The Application of EnerPHit Standard to Residential Tower Blocks in the UK

Soha Hirbod

Faculty of Humanities

School of Architecture

Thesis submitted to the University of Kent for the degree of Doctor of Philosophy

September 2018

75,000 words

Declaration

I, Soha Hirbod declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University;
- Where I have consulted the published work of others, this is always clearly attributed;
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;

Acknowledgements

I would like to express my deepest gratitude to Dr. Henrik Schoenefeldt, my research supervisor, for all his support and enthusiastic encouragement. I appreciate his continuous guidance and constructive recommendations during the development of this research. He has been a tremendous supervisor.

I wish to thank Prof. Marialena Nikolopoulou, my second supervisor, for her advice and insightful comments on the progress of my research. I am also grateful to University of Kent for offering me 50th Anniversary PhD Scholarship.

I would like to thank James Traynor and Loreana Padron who provided me an opportunity to join ECD Architects, offered valuable advice, and extremely useful sources of data. My grateful thanks are extended to the staff of ECD Architects, Portsmouth City Council, Keepmoat, and Keegans for their assistance with data collection.

I am truly indebted and thankful to my friends Azin, Orod, and Reza for encouraging me to embark on this journey and supporting me through the way. I am also thankful to my friend Bahar for her efforts to keep me motivated and uplifted.

Finally, I wish to thank my parents and my brother Kousha for their unlimited love, support and patience during this study.

Thank you all.

Soha Hirbod

Abstract

This study examines the refurbishment of residential tower blocks in the UK according to the EnerPHit standard, which is an adaptation of the Passivhaus standard for retrofit. Currently, no single high-rise building in the UK has achieved this standard.

The research focuses on the case study of Wilmcote House, a social housing tower block in Portsmouth owned and managed by Portsmouth City council. Wilmcote House is the first UK tower block being refurbished using the EnerPHit standard. Nevertheless, the building will not fully achieve EnerPHit by the time of project completion due to a lack of compliance with the primary energy demand. The Wilmcote House case study involves an investigation of the project process from the tender early stages to the delivery of the building. Research methods such as interviewing the project team members, direct observations of the project proceedings on site, attending site meetings, and archival research into the design process have led to important insights into the challenges of the pioneering real-life project.

The study also investigates the refurbishment project of [REDACTED]and [REDACTED], two other social housing tower blocks in [REDACTED], to make cross-case comparisons. [REDACTED]appointed the same architects to propose a design for the refurbishment of the blocks based on EnerPHit, but they decided not to proceed with the project following the feasibility stage. The rare opportunity of the author to work with the architects at the initial stages of the [REDACTED]and [REDACTED]projects and to carry out embedded research has provided a critical understanding of the project complications.

Based on the case studies, the research aims to uncover the specific requirements and difficulties related to the process of applying EnerPHit to UK tower blocks. The study also examines possible solutions to overcoming the challenges encountered at different stages of the process. The research reveals that the approach of the client and the architects towards the tower block refurbishment are two determining factors in adopting EnerPHit; the physical properties of tower blocks can create difficulties with meeting EnerPHit criteria such as primary energy demand, and the requirement for EnerPHit training and lack of sufficient communication between the teams can seriously complicate the construction stage.

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Introduction

I.Prologue

The construction of residential tower blocks in the UK started after World War II when the country faced a housing shortage. Local authorities built tower blocks to address this housing crisis by providing society with many new homes as fast as possible (Glendinning & Muthesius, 1994). However, the use of unsuitable materials, poor workmanship, and insufficient supervision led to serious problems in the tower blocks, particularly energy inefficiency (Shabha, 2003). Lack of energy efficiency in tower blocks increases the risk of fuel poverty because most of their tenants live on lower incomes. In fact, 71% of tenants living on or above the fifth floor are social rented sector tenants (Scott, 2014). In addition, the energy inefficiency of the buildings results in high levels of CO_2 emissions, which adversely affect UK carbon reduction[1] targets. Set in 2008 through the UK Climate Change Act, one of the most important targets was the reduction of GHG emissions by 80% by 2050, compared to 1990 levels (Climate Change Act, 2008). Because a quarter of the UK's greenhouse gas emissions are related to households (Palmer & Cooper, 2013), it is necessary to improve the energy efficiency of existing buildings to achieve this target.

Currently, the only refurbishment benchmarks in the UK that existing buildings are required to comply with are UK building regulations. The energy efficiency requirements are provided in document L1 B under "Conservation of fuel and power in existing dwellings". Performance targets and assessment methods such as the Zero Carbon Policy introduced in the 2000s were designed to be applied in new buildings and did not address refurbishment schemes. However, improving existing stock is of greater relevance because it is predicted that around 75% of housing stock will still exist in 2050 due to the low rates of demolition and replacement in the UK (Ravetz, 2008). Therefore, using a standard which would significantly upgrade the efficiency of existing buildings would have a considerable contribution to carbon reductions in the UK.

One of the well-known low energy standards is the German Passivhaus which specifies clear energy efficiency targets for buildings. The Passivhaus standard has been widely adopted in some European countries during the last two decades. However, it is not always viable to fully comply with Passivhaus in the refurbishment of existing buildings; thus, the Passivhaus Institute in Darmstadt introduced a new standard for retrofit projects, known as EnerPHit.

[1] In this thesis, the word 'carbon', when not followed by dioxide, is interchangeable with carbon dioxide.

EnerPHit has less stringent performance criteria than Passivhaus (McLeod, et al., 2012). As a ‘foreign’ standard, EnerPHit had been introduced to the UK to achieve more energy efficient building. By focusing on increasing fabric efficiency, it provides a potential model for UK refurbishment projects. The first refurbishment project to achieve EnerPHit in the UK was completed in 2008 (Seaman, 2014) and over the past ten years, a significant number of buildings covering residential, commercial and educational projects have achieved EnerPHit. Belonging to a category of existing building stock in the UK, requiring a high level of improvement, tower blocks could also be retrofitted to the EnerPHit standard. Both EnerPHit-certified high-rise retrofits and new Passivhaus tall buildings are achievable and can be found in some countries such as Germany and Austria.

Nevertheless, the use of EnerPHit in the UK has been mostly limited to low-rise buildings and despite a few attempts, no existing high-rise building has achieved EnerPHit status of yet. The project pioneering the application of the EnerPHit standard to existing high-rise buildings within the UK was Wilmcote House, a post-war tower block constructed in 1968, located in Portsmouth, and owned by Portsmouth City Council. This research uses the case study of Wilmcote House to investigate the process of applying EnerPHit to UK tower blocks. Wilmcote House consists of three 11-storey interlinked blocks set around a courtyard. The blocks have concrete prefabricated structure, which was one of the most common building methods of the time. By 2010, some of the main elements of the building were near the end of their serviceability (ECD Architects, 2012). The poor external envelope had caused various problems, such as air leakage, condensation, and mould growth, leading to uncomfortable living conditions (ECD Architects, 2012). In addition to the ineffective thermal performance of the façade, the inefficiency of the heating system resulted in high energy bills for the building’s residents, who were mostly on lower incomes and at risk of fuel poverty[2] (Buckwell, 2012).

The council initially focused on conventional refurbishment steps such as upgrading the heating system. Following their analysis of the building conditions, they concluded that its problems were too extensive, and it was essential to carry out a deep retrofit to extend the life of the buildings (Groves, 2015). Subsequently, they appointed architects to design a

[2] “A household is considered to be fuel poor if:

- they have required fuel costs that are above average (the national median level);
- were they to spend that amount, they would be left with a residual income below the official poverty line.” (Department for Business, Energy & Industrial Strategy, 2013)

refurbishment scheme. ECD, the project architects, concluded that the long-term solution to improving the condition of the building was to maximise the efficiency of the building fabric (Groves, 2015). Being familiar with Passivhaus and its fabric first approach, ECD proposed to use the EnerPHit standard; nevertheless, they also prepared an alternative scheme based on improving the fabric of the building to a level slightly above UK building regulations and replacing the heating system (ECD Architects, 2012). The client decided to proceed with the EnerPHit option because it would minimise the heating demand (ECD Architects, 2012). Consequently, the reliance on the heating system and the energy bills would reduce significantly. Furthermore, the residents would be protected from the future potential rise of fuel prices. Following the design stage of the project, it was realised that the building was expected to meet all the EnerPHit requirements except for primary energy demand. The following image shows the courtyard and street facades of Wilmcote House.

