 7 (overleaf) illustrates the level of technology involved in order for Crossway to function successfully.

Figure 06 : Steico Timber Frame being constructed

Conclusion

In all honesty, one cannot conclude the subject of this chapter within the ebook as this is only the beginning for Passivhaus in the UK and every architect works differently. Germany and Austria, who are the leaders in the standard, have been achieving the standard since the early 1990's (Darmstadt, Germany), which is a staggering 24 years ago compared to the first Passivhaus in the UK in 2008.

"People need to realise whether they want Fiat Design and Mercedes Technology or just a good Ford which might not achieve Passivhaus but still provides good quality comfort but at a good price…we cannot forget our commitment to clients"

When assessing the case study at hand, of course the building is a successful Passivhaus, with exceptional results, but more importantly, the level of adaptation required was not as high as anticipated at the beginning of the project. Richard's design process was not deferred; he stuck to his architectural principles which for me are integral to a successful integration of Passivhaus in the UK. Of course tools such as PHPP are great for the standard, but it should remain a tool and should not over rule the design stages.

The most apparent adaptation was discovered during the planning process, but surprisingly it was a social issue, not a technical one. All be it, Crossway is an exceptional case study in the fact that the Passivhaus Standard was not fully considered until the Technical Design stage, but it can help enlighten that in the wider context, the public perception of the standard is so important that the way it is understood needs to become more evident so that clients will be willing to give the model a go. People need to be aware that Passivhaus is not a design issue but by looking at the post occupancy results, it is a way to improve the internal comfort of a building, not the exterior.

As expected, quality control and specialist input was the key during technical design and building construction. What was more important however, was collaboration and trust during these stages. In the context of 2007, Crossway was experimental in every way, so trust in the design and build team that the results would be positive was key throughout and I believe this was proved correct when one observes the end result of the project. I believe Richard would agree that it could not have been possible without the input of 'clever people' throughout.

Crossway has shown me that one must not forget the social context surrounding us in this country. The mindset is different in Germany than it is in the UK, where efficiency and quality weigh in more than cost, as the Guardian suggests in it's article in March 2011, '…according to statistics from the OECD, your average German builder works 256 fewer hours a year than their British counterpart and yet gets a lot more done'. This is by no means a negative take on the situation but more of an ingredient which cannot be forgotten when considering a Passivhaus build. Of course, as the standard grows in the UK then costs may decrease as UK companies will source the technologies and specialist builders will increase, but one must understand that at this moment, extra costs may need to incur in order to achieve a Passivhaus, as was the case with Crossway.

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Author Information

I am a fifth year Master of Architecture student with an interest in Passivhaus having completed a piece of work about Crossway house for a previous submission during the fourth year of study. I became intrigued in how, as architects, we need to adapt the way we work in order to achieve a Passivhaus certification in this country, which led to the title of this chapter.

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Housing Discussion

This collection of case studies set out to establish the key challenges involved in delivering the Passivhaus standard in the UK. The scope of this investigation does not allow general conclusions to be drawn about whether the Passivhaus standard is a viable option for creating sustainable new homes as Britain aims to achieve its carbon reduction targets. However, it does give a crucial insight into how Passivhaus can be implemented in the UK and the decisions and challenges involved.

Public awareness has been found to be a key issue, this can be considered in terms of the general public but also with in the industry itself. Many of the case studies highlighted issues with knowledge of Passivhaus particularly within the planning and construction industry. Acknowledging that the projects vary from 2007-2011, this limited understanding appears to have been a significant barrier in the early projects, however the evidence suggests that over time the general awareness has improved and will continue to do so.

Several of the case studies faced difficult planning situations, whether they be in a tightly confined space or an Area of Outstanding Natural Beauty. These studies have shown a trend for councils to be supportive of Passivhaus in general and in some cases aided the planning approval. Investigations show that this is partly due to the expected high quality of a Passivhaus project, potential publicity (good or bad). However, success can also be contributed to Passivhaus ability to adapt aesthetically in terms of materiality and form.