Figure I. Wilmcote House courtyard façade (on left) and street façade (on right) (www.buildingcentre.co.uk, 2016).

There is one other UK tower block refurbishment project aiming to achieve EnerPHit standard which started three years after the design of the Wilmcote House refurbishment scheme. This project involves the refurbishment of three post-war tower blocks in Glasgow (Collective Architecture, 2015). The project is not yet completed, and it is unclear whether it will meet all EnerPHit requirements. The initial studies of the project architect indicate that the refurbishment scheme will not lead to achieving the primary energy demand of EnerPHit (Daly, 2016). Taking into account this project and the Wilmcote House refurbishment, there have been two tower block refurbishment projects in the UK using the EnerPHit model, but hitherto none has achieved the standard. This indicates that there are certain challenges to upgrading the UK post-war tower blocks to EnerPHit level. Being close to the point of completion, the investigation of Wilmcote House provides an exceptional opportunity to gain insights into the whole process of applying EnerPHit to UK tower blocks. This research aims to explore this process and uncover the difficulties and challenges associated with it by focusing on the Wilmcote House case study.

II. Background

This section gives a brief history of post-war tower blocks in the UK and looks at their current situation to explain why they require to be refurbished. It then examines the major refurbishment schemes developed by the UK government affecting tower blocks among other existing building stock. Following this investigation, EnerPHit is introduced as a potential refurbishment standard which can be used in UK buildings. Subsequently, the EnerPHit approach is compared to the approach of other refurbishment programmes in the UK.

II. I. The history of tower blocks

Tower blocks became a popular form of public dwelling after World War II. It is estimated that approximately 6,535 residential blocks were constructed in the UK (Shabha, 2003) comprising around 400,000 dwellings (Scott, 2014). The total number of dwellings in the UK was estimated to be 23,733,000 in March 2016 (Department for Communities and Local Government, 2017). Thus, the post war tower blocks accommodate less than 1.7% of dwellings in the UK. Tower blocks were initially highly praised, but fell out of favour within society some two decades later. Following World War II, the country faced a housing crisis. There was a requirement to replace the buildings destroyed during the war and to fix the problems caused by the very low standard of 19th century dwellings (Dunleavy, 1981). Tower blocks could be a suitable solution to tackle housing shortages because they could house a large population on a smaller footprint (Hanley, 2007) and in a shorter timeframe. Nevertheless, both Glendinning and Muthesius (1994) and Dunleavy (1981) argue that the construction of tower blocks did not merely address the housing shortage; it was also influenced by the aspirations of their architects and owners, such as councillors and government officials. These producers had political motives. For instance, local authorities tried to impress their voters by constructing these blocks to show post-war progress (Hanley, 2007). On the other hand, designers were influenced by the ideal approach of the architects of the day, such as Le Corbusier, both in terms of modern urban living and their brutalist architectural style (Dunleavy, 1981). They wanted to build high to move beyond the monotonous design which was commonplace in the initial years after war. Tower blocks were radically different from the existing buildings of the time in form, design, construction and conception of use (Glendinning & Muthesius, 1994).

According to Towers (2000), some general traits of post-war residential tower blocks are that their height exceeds their width; they typically have 10 or 11 floors, but they can rise to higher than 30 floors; their access is via one entrance point; and they have a single lift and stair shaft leading to landings or corridors on every floor (or every two floors in blocks with maisonettes). The blocks consisted of flats or maisonettes. A maisonette in a tower block is a unit with two floors and a small staircase connecting the two. In a maisonette the bedrooms and the living rooms are spread over two floors; subsequently, maisonettes can create a greater feeling of a private home. New construction methods were used to build tower blocks. In the early 1950s, most high-rise buildings relied on steel, but this material was expensive and its fabrication and transportation challenging. Alternatively, reinforced concrete frame construction was used in the UK. The most significant construction method used in the majority of 1960s tower blocks was the large panel system (LPS). In this method, walls, roofs and floors are made of precast concrete produced in factories off-site, with window and door frames affixed to the panels. Consequently, the joinery work was minimised. LPS blocks typically consist of precast concrete floors, roofs and wall panels made off-site, connected by different kinds of joints on-site, therefore resulting in simpler and faster construction (Glendinning & Muthesius, 1994).

Thus, tower blocks appeared to be the perfect solution at the time, becoming the dominant typology of social housing in the 1950 and 1960s. They conformed to the housing plans of the government and local authorities, reflected the architects' opinions, and improved the standard of housing. The flats offered private toilets, bathrooms, kitchens and better views of the outside. Nevertheless, tower blocks began to lose popularity shortly after they were built. Many different reasons have been proposed to explain the failure and demise of the tower block. This study explains some of the more evident and significant ones. A lack of security, and high rates of crime and vandalism became common features in many blocks, adversely affecting the lives of the residents. This has been frequently covered across many different forms of media, from the point at which these problems originally occurred up to and including the present day. While it has been argued that some social problems are inherent in high-rise buildings (Dunleavy, 1981), Glendinning and Muthesius (1994) point out that many of the problems in residential tower blocks have roots in poor management, and the exclusion of communal facilities and concierges from the design to minimise costs.

Another important factor which contributed to society's lack of trust in residential tower blocks was the partial collapse of a 22-storey tower block in London called Ronan Point. In 1968, one of the occupants of Ronan Point lit a match resulting in a gas explosion, initiating the partial collapse of the building structure. Subsequent investigations showed that the tower had serious flaws in its design and construction. As in most 1960s tower blocks, the building consisted of precast concrete panels with no structural frames, with connections relying mostly on friction. In the event of a partial collapse, the block could not redistribute forces because it lacked alternative load paths. Similarly, investigators discovered the evidence of extremely poor workmanship at the critical connections (Pearson & Delatte, 2005).

The Right to Buy policy arguably exacerbated many problems encountered in tower blocks. In 1980, under Margaret Thatcher's Conservative government, the Right to Buy policy was introduced. It gave the tenants of council houses a right to buy their flat or house considerably below the market price (Marsh & Rhodes, 1992). Nevertheless, more houses were bought than flats under the Right to Buy policy; although they made up 30% of housing stock, only 5% of sales between 1981 and 1985 were of flats. The reason for this was that tower blocks had become unpopular by this period (Forrest & Murie, 1988). Tenants who bought their houses were mostly employed; on the contrary, the sales rate was low in areas with higher unemployment. Consequently, the quality of council housing changed. The most desirable council houses were sold, with the remaining properties, which were more likely to be flats, becoming less desirable. This led to a change in the social composition of the tenants, with tower block residents becoming similar in terms of social class and sharing characteristics associated with poverty (Forrest & Murie, 1988). In other words, residential tower blocks became the homes of poor people.

Due to the problems faced at tower blocks and the negative opinion of society towards them, a considerable number of them were demolished in the 1990s and 2000s (Barnett, 2016). Remaining blocks continue to be affected by design, construction, and social problems. Poor maintenance, insufficient inspections, and a lack of repair have exacerbated the problems over time. Consequently, existing tower blocks suffer from structural problems: condensation, cold bridging, water ingress resulting from a lack of proper insulation, the use of inferior materials, poor workmanship, and insufficient maintenance (Shabha, 2003). Furthermore, it should be noted that UK building regulations were originally enforced after 1976. This was when minimum standards for insulation were set for the first time. Most of the buildings constructed prior, including most post-war tower blocks, had single glazing and uninsulated roofs and floors (Dowson, et al., 2012). The energy inefficiency of the blocks resulted in high energy bills for its occupants who were generally on lower incomes. Currently, UK tower blocks belong to the category of 'hard to treat' properties (Department for Communities and Local Government, 2014). To improve the quality of the residents' lives and to reduce carbon emissions resulting high energy consumption, it is necessary to refurbish existing tower blocks. The UK government has been planning different programmes to enhance the existing building stock. The following explores the programmes affecting the social housing stock and their possible effects on improving residential tower blocks.

II. II. Energy efficiency schemes for existing buildings

Over the past twenty years, retrofit schemes in the UK have focused on improving insulation levels and upgrading outdated heating systems. In 2000, the government introduced the Decent Homes standard and committed to bringing all public dwellings to a basic level of quality by 2010. This was a minimum standard that had to be met by council homes and housing association homes (Shelter, 2018). Therefore, the responsibilities of the local authorities and registered social landlords increased in terms of repairing their building stock. Firstly, to meet this standard, the dwelling must not have any Category 1 HHSRH (Housing, Health and Safety Rating Hazards). This includes examining the level of structural integrity, security, hygiene, excessive heat or cold, asbestos, dampness etc. Secondly, the property should have an acceptable level of repair and modern facilities and services. In addition, adequate thermal comfort should be provided inside the building (Dowson, et al., 2012). A lack of sufficient thermal comfort due to failure at the HHSRH evaluation was the main reason why some dwellings did not meet the standard by 2010; they had both inefficient insulation and heating systems (Dowson, et al., 2012). It should be noted that Decent Homes is merely a minimum standard that recommends the use of UK building regulations as a guide. Under the Decent Homes standard, the building components should be upgraded if they are older than their standard life or need major repair[3]. Nevertheless, Decent Homes does not require specific performance targets.

EEC (Energy Efficiency Commitments) 1 and EEC 2 were the UK Government's main efficiency tools for existing housing stock. These schemes were expected to cut CO_2 from

[3] In terms of heating, the standard considers any oil or gas programmable central heating, electric storage heaters, warm air systems, and underfloor systems to be efficient. The level of insulation required depends on the type of heating. For properties with oil or gas programmable heating, providing 50mm loft insulation and cavity wall insulation (if they have a loft or cavity wall) is found to be effective. For properties with electric storage heaters, LPG or programmable solid fuel central heating, a higher level of insulation (at least 200mm of loft insulation) is required (Department for Communities and Local Government, 2006).

housing by 1% per year. Under EEC, gas and electricity suppliers were required to achieve energy savings in homes between 2002 and 2008. Following EECs, CERT (Carbon Emissions Reduction Target) set out CO_2 reductions to be achieved by suppliers from 2008 to 2012. CESP (Community Energy Saving Programme) was also in force between 2009 and 2012. Under CESP, gas and electricity suppliers were required to achieve energy savings in homes within low-income areas of Britain (Palmer & Cooper, 2013). Based on all the schemes mentioned here, energy companies promoted energy efficiency measures such as insulation and efficient appliances to homeowners by means of grants and subsidies. However, these companies were criticized for promoting measures which would reduce the costs to the company rather than being the most appropriate option for the dwelling. For instance, lofts and cavity walls were mostly insulated under these schemes; whereas, only a very small number of solid wall insulations were achieved because of their higher costs (Wetherill, et al., 2016). Figure I shows the number of households in which insulation measures under EEC and CERT have been installed.

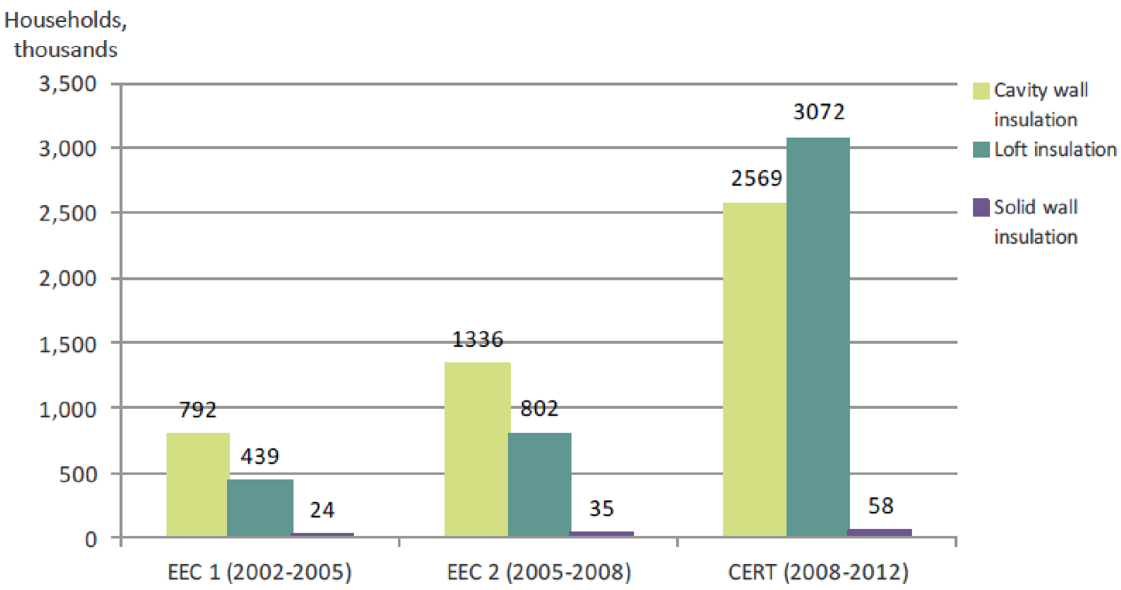

Figure II. Insulation measures installed under EEC and CERT (Palmer & Cooper, 2013).

Therefore, later schemes were designed with a focus on improving the energy efficiency of ‘harder to treat’ dwellings with solid walls, ‘hard to treat’ cavity walls, and vulnerable or low-income households. The Green Deal was a scheme effective from 2012 to 2015 and designed to make energy improvements at no upfront cost for householders, while reducing CO_2

emissions and helping the vulnerable (Palmer & Cooper, 2013). According to Government sources, residents felt they could not take energy efficiency measures because they were not able to pay for the associated upfront costs, and could not trust the overall quality of the work. Nevertheless, under the Green Deal, homeowners could pay for improvement costs through savings on their energy bills (2010 to 2015 government policy: household energy, 2015)[4]. Only a small number of households used the Green Deal, potentially because the financial aspect of the scheme was too complicated to set up with individual companies (Vaughan & Collinson, 2014).

The ECO (Energy Company Obligation) scheme which initially worked alongside the Green Deal, provides further assistance for 'hard to treat' properties and vulnerable households. Launched at the beginning of January 2013, this scheme is funded by energy suppliers and has replaced CERT and CESP (Palmer & Cooper, 2013). The Carbon Emissions Reduction Obligation (CERO), Carbon Saving Community Obligation (*CSCO*), and Affordable Warmth Obligation are specified commitments within the ECO (2010 to 2015 government policy: household energy, 2015):

- CERO provides both primary measures: including solid wall, cavity wall and loft insulation, and connections to district heating systems; and secondary measures such as double glazing.

- CSCO provides primary measures (insulation and connections to district heating) to dwellings in specified low-income areas. The energy suppliers must achieve 15% of their obligations in rural areas.

- The Affordable Warmth Obligation provides insulation and heating measures to residents of private homes who receive specific means-tested benefits. The target of this obligation is to support low-income residents who are exposed to the effects of living in cold homes.