Moving on to implementing the standard, in all of the case studies Passivhaus required a higher level of detail and input in the early stages. Highlighting the benefit of a collaborative approach, which is not commonly adopted within traditional UK procurement methods, for example having the construction team on board during the design process, allows team members to work together solving potential issues. This is beneficial for all parties as it heightens quality control, with the main focus being on air tightness and the avoidance of cold bridging to improve efficiency and reduce the likelihood of issues on site.

Using PHPP in the design process proved to be contentious. One case study found the software to be beneficial as an iterative design process with minimal impact on design restrictions. However, another case study raised the issue of the software limited the design.

When investigating the construction stage, it was apparent throughout the majority of the case studies that a heightened understanding during the technical design process generally improved the work on site. It became apparent that training before and on site took part throughout the build and was generally seen as an extra cost but a benefit for those involved. The investigation illustrated that the mentality and skill level of the building industry in the UK needs a willingness to adapt at times in order to appreciate the implications of achieving the Passivhaus standard. In particular, with an economy and construction industry so firmly based in tradition, we still find the UK struggling to confront the tough reality of a rapidly evolving global environmental landscape. And so, until the importance of building fabric and services performance fully permeates the house-building and house-buying market, forcing an understanding of new technology and new ways of living, we will continue to find the United Kingdom failing to hit its greenhouse gas emission and energy.

A common misconception that Passivhaus' require a high level of operative input has been dispelled when examining the post occupancy results of each build. A number of case studies proved that the handover process has developed to ensure that the homes are used to their full potential. From on the day tutorials, which were ineffective compared to structured educational assistance over a longer period, such as the soft landing approach, once the occupants had settled in proved much more successful.

Overall, the investigation has demonstrated that Passivhaus is becoming widely accepted in the UK as architects, contractors and housing associations have gone on to build more Passivhaus' while in some cases restructuring existing companies around the standard. Generally, the processes involved to achieve a Passivhaus are learning from early mistakes and becoming much more 'UK friendly' which was proven in one case study with the amalgamation of traditional building techniques to Passivhaus Standard which could become a catalyst for expansion.

Acknowledgements

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Discussion
What are the overarching findings?

This book has investigated the learning process that project teams underwent during the designing and implementation of thirteen PassivHaus projects in England, which included educational buildings, new housing and retrofit schemes. These projects, completed between 2009 and 2013, were part of pioneering efforts to adapt the PassivHaus standard within the context of the UK, undertaken by teams with no or very limited previous experience with the PassivHaus standard, associated technologies or working methods. Studies of the process revealed that the standard drove explorations of new design methodologies, research and development and new forms of collaboration between the designers (not all of which were architects) and the wider construction industry. The case studies have given very detailed insights into the challenges underlying each individual project, but they did not allow identifying how far the challenges encountered in one case are unique to that particular case or commons to PassivHaus design in the UK more generally. In this final section, however, a cross-case analysis is used to investigate some of the overarching themes. The case studies were linked by five common strands, which are continuity, education, innovation, collaboration and rigour.