[4] To use the Green Deal, the householder had to initially get an assessment of the property. In the next stage, the *Green Deal* assessor visited the property and provided a Green Deal Advice Report which included information on the energy use of the property, recommended improvements, etc. If the householder decided to have the work carried out, they could ask a Green Deal Provider to arrange the installation. Subsequently, the householder could pay for the installation themselves or ask for a Green Deal finance plan (Green Deal: energy saving for your home, 2015).

The Energy Company Obligation scheme was initially welcomed by architects, builders, and homeowners. It could encourage householders to start improving the energy efficiency of their properties while relying on funding from the ECO. However, some changes to the ECO were later announced by the Government, who were believed to have watered down the scheme (Mason, 2014). According to this announcement, ECO was to be extended to 2017, with the same level of funding allocated to CSCO and the Affordable Warmth Obligation maintained until 2017. CERO was the target of the main changes. CERO provides insulation for some of the most inefficient homes which could have the largest impact on reducing CO_2 emissions and heating costs, but the Government decided to cut the investment in this area by 33%. The other change was to the target of CERO. Originally designed to cover solid wall and hard to treat' cavity wall properties, cavity wall and loft insulation also fell into this category. According to the Government, the funding cut from CERO was anticipated to result in a saving of £30 to £35 on a dwelling's energy bills; however, this would lead to a reduction in the delivery of the ECO (Department of Energy and Climate Change, 2014).

Thus, it can be understood that retrofit schemes in the UK have aimed at improving the energy efficiency of the existing building stock, but have not specified particular energy performance targets. They have mainly focused on two building elements: the heating system and insulation. Nevertheless, the schemes have not covered all the existing stock, partly because they were not executed properly and some of them such as the Green Deal had certain complications. The number of 'hard to treat' properties receiving refurbishment measures has been significantly lower than other properties. These measures are generally more difficult to achieve; furthermore, the government has reduced the obligation towards the improvement of these properties. Belonging to the category of 'hard to treat' dwellings, tower blocks have been affected by this situation. Some blocks have been improved under Decent Homes, but this standard does not necessarily increase the energy efficiency of the properties significantly. ECO could provide a good opportunity for the deep retrofit of tower blocks, but later changes to the scheme limited this opportunity. EnerPHit standard takes a different approach towards the retrofit of buildings. It requires different elements of building to achieve a high level of efficiency and to minimise reliance on a heating system. The approach and targets of EnerPHit are discussed in the following section.

II. III. EnerPHit standard

The EnerPHit standard is the retrofit version of the German Passivhaus, a low energy building performance standard, aiming to minimise energy consumption and maximise thermal comfort.

Because of the difficultly of achieving the requirements of Passivhaus in challenging refurbishment projects, EnerPHit was developed with less stringent performance criteria (Hopfe & McLeod, 2015). Passivhaus standard was launched in 1988 by Wolfgang Feist and Bo Amandson who were undertaking a research into low-energy houses in Northern Europe. Passivhaus buildings were defined as "buildings which have an extremely small heating energy demand even in the Central European climate and therefore need no active heating. Such houses can be kept warm passively, solely by using the existing internal heat sources and the solar energy entering through the windows as well as by the minimal heating of incoming fresh air" (Feist, 2014). In 1991, the first Passivhaus building was completed in Darmstadt-Kranichstein, Germany (Feist, 2014).

To achieve Passivhaus, clear performance targets have been specified. One of the major targets for Northern and Central European Climate is that the building has a heating demand of less than 15 kWh/m^2.yr or space heating load of less than $10W/m^2$ (McLeod, et al., 2011). The threshold of 15 kWh/m^2.yr typically relates to the heating load of $10W/m^2$ which is the maximum amount of heating load if the building is to be heated only via the supply air coming from the ventilation system[5] (Dreimane, 2016). Another important Passivhaus target is a primary energy demand of less than 120 kWh/m^2.yr (McLeod, et al., 2011). The primary energy requirement considers the electrical and non-electrical demand of the heating system, lighting, ventilation, cooking, plug loads, and appliances (Hopfe & McLeod, 2015). In his study "Passive Houses in Central Europe", Feist used computerised simulations of the building energy to test the feasibility of Passivhaus (Feist, 2014). In this study, the characteristics of building components affecting the energy consumption were varied and optimised with regard to efficiency, cost, and living quality. It was realised that building energy optimisation could not be achieved by only minimising heating energy; in fact, total household energy use had to be reduced. Otherwise, heating demand could be reduced by using inefficient electrical devices leading to high internal heat gains (Feist, 2014). The primary energy demand limit of 120 kWh/m^2.yr relates to the minimised space heating/cooling energy ($\leq$ 15 kWh/m2.yr) and the low levels of energy consumption achievable with efficient hot water systems, energy efficient appliances and low energy lighting.

[5] According to Deutsches Institut für Normung (German Institute for Standardisation) 1946, the minimum fresh air flow rate for one individual is 30 m3/h. To avoid the burning of dust particles, fresh air can be heated by a maximum of 30 K. The heat capacity of air at 21°C and standard pressure is 0.33 Wh/ m3.K. Therefore, the capacity required per person is: 30 m3/h/per * 30 K *0.33 Wh/ m3.K = 300 W/pers. On the assumption that the living area per person is 30 m^2, the heating load would be 10 W/m^2. (Dreimane, 2016)

To meet the energy performance targets, the build fabric must be superinsulated and airtight. In cool and temperate climates, the U-value of walls, floors and roofs should be less than 0.15 W/m^2K, with the U-value of windows and doors required to be less than 0.85 W/m^2K (McLeod, et al., 2011). Passivhaus has a strict airtightness demand to minimise the consequences of air leakage: such as draughts, moisture convection, occupant discomfort; and an increased requirement for space heating and cooling. The airtightness target is $n50 \leq 0.6\ h^{-1}$ @ 50 Pa, expressed as the number of air changes in an hour at a pressure of 50 Pascals. To meet this requirement, it is necessary to use a continuous airtight barrier made of appropriate materials (Hopfe & McLeod, 2015). It is important to note that the airtightness level specified by UK building regulations demand is 10 $m^3/hr/m^2$ @ 50 Pa (Department of Community and Local Government, 2006) which is not difficult to achieve. It should be considered that only a building more airtight than 3 $m^3/hr/m^2$ @ 50 Pa is considered to be airtight to a level that the utilisation of mechanical ventilation will be required (Jaggs & Scivyer, 2009). It is not possible to directly compare Passivhaus and UK building regulations airtightness targets because they are based on two different methods of calculation. According to Hopfe and McLeod (2015), the level of air leakage acceptable in a Passivhaus building is roughly 5 times less than the maximum level specified by UK building regulations.

Another important requirement of Passivhaus is to minimise thermal bridges. A thermally conductive bypass route for heat loss is typically provided at geometric junctions and connections (McLeod, et al., 2011); therefore, designers should assess them carefully when they plan the thermal envelope. If thermal bridges are not eliminated, they can possibly result in up to 50% of the transmission heat transfer in a Passivhaus building (Hopfe & McLeod, 2015). The proper installation of external insulation at junctions and connections is critical to reducing thermal bridges. The building form affects the proportion of thermal bridges, with buildings with more complex forms possibly containing a higher level of thermal bridges. Generally, Passivhaus buildings have compact forms. The compactness is defined by the ratio of the surface area to volume (A/V). This ratio has a significant effect on the total energy demand of the building. Buildings with lower A/V (form factor) are more compact. In other words, they have a smaller surface area. Thus, they require less insulation, and have a lower level of thermal bridges. The building orientation affects the energy demand as well. In the Northern hemisphere, a Passivhaus building should face south where it is possible. This allows the building to benefit from solar gains on south-facing facades in the winter. (McLeod, et al., 2011)

The utilisation of mechanical ventilation with a heat recovery system is required in Passivhaus buildings. In the Central European Climate, average ventilation heat losses are 35 $kWh/m^2.yr$, more than twice the Passivhaus heating demand (Feist, 2014). Due to heat losses, it is not possible to rely on natural ventilation, particularly in the winter. Furthermore, buildings with high levels of airtightness will trap odours, moisture, pollutants, and heat if they are not provided with an appropriate ventilation system. Thus, it is necessary to use a system of ventilation that will remove stale air inside the building and replace it with fresh air from outside. In a mechanical ventilation and heat recovery system, fresh air enters the building and passes through a heat exchanger where it gains/dissipates heat to reach an appropriate temperature before passing into the habitable areas. The stale air is extracted from wet areas, such as bathrooms and kitchens, where odours and vapour are generated. Prior to exiting the building, stale air passes through the heat exchanger releasing heat. The heat recovered from this exhaust air is used to warm up the incoming fresh air without mixing them. Figure II shows the features of MVHR in a typical dwelling. Filters are installed within the MVHR system to remove the possible pollutants in the air drawn from outside the building. Thus, the MVHR system reduces heating demand while increasing the occupants' comfort by maintaining a high level of air quality. Passivhaus requires the MVHR system to have a heat recovery efficiency of higher than 75%[6] and a fan power of lower than 0.45 Wh/m^3. (Hopfe & McLeod, 2015)

[6] The Passivhaus calculation method for heat recovery efficiency can be found in chapter 8 of "The Passivhaus designer's manual - A technical guide to low and zero energy buildings" by Hopfe and McLeod (2015).

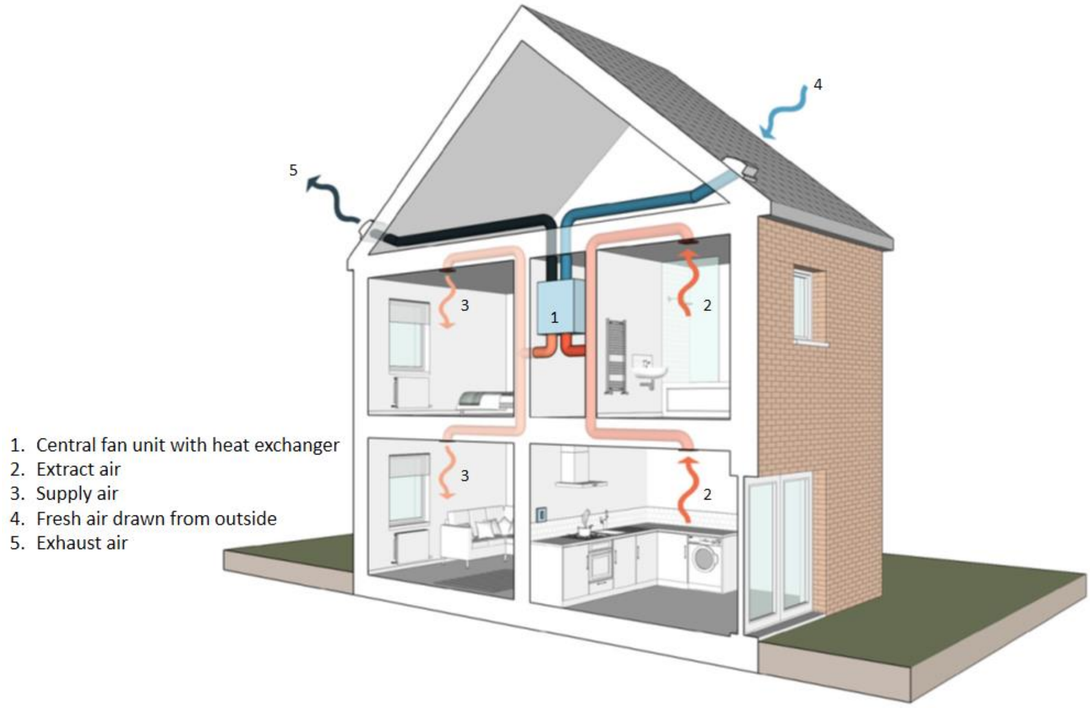

Figure III. Features of MVHR in a typical home (NHBC Foundation, 2016).

Compliance of the design with Passivhaus/EnerPHit is assessed via PHPP (Passivhaus Planning Package). PHPP program is used to calculate the performance targets of a building and evaluate them against Passivhaus/EnerPHit criteria. The PHPP calculation must be prepared as an Excel file with calculations of all the project details, such as climatic data, U-values, areas, windows, shading, ventilation, heating, cooling, etc. (Passive House Institute, 2016). Figure III illustrates the main traits of Passivhaus.

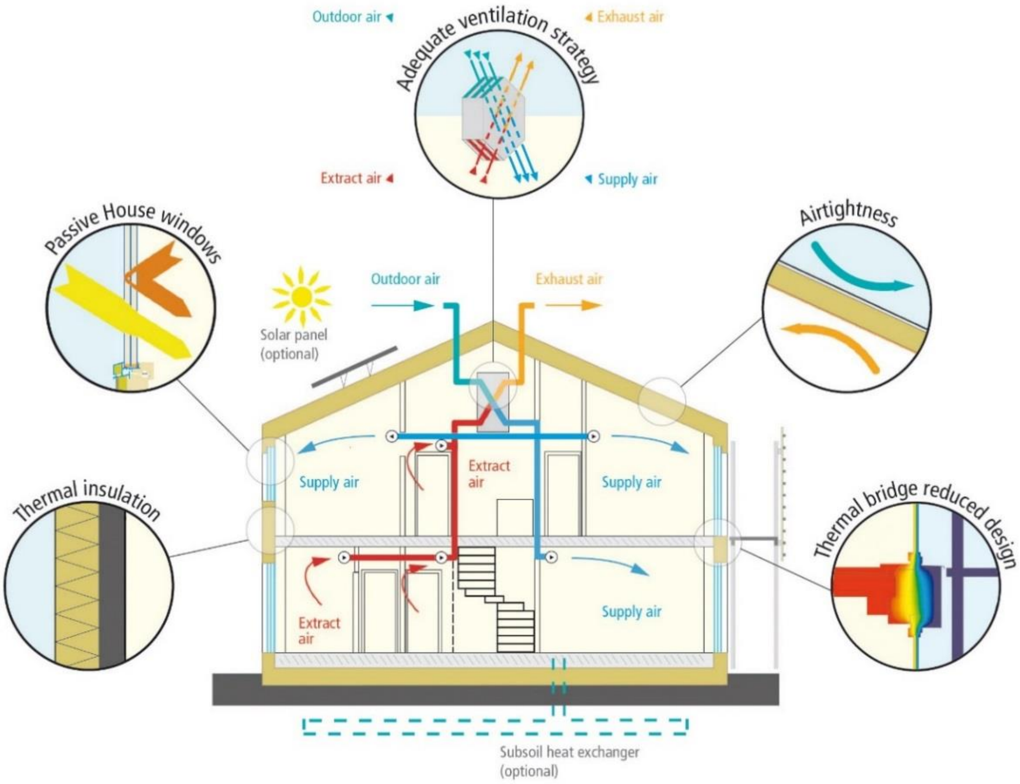

Figure IV. Basic principles of Passivhaus buildings (Passive House Institute, 2015).

EnerPHit standard has exactly the same principles as Passivhaus; nevertheless, it has slightly different requirements. The following table shows the requirements of Passivhaus and EnerPHit. As can be seen from the table, Passivhaus has more strict requirements in terms of heating demand, primary energy demand, and airtightness.