Design methodology: rigour and evaluative tools

Architects went to great length acquainting themselves with new technologies and working methods. Some of the practitioners could successful draw on their understanding of the fundamentals of building physics and their experience with the traditional principles of climatic design or certification schemes, such as the Code for Sustainable Homes or BREEAM. This demonstrated that PassivHaus design builds directly on fundamental principles of low energy design, such as solar orientation, minimization of cold bridges, high airtightness standards and insulation levels, but the case studies have also highlighted that there was one very critical distinction: the level of technical rigour in the design, detailing and construction. In contrast to the much broader approach to sustainability underlying the UK's Code for Sustainable Homes, the PassivHaus methodology made design teams focus on the task of achieving buildings with a low operational energy demand. All of the project teams studied in this research project had gone to great length to acquaint themselves with the rigorous design methodology, which included the use of various evaluative tools. The design process was driven by a performance-based approach, with PHPP and a series of auxiliary software tools providing the designers with feedback on the performance implications of design decisions. The Camden case study, for instance, illustrated the use of PHPP as tool for evaluating and refining design solutions both at concept and detail design level. Evaluative tools played a significant part in this process as they provided designers with critical feedback on the overall performance of their schemes and individual components. In addition to PHPP, more specialist software were deployed, including TAS, a dynamic thermal simulation tool that was used for an overheating study in the design of the Rural Regeneration Centre. The thermal bridge analysis tool THERM was used in the development of details for Grove Cottage and the Centre for Disability studies. The latter is an open-source software tool that was developed by the laboratory of the US Department for Energy to model the heat-transfer through building components. It generates cross-sections, which show designers the heat transmission paths through building components in a visual form. It helps identifying where thermal bridging occurs within construction details during their development, and such provides designers with critical feedback on the performance of details. This feedback was important as designers were required to direct much energy to the development of details from a performance perspective. Many details were developed primarily to address airtightness, condensation or cold bridging issues, but had a limited bearing on the design from a formal architectural perspective. The emphasis on energy performance, also required designers to consider technical design questions from an early stage, in particular if PHPP was to be used as an evaluative tools in the design development process rather than just at the end for final certification. The Camden case study, Grove Cottage and Grey Lyn have illustrated how questions of construction were considered in conjunction with the questions of the general building form and orientation. In case of a significant deviation from the recommended form factor, which often resulted from the need to accommodate site constraints, formal architectural aspirations or spatial requirements, a higher performing envelope could be used to compensate, but with the consequence of increased external wall thicknesses, costs and reduced internal floor area unless alternative insulation materials with higher performance were adopted. An exceptional example of the use of PHPP in this iterative design process was the Camden project, which included the evaluation of fourteen strategic design moves in the PHPP energy model. This shows that as the design was highly performance driven, questions of technical detailing, technical specification and the general building form were highly interdependent considerations. Building form, orientation and wall to glazing ratios were variables designers could work with. In many of the projects PHPP, which was fed with detailed technical and geometric data, played a key role in maintaining the feedback loop between inquiries into the general form of the building and the specification of the thermal envelope.

The study of the design processes has also shown that PassivHaus design, despite the strong emphasis on energy performance, which at times had challenged some of the architectural ideas put forward by the architects or clients, had not stifled architectural creativity. The level of design flexibility and freedom, however, was found to be highly dependent on a good understanding and application of key performance related design variables and the use of evaluation tools. BRE's Passivhaus primer and the PassivHaus Handbook outline what might be described as the canonical principles of PassivHaus design, such as the use of compact forms, south orientation of glazed areas for maximising solar access in winter and reduced window areas in the north. The case studies have shown that these design principles cannot always be religiously followed but in most case were only a starting point. The analysis of the design process has demonstrated that the standard allows for a high degree of design flexibility if the full range of design parameters affecting fabric heat loss and solar gains are fully understood and utilized by designers. Grey Lyn, for instance, starting with a diagram of the ideal arrangement, but the final form of the building had undergone several iteration in order to reconcile the energy requirements with architectural ideas, internal functional demands and various site and planning constraints. A variety of buildings forms, including Underhill House, a subterranean house organized around a sunken courtyard and Crossway House with its timbrel vault spanning across a series of stacked boxes. These creative solutions were only possible due to the exceptional understanding of the principles and aspirations to push the boundaries from a design and technology point of view. This contrasts with the design of Howe Park. Here the designers and contractors did not have the same level of confidence. To minimize risks in the delivery of their first ever PassivHaus scheme, choose to follow the canonical principles more closely, resulting in a simpler cubic form.

Innovative Practice

The research has also shown that the architects, consultants and contractors considered these pioneering projects as investments into R&D as well as major exercises in continued professional development that would equip them with the specialist technical knowledge, skills and practical experience required to enter the emerging UK PassivHaus market. In all of the projects extra time and financial resources were provide for research and development, training, building up supply chains and collaborations involving UK and central European consultants. In the case of Crossway House the architect purposely employed various technical consultants as a means to developing an area of expertise in the area of low energy design.

The Princedale, Hadlow, Camden and Exeter projects illustrate the important role research and development and the knowledge transfer with continental Europe had played in the learning process underlying these pioneering projects. Many of the project teams, partly due to the absence of a mature supply chain of PassivHaus components and partly due their limited experience with the technical and managerial implications of the standard, formed strong partnerships with European experts in the area. These included architects, engineers, manufacturer of prefabricated buildings components and suppliers. These acted as consultants and in some cases were extensively involved in the technical design development and/or in the supervision of the construction. In one case an Austrian architect had joined the UK practice for a longer placement first to gain insights into the British building industry and second to assist the architects in the development of details, based on Austrian timber construction systems. Many of the projects also demonstrated the importance of extensive technical research, which included building performance evaluations conducted in collaboration with university departments, the development of advanced construction details for new buildings and retrofit projects as well as the prototyping of PassivHaus compliant window systems and concrete-based prefabrication systems. The latter was done in partnership with architects and manufacturers in Belgium and drew on lessons with similar systems in Germany. As such the PassivHaus schemes have provided the impetus for the type of innovative practice that the Department for Business, Innovation and Skills and the Department of Energy and Climate Change aims to promote. In the report UK Construction, An economic analysis of the sector (July 2013) the Department for Business, Innovation and Skills emphasizes that the UK building industry suffers from the insufficient investment in research and development and collaboration between research institutions and businesses for the UK industry to harness the full potential of a global sustainable construction market.

However, all of the schemes covered in this research have to be considered pilot projects that were breaking new ground in the field of sustainable design, construction and procurement. Four of the case studies benefitted from grants provided by the Technology Strategy Board through two funding schemes, *Retrofit for the Future* and *Building Performance Evaluation*, which covered the extra costs for feasibility studies, research and development and the implementation of pilot schemes and post-occupancy evaluations. The use of post-occupancy evaluations allowed the implementation of the evidence-based research model underlying the Softlandings Framework and the new RIBA Plan of Work (2013). Empirical data on energy performance and user satisfaction gained in one building is utilized to feedback into the design of future projects. The consultation and education of building users received much attention during the hand-over and post-occupancy stages. The involvement of the user was part of the learning process for the project teams. User-behaviour can have a significant impact on building performance from the point of air quality, health, thermal comfort and energy use, if building users have not been sufficiently introduced to the environmental principles. The functioning of the MVHR, for instance, can be compromised by the opening of windows for extensive periods over the winter months. To address this issue most of the case study projects involved training sessions for building users and the development of intuitive user-guides, which explain how systems function and how they can be adjusted. This is found to be particular important in the three educational buildings.

Education, Skills and Construction Assurance

In all of the case studies introducing builders to new technologies, building methods and higher quality standards had been an important part of the process. In the context of PassivHaus ensuring a high quality of on-site construction was a means to reducing the risk of failing to pass certification or meeting the high energy performance targets in practice (performance gap). Strategies for addressing the issue of skills and construction quality varied significant between projects. In the case of the projects in Camden and Hadlow, for instance, this issue was largely avoided through the extensive use of prefabricated building components that had been imported from continental Europe. Other projects, such as the retrofit schemes, Denby Dale, Grey Lyn and Montgomery School, relied more extensively on the use of local skills. Most of project exploited system of construction that were relatively new to the UK but the design of Grove Cottage, Essex Disability Centre and Denby Dale explored the possibility of adapting German details to accommodate local skills and materials or adapting British building traditions to the requirements of the PassivHaus standard. In the context of Denby Dale, for instance, the project team went to great length to adapt traditional cavity wall construction to PassivHaus requirements. This involved various technical refinements in order to eliminate cold bridges, achieve the necessary airtightness and higher levels of thermal insulation, but also close supervision during construction to ensure it was executed at the required quality. In the Grey Lyn project, on the contrary, the use of traditional cavity wall construction was rejected for being economically unviable due to the cost for constant supervision in order to deliver the necessary quality. The architect, Paul Mallion, argued that the general quality of cavity wall construction in the UK was poor and that it could only be raised through extensive training and close site supervision. By reducing the level of supervision, the use of prefabricated timber-frame systems was considered a more cost effective way of achieving the necessary quality. It to be stressed that the high level of supervision provide in many of the project was only economically feasible due to the fact that many of the houses were owned by the architect themselves, who together with their wives or husbands, were able to monitor the construction very closely. This allowed identifying mistakes or cases of poor workmanship timely when it was not too late to make amendments.