Table I. Passivhaus vs. EnerPHit requirements (BRE, 2014)

	Passivhaus	EnerPHit
Specific Heating Demand	$\leq$ 15 kWh/m^2.yr	$\leq$ 25 kWh/m^2.yr
Specific Cooling Demand	$\leq$ 15 kWh/m^2.yr	$\leq$ 15 kWh/m^2.yr
Primary Energy Demand	$\leq$ 120 kWh/m^2.yr	$\leq$ 120 kWh/m^2.yr + ((Specific Heating Demand - 15 kWh/ m^2.yr) x 1.2)
Airtightness	n50 $\leq$ 0.6 h^{-1} @ 50 Pa	n50 $\leq$ 1 h^{-1} @ 50 Pa

Unlike refurbishment schemes in the UK where there is focus on upgrading the separate elements of buildings such as the heating system and insulation, the EnerPHit standard, provides a model for a more comprehensive and holistic approach to refurbishment. It addresses energy consumption, the efficiency of building elements, appliances and services, occupants' comfort, and specifies clear performance targets. All features of a building, such as its form and orientation, affect the achievement of EnerPHit. Also, the requirements of EnerPHit are significantly more stringent than UK building regulations. As shown in table II, the U-value targets of EnerPHit are far above UK building regulation targets for existing buildings. Furthermore, the EnerPHit standard requires an airtightness of 1.0 air changes/ hr @ n50 which is challenging to achieve in the UK. Nevertheless, the UK building regulations do not specify an airtightness target for refurbished existing stock. As discussed earlier, the airtightness requirement for a new build is 10 $m^3/hr/m^2$ @ 50 Pa, considerably below the EnerPHit level.

Table II. The U-value targets of EnerPHit vs. UK building regulations (Passive House Institute, 2016), (Department of Community and Local Government, 2016).

Building elements	U-value ($W/m^2.K$)	
	EnerPHit	UK building regulations
Walls	0.15	0.30
Roof	0.15	0.18
Floor	0.15	0.25
Windows (overall)	0.85	1.6
Doors	0.85	1.8

The application of EnerPHit to UK building stock can result in significant energy savings. The specific heating demand of EnerPHit is 25 $kWh/m^2.yr$ or less. By comparison, the average heating use for existing building stock in the UK is 180 $kWh/m^2.yr$, 100 $kWh/m^2.yr$ for refurbished stock and 50-60 $kWh/m^2.yr$ for new builds (Dowson, et al., 2012). Hence, EnerPHit has the potential to reduce the heating energy demand of existing stock by up to 75%.

Nevertheless, due to its different approach to refurbishment and strict targets, there have been certain challenges in using this standard in the UK. Typically, tower blocks have some advantages over low-rise buildings in terms of compliance with EnerPHit because they are more compact. Consequently, they are expected to be more airtight and to have a lower level of heat transfer. The following section reviews the perception of EnerPHit in the UK to clarify the potential complications of meeting EnerPHit requirements in the country. Additionally, the general difficulties of refurbishing UK tower blocks are also investigated to evaluate the possibility of their upgrade to the EnerPHit level.

III. Aims and objectives

This study investigates the application of EnerPHit standard to post-war residential tower blocks, categorised as a type of hard to treat properties in the UK. EnerPHit takes a fabric first approach requiring the buildings to have superinsulated and extremely airtight fabric. Nevertheless, the investigation into the condition of UK tower blocks shows that they have serious structural problems and poor fabric. This brings up questions regarding the feasibility of meeting EnerPHit requirements in the UK tower blocks: Is it technically viable to superinsulate a tower block and achieve an airtight and thermal bridge free fabric? Is the UK construction industry capable of producing and implementing appropriate solutions to comply with EnerPHit requirements in tower blocks? Are the social landlords capable of meeting the expenses of upgrading their tower block stock to the EnerPHit level?

This research aims to seek answers to the above questions, and to investigate any other challenges related to the process of applying EnerPHit to UK tower blocks. In addition to identifying the difficulties, the research examines the possibility of overcoming them. Thus, the main questions the research addresses are: what are the challenges of applying EnerPHit to tower blocks in the UK? And how feasible is it to achieve EnerPHit in UK tower blocks? The research focuses on the case study of the Wilmcote House project, from the initial to the final stage to detect and analyse the challenges related to each stage. The stages are defined based on the key responsibilities of the main groups involved in the project, such as the client's decision process to use EnerPHit, the development of the architects' design solutions for achieving main requirements of EnerPHit, and the contractor's plans to implement the design on site.

IV. Structure

Chapter 1 of the thesis reviews the literature related to the adoption of Passivhaus standard in the UK and the refurbishment of UK tower blocks. Chapter 2 describes the methodology used to carry out the research, explains the case studies and the qualitative research methods used to carry out the case study, and examines the research limits. The remaining chapters focus on determining stages of Wilmcote House refurbishment project, and are structured as below:

Chapter 3: examines the decision of Portsmouth City Council, the owner of Wilmcote House, to achieve EnerPHit. This chapter seeks to detect factors likely to encourage a tower block owner to use EnerPHit. It focuses on the different options social landlords can adopt when a tower block needs significant improvements. The options include demolition, repairs, and deep refurbishment. This chapter investigates the perspective of the landlord leading to select EnerPHit refurbishment.

Chapter 4: investigates the Architects' role in the client's decision to use EnerPHit. This chapter explains how the background of the architects, their familiarity with Passivhaus, and their project investigations contributed to adopting EnerPHit. Furthermore, the chapter explores how the architects examined the feasibility of achieving EnerPHit through testing the structural stability and airtightness of the building and consultation with the residents.

Chapter 5: focuses on different fabric proposals and heating system options developed to refurbish Wilmcote House; one targeting EnerPHit and the other one aiming for a level higher than building regulations. The purpose of this chapter is to compare the fabric specifications of EnerPHit with a more conventional refurbishment option and explain what type of heating methods are suitable to be utilised in conjunction with EnerPHit fabric. The chapter explores the critical effects of the tower block heating system on its compliance with EnerPHit.

Chapter 6: examines how the architects developed the EnerPHit refurbishment scheme after the client investigated the fabric and heating proposals for both refurbishment options and decided to proceed with EnerPHit proposal. The chapter explains how the architects produced the design and specifications of refurbishment elements specifically related to EnerPHit requirements such as Mechanical Ventilation and Heat Recovery system.

Chapter 7: focuses on the period of transition from design to construction. The chapter explains how the architects prepared the tender documents and how the contractor planned to achieve

EnerPHit on site. The main stages of the contractor's quality assurance process such as design review and EnerPHit training are examined in this chapter.

Chapter 8: explains the problems encountered at the construction stage leading to significant delays and dissatisfactions. This chapter discusses the perspectives of different stakeholders on the reasons behind the construction problems.

Chapter 9: discusses the main findings of the study.

Chapter 10: presents the conclusions of the study and suggestions for future research.

Chapter 1: Literature Review

1.1 Introduction

The application of EnerPHit to UK tower blocks is a new phenomenon. There have only been two tower block refurbishment projects in the UK aiming for EnerPHit, but hitherto none of them has fully achieved the standard or formal certification. Consequently, there has been very limited academic research in this area. Nevertheless, both the utilisation of Passivhaus standard in the UK and the refurbishment of residential tower blocks have been researched separately, particularly in the last two decades. This section examines how the Passivhaus standard has been received in the UK; what are the motives of Passivhaus supporters in the UK? And what are the arguments against using Passivhaus? To find answers to these questions, the academic research and perspectives of some Passivhaus adopters are investigated. This investigation reveals the general challenges of adopting Passivhaus in the UK. To understand how these challenges may affect the adoption of the retrofit version of Passivhaus to UK tower blocks, it is essential to examine how tower block refurbishments in the UK are different from conventional projects. Are there any issues associated with carrying out this type of project? After identifying these issues, it will be possible to identify the potential difficulties of applying Passivhaus principles to UK tower blocks.

1.1.1 Adoption of Passivhaus in the UK

Since the completion of the first Passivhaus dwelling in 1991, thousands of buildings have been built to this standard in different countries. After Germany, Passivhaus found acceptance in many countries including Austria, Sweden and Denmark. However, the UK was very slow in taking up this standard. In 2007, when there were no certified Passivhaus buildings in the UK, there were more than 10,000 in Germany. The utilisation of Passivhaus in the UK is a result of the familiarisation with this standard by architects and energy consultants in the early 2000s. Some of them, such as Justin Bere the director of Bere Architects, has been significantly supportive of the adoption of Passivhaus in the UK. Due to efforts of its supporters, the first Passivhaus buildings were completed in the UK by the end of the 2000s, leading the way for many other Passivhaus projects (AECB, 2012). Thus, the UK government, the whole construction industry, and building dwellers did not have a significant role in the adoption of Passivhaus. Consequently, Passivhaus and its benefits have not been fully understood and there have been disagreements over the suitability of the standard. Furthermore, attempts to achieve Passivhaus have faced certain difficulties. This section analyses the main factors behind the conflicts and the challenges.

Most Passivhaus advocates within the UK believe that this standard is an effective way of reducing energy consumption, thus achieving UK carbon reduction targets. The UK government has been committed to reducing the level of Greenhouse Gas emissions for more than 20 years. Furthermore, the Climate Change Act 2008 requires an 80% reduction of GHG emissions by 2050, compared to 1990 levels. The UK government resisted adopting the Passivhaus standard and developed alternative policies and energy metrics to achieve its targets; nevertheless, there have been doubts about their feasibility and effectiveness (McLeod, et al., 2012) (McManus, et al., 2010) (Osmani & O'Reilly, 2009). Some studies argue that Passivhaus provides a better opportunity to meet climate change targets, but some UK government policies have acted as barriers to the adoption of Passivhaus standard. Before examining these arguments, the carbon reduction policies of the UK government are briefly explained.

The Zero Carbon Policy was one of the important strategies introduced by the government to meet the Climate Change Act target. The Labour government committed that from 2016 all new homes would be 'zero carbon' (Zero Carbon Hub, 2015). The first definition of a zero carbon home was one that achieved a Level 6 on the Code for Sustainable Homes. Introduced in 2007, the code was a tool designed to enhance the environmental performance of new houses (McManus, et al., 2010). The Code for Sustainable Homes applied a 1 to 6-star system to measure the sustainability performance of a building based on nine categories[7] of sustainable design (Department for Communities and Local Government, 2010). In the category of Energy and Carbon Dioxide Emissions, each house was rated for its percentage of improvement on target emission rates according to UK building regulations (McManus, et al., 2010). Code level 6 was the highest rating requiring Zero CO_2 Emissions. In the roadmap set out by Zero Carbon Policy, all new dwellings were required to achieve this level by 2016. In this requirement, carbon emissions included both regulated energy emissions (space heating, hot water, lighting and ventilation) as well as unregulated energy such as appliances; however, unregulated energy use was excluded from the definition in 2011 (Zero carbon homes, 2015).

The concern and uncertainty from the construction industry over this definition and its workability resulted in a revised definition (McLeod, et al., 2012). According to the new version, all new homes are required to mitigate all carbon emissions produced on-site from the

[7] The categories were Energy and Carbon Dioxide Emissions, Water, Materials, Surface Water Run-off, Waste, Pollution, Health & Well-being, Management, and Ecology (Department for Communities and Local Government, 2010).

regulated energy consumption, through different measures. To qualify as zero carbon, a home had to meet three core requirements including the Fabric Energy Efficiency Standard (FEES), Carbon Compliance levels, and reducing remaining emissions to zero using allowable solutions if necessary (Figure 1.1). The proposed FEES levels were 39 kWh/m^2.yr for apartment blocks and mid-terrace homes, and 46 kWh/m^2.yr for end terrace, semi-detached and detached homes. The recommended carbon compliance levels were 10 kg CO_2 (eq)/m2/y for detached houses, 11 kg CO_2 (eq)/m2/y for attached houses and 14 kg CO_2 (eq)/m2/y for low-rise apartment blocks (up to 4-storeys). Through the mechanism of Allowable Solutions, carbon emissions which could not be cost-effectively off-set on-site would be tackled though nearby or remote measures such as payment to a fund investing in abatement projects (Zero Carbon Hub, 2015).

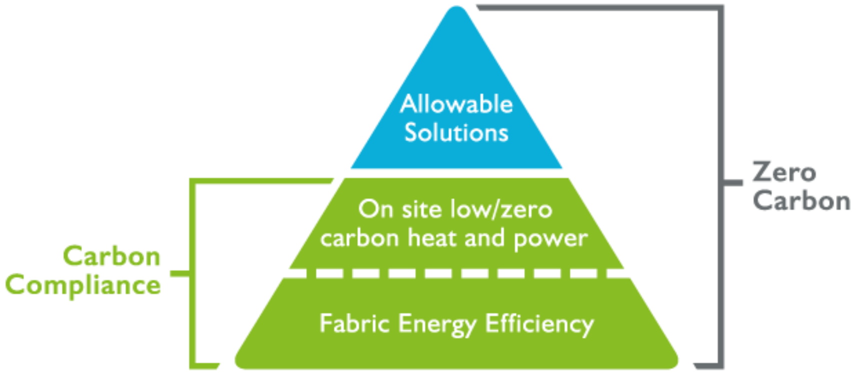

Figure 1.1. Zero Carbon Policy (Zero Carbon Hub, 2015).

Robert S. McLeod and Christina J. Hopfe, editors of the book "Passivhaus Designer's Manual: A technical guide to low and zero energy buildings", have carried out different studies on the use of Passivhaus, and criticised the revised definition of the Zero Carbon Policy. In their paper "An investigation into recent proposals for a revised definition of zero carbon homes in the UK", McLeod, Hopfe, and fellow researcher Yacine Rezgui investigated the reasons why using the revised Zero Carbon Policy might not lead to achieving the Climate Change Act targets. The paper argues that using a more rigorous 'fabric first' approach, such as Passivhaus, would be better suited to UK climate change and energy policies. One of the main criticisms of the revised Zero Carbon Policy is the introduction of allowable solutions. According to the paper, this concept was a form of carbon offsetting focusing on increasing short-term economic benefits to industry without directly addressing problems at the source. For instance, the revised Zero Carbon definition omitted carbon emissions from appliance energy consumption;

nevertheless, it gave a high ranking to the use of energy-efficient appliances as an allowable solution. Thus, it was possible to use the reduction of emissions from the sources included in the original definition of the Zero Carbon Policy as a method to offset emissions occurring elsewhere.

Another problem presented by this approach was that carbon offsetting by energy efficient appliances would not be permanent because most of these appliances have short lifespans of 10 to 20 years. Consequently, these carbon offsetting methods could not guarantee the necessary reduction in carbon emissions. On the contrary, Passivhaus limits the total primary energy demand related to both regulated and unregulated energy to 120kWh/m^2.yr. Furthermore, Passivhaus has at least three times better fabric energy efficiency than the FEES target specified by the Zero Carbon Policy. Therefore, the level of total energy consumption in a Passivhaus building is significantly lower. The Department of Energy and Climate Change (DECC) estimates that domestic cooling demand will grow by 2050, adding around 50 TWh of energy demand to the net climate change effects of the UK building sector; this was not taken into consideration by the Zero Carbon Policy. On the other hand, a Passivhaus building has the potential of minimising both cooling and heating demand through its highly efficient fabric. (McLeod et al., 2012)

The significance of improving energy efficiency is discussed by Robert Lowe and Tadj Oreszczyn (2008) in their study “Regulatory standards and barriers to improved performance for housing”. The study points out that the key target of UK energy and environmental policies is to reduce the considerable level of carbon emissions over a short period of time; nevertheless, it necessitated that energy efficiency in dwellings improved faster and more extensively than was likely to be achieved by the environmental policies. The paper argues that the policy was one of the main barriers to make progress in this area. The authors believe that the zero carbon target could divert financial and human resources from the important task of reducing energy consumption in dwellings, particularly enhancing fabric performance. They suggest that insisting on on-site renewables would result in additional costs and complications. To solve these issues, the government might keep redefining the target leading to further confusions and capital losses. The study finds it necessary to use a strategic approach to gathering evidence on heating, ventilation systems, construction systems, materials, and their impact on carbon emissions, and proposes to transfer the knowledge of building to the Passivhaus standard throughout the UK construction industry.