These challenges highlight some of the broader implications of the current standards of vocational education in the UK. Various studies have highlighted that the UK construction industry suffers from significant low-skills equilibrium, acting as a major obstacle to the successful delivery of low-energy buildings. The project teams covered in this book, however, had gone to great length to successfully address these wider issues:

- first by adopting a collaborative approach in which architects involved clients, consultants, contractors and suppliers more directly in the development of projects through all stages.

- second by monitoring construction quality through site supervisions and empirical performance evaluations, involving the use of thermography, airtightness tests and post-occupancy evaluations.

- third by involvement in technical research, including the development of new technical solutions that could be deployed in other projects.

- fourth by addressing educational needs, with skills training seminars, team workshops, mentoring schemes and increased site supervision being made integral parts of the project.

In all of the case studies education formed a critical and integral part of the project for all parties involved. These illuminated the potential of the PassivHaus standard in acting as a major driver for a skills renaissance in the building industry, introducing contractors not only to more advanced construction methods, but also to much higher quality standards. In all of the case studies the training, briefing and supervision of builders was taken as an important part of the project. Extra care was invested in communication, training and supervision partly due to the pioneering nature of the projects studied. The majority of contractors had no or very limited experience with Passivhaus and associated construction standards. Architects were required to produce considerably larger numbers of working drawings, showing a high level of detail. Architects could no longer rely on contractors adopting more conventional details that were designed to fulfil the minimum mandatory requirements set out in Part L. Builders had to be more clearly instructed and supervised and in many cases special training and briefing sessions were provided to the contractors. Drawings were produced for each type of junction, showing, among others, the exact position of the airtightness layer and thermal insulation layers around critical junctions. These 'unconventional' details had also to be explained to builders, as many of them were not able to read them or understand the requirements. The projects in Camden and Hadlow, for instance, have demonstrated the potential of briefing session with the construction teams, involving the use of PowerPoint presentations, BIM models and three dimensional simulations to explain the project and specific technical requirements in full detail. The latter was also used to seek input from builders during design meetings. This highlights very clear that the PassivHaus standards, or low-energy design more generally, has direct implications for architectural practice and how it engages with other related professions on which it relies to successfully delivery projects. The Farrell Review identified the need for establishing stronger links between the education of architecture, civil engineering and urban design, but this research has revealed potential benefits in extending these links to vocational education. It raised the question:

Does the UK vocational education system, typically delivered by regional technical colleges, and its relationship to the university-based education of architects and engineers, need to be reformed to overcome the traditional division between the designers and makers of buildings?

The latter was found to be a major barrier to the successful delivery of low energy buildings in the UK. A more collaborative approach, involving contractors, suppliers component manufacturer through all stages, was also a key factor, in particular at the pioneering stage when all of the parties were in the process of gaining experience with the new standards and associated design methodologies, technologies and construction systems. The majority of case studies were the outcome of a collaborative model of practice, in which cross-disciplinary teams of architects, contractors, suppliers, consultants and some cases researchers from University Departments, were involved more actively and directly in the design development from an early stage. In addition to facilitating cross-industry collaboration in research, design and construction, the collaborative model was a means to maintain a highly level of continuity from initial design through to the completion. The case studies have not only shown that traditional procurement methods, where the design and construction process are separated, were challenges but also strongly suggest that Design and Build or Integrated procurement methods were more adequate. This was demonstrated by design and built companies, Eurobuild, Princedale Housing, Green Building Store, who by unifying the roles of the architect, engineer and main contractor under roof, were able to take a more integrated approach to the design, procurement and construction processes.

It is evident that all but one of the thirteen case studies were one-off bespoke projects, delivered by project teams and small companies that were highly committed to both quality and technical innovation. The collaborative approaches that were demonstrated by these projects also provided a potential model for reforming traditional models of practice. It suggests that small to medium sized enterprises are leading the way in developing these new models of practice for the UK building industry. All of the cases have shown that the PassivHaus standard had provided contractors and their builders with the impetus to give an exceptionally high level of attention to the quality of execution, which in many of the interview was described as a significant culture shift in British building practices. The projects, however, have also shown that the projects were done by small to medium sized companies, which, despite the lack of experience with the PassivHaus standard, already had a strong interest in technical innovation and sustainable design. These findings raise the important questions of how this culture shift could be extended to larger companies and commercial development. Does the reliance on commitment to quality in the execution, which is only partially reviewed as part of the certification process, make the standard vulnerable? It is to be highlighted here that PassivHaus certification is largely based on the performance as predicted by the PassivHaus Planning Package (PHPP) and the only form of empirical testing required for purpose of certification is the airtightness test. The PHPP is recognised as a highly rigorous performance prediction tool with extensive empirical evidence demonstrating its reliability, but the predictions are based on the assumption that the building is executed with extensive care and adhering to the approved details. In all of the thirteen case studies meticulous attention was given to the execution of junction details and the installation of insulation and the airtightness layer. The mandatory blower door tests provide a means of empirically verifying the quality of the construction in terms of airtightness and contractors can be made accountable for the test results. In some of the case studies, such as the Camden and Grey Lyn projects, the first blower door test revealed leaks in the external envelope and contractors had to identify the position of leaks and close them. Hence it has to be understood as a means of making the on-site team accountable for the quality of the construction, but other aspects of the construction, such as the execution of thermal bridge free junctions, are not empirically evaluated as part of the certification process in full detail. In the 'The certification criteria for domestic Passive House buildings' the PassivHaus Institut states that the inspection of construction work is not automatically covered by certification, but construction managers are required to make declaration that acknowledges any deviation from the original drawings and to supply photographs and other evidence documenting the construction. Irrespective of the PHPP results, however, the supervision of the execution of details on site was found to be a prerequisite to avoiding the risk of a great performance gap between the predicted and actual performance.

The case studies covered in this study are exceptional in terms of the commitment of architects, clients and contractors to construction quality and ambition to achieve the best performance results. In all of the projects the construction was under close supervision and on some projects thermo graphic imaging was used to check thermal bridges and the execution of the insulation layer. Several university departments were also engaged in conducting systematic post-occupancy evaluations, addressing energy use, thermal comfort and air quality. Althought not mandatory for certification, these post-occupancy studies provide hard evidence of actual building performance, which can be directly compared against the performance benchmarks. The group of architects and contractors involved in the thirteen projects had an exceptional interest in the quality of construction of buildings from an energy performance point of view, aiming to achieve ever better airtightness standards and better solutions to thermal bridging issues, reflecting a technical design ethos that is prevalent among PassivHaus architects and engineers in Austria and Germany. In the UK, however, this meticulous technical approach has to be understood as a culture shift within architectural practice. In case of project such as Cross-way House and Grey Lyn, projects were driven by the personal ambition of the client-architect to optimising the performance of the building fabric and environmental systems. This also shows that the successful delivery of the PassivHaus standard, not just to pass certification but also to meet the energy performance targets in real life, was heavily reliant on contractors and developers commitment to quality. The question remains as to how far this high quality standard can be maintained in the context of large scale commercial developments?

The UK building industry, compared to their Austrian or German counterparts, has a limited experience with delivering the PassivHaus standard. Pioneering efforts over the past eight years to implement buildings of this standard in the UK, however, has provided the impetus for cross-industry collaboration, technical innovation and evidence-based design.

A collaborative research project, coordinated by Dr. Henrik Schoenefeldt at the University of Kent, has shown that the delivery of PassivHaus certified buildings in the UK relied extensively on imported technologies, construction methods and collaborations with manufacturer and contractors in continental Europe, but also drove the developing new solutions within the UK. Some of these built directly on existing skills and building traditions within the UK.

Using multi-methodology research, the project investigated the learning process underlying the delivery of fourteen buildings, certified between 2009 and 2013. Largely based on the study of the original project correspondence and semi-structured interviews with clients, architects, town planners, contractors and manufacturers, these case studies have illuminated the more immediate technical as well as the broader cultural challenges. This included the development of new forms of collaboration between architects, university-based researchers, consultants, clients and contractors in research, design, quality control and education.

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