Some architects who have been using the Passivhaus standard have reached similar conclusions by comparing UK climate policies with Passivhaus in practice. Gale & Snowden Architects (n.d.) point to the low energy demand of Passivhaus as one of its main advantages over UK policies. They argue that it is possible to heat a Passivhaus building with less than 1.5 litres of heating oil/m²/yr.; therefore, the total annual heating of a 64m² two bed flat would cost £38 (based on a price of 40 pence a litre for heating oil). They believe that the energy savings in Passivhaus buildings would continue to be achieved over the lifespan of the building because they are the outcomes of fabric efficiency, building design, and orientation. On the contrary, Zero Carbon Policy relies on high technology equipment with shorter lives. Gale & Snowden Architects suggest that the minimised energy demand in Passivhaus buildings leads to lower energy costs for tenants and protects them from potential future changes in fuel costs. Nevertheless, tenants were less likely to benefit from buildings with higher energy consumption equipped with on-site renewable energy. For instance, the energy produced on site by photovoltaic panels would be sold back into the grid via the landlord meter. Therefore, only the building owner would benefit from using photovoltaic panels. In case heat pumps were installed in the building, fuel costs would be greater due to the three times higher cost of electricity compared to gas. In general, the architects supporting the use of Passivhaus in the UK, such as Gale & Snowden, Bere Architects, and ECD Architects, value the fabric first approach because they find it to be the most effective long-term solution to increasing the energy efficiency of buildings.

But why was Passivhaus standard not adopted by UK policy makers, despite its potential to achieve higher energy savings? Passivhaus was dismissed by the Zero Carbon Hub task force. Formed in 2008, the ZCH was an initiative of the National House Building Council (NHBC) Foundation to facilitate the delivery of homes with low and zero carbon emissions. In December 2008, the ZCH held meetings with industry stakeholders across the UK about the definition of zero carbon homes. The ZCH consultees had divided opinions on the buildability of Passivhaus. One opinion was that the performance specifications of Passivhaus were buildable and represented the level of necessary ambition. Nevertheless, 47% of consultees expressed serious concerns about the buildability of Passivhaus at mass scale. It is worth noting that according to the report of ZCH, the audience did not consider themselves to be experts and did not fully understand the challenges of meeting zero carbon.

Another important concern identified by the ZCH as an obstacle to adopting Passivhaus in the UK was providing the indoor air quality associated with airtight homes, relying on mechanical ventilation and heat recovery systems. According to a 2009 report by ZCH, this area was not sufficiently understood across the industry, and higher levels of monitoring and research were required to clarify the link between low air permeability and appropriate ventilation systems (McLeod, et al., 2012). However, McLeod et al. (2012) argued that there was already an increasing level of post-occupancy studies on improved indoor air quality and its correlation with residents' well-being in low energy buildings ventilated by mechanical ventilation. To shed more light on this, the indoor air quality requirements are examined, and the outcomes of some relevant studies are reviewed.

Some of the main factors affecting the indoor air quality are humidity, temperature, ventilation, particles, chemicals, and the indoor level of CO_2 (The Scientific Committee on Health and Environmental Risks, 2008). According to the study by Brelih and Seppanen (2011), the regulations regarding indoor air quality are not consistent in different European countries. This reveals that there are different perceptions of indoor air quality. In the UK, the minimum air temperatures for different areas of dwellings are recommended to be between 17°C and 22°C, while the recommended maximum summer temperature is 25°C (CIBSE Guide A, 2015). Maximum relative humidity (RH) is recommended to be 60% to achieve an acceptable indoor air quality (McGilla, et al., 2014). CO_2 concentration in the air indicates the effectiveness of building ventilation, but it is not an indicator of overall indoor air quality (ASHRAE, 2016). According to EN13779, a dwelling with indoor level of CO_2 exceeding 1000 ppm[8] above outdoor air has insufficient ventilation (Selincourt, 2015). Following the review of indoor air quality requirements, the question is: Do the houses with the MVHR system provide acceptable levels of indoor air quality?

Sharpe et al. (2014) describe the environmental conditions in 26 low energy houses in Scotland. Some of these house were naturally ventilated, while the others used MVHR system. The research only monitored the bedrooms. The outcomes of the study reveal that average indoor CO_2 in winter was 1292 ppm for the naturally ventilated houses, and 858 ppm for the houses with MVHR system. Generally, houses with MVHR had better ventilation rates[9]. A post-occupancy evaluation of the Wimbish Passivhaus development comprising fourteen

[8] parts per million
[9] "Ventilation rate is expressed in litres/second per person (l/s/p), taking account the occupancy of each room" (Sharpe, et al., 2014).

Passivhaus dwellings in Wimbish, Essex showed that indoor CO_2 levels were around or below 1000 ppm, and the RH levels were within the acceptable range (Selincourt, 2015). These studies show that it is feasible to meet the requirements of indoor air quality using MVHR system in low energy dwellings. Furthermore, one advantage of MVHR is that the fresh air supplied by this system passes through filters so the particles such as dust are removed. This can further contribute to the indoor air quality.

However, in many cases, problems have been reported with using the MVHR system. One of the main problems is about the high noise levels. This leads some occupants to turn down or switch off the system (Selincourt, 2015). It should be considered that this problem is very unlikely to happen in a Passivhaus building because Passivhaus has a specific limit for the noise levels in rooms. Generally, the MVHR system is expected to be more efficient in Passivhaus buildings due to the higher system performance requirements and the emphasis of Passivhaus on effective workmanship and supervision (Selincourt, 2015), but there have been significant issues related to using the MVHR system in Passivhaus dwellings. It has been argued that these issues were caused due to lack of sufficient knowledge about the system. Without an adequate understanding of the system function and maintenance requirements, such as replacing the filters, the system may not deliver its full potential and result in overheating (Cutland, 2012) (McGilla, et al., 2014). Therefore, it is essential to educate the occupants in operation and maintenance of the MVHR system.

Generally, the requirement to utilise the MVHR system has been one of the controversial aspects of adopting Passivhaus in the UK. When the first UK Passivhaus buildings were built, MVHR was a new technology to the UK construction industry, and the mechanisms supporting the MVHR design and training were not sufficient (Lynch, 2014). Furthermore, the necessity of using MVHR in the UK climate was questioned. One of the main critics of using MVHR in the UK is Bill Dunster, the designer of the well-known BedZED[10] development. Dunster supports aspects of Passivhaus that lead to the energy-efficient building skin, but he does not support the utilisation of MVHR due to its electricity consumption. He believes that it is adequate to rely on natural ventilation and it is not appropriate to use "electricity-hungry, fan-driven, heat-recovery ventilation" (Dunster, 2010). In addition, he argues that it is unnecessary to achieve the stringent airtightness requirement of Passivhaus in the temperate southern UK

[10] BedZED is an "environmentally-friendly housing development in Wallington, a suburb of London" (ZEDfactory, 2003).

climate. However, research has shown that his view about the level of electricity consumed by an MVHR system is exaggerated.

In 2009, AECB (The Association for Environment Conscious Building) carried out case studies to compare the energy use and CO_2 emissions from natural ventilation and MVHR in a Passivhaus house (AECB, 2009). The results show that with MVHR, the space heating energy demand is considerably lower; thus, it leads to lower carbon emissions. Paola Sassi (2013) compares the performance of two flats aiming for Passivhaus, one with natural ventilation and the other with an MVHR system in the south of England. This study shows that utilising MVHR is more energy efficient than natural ventilation when providing a uniform temperature in all the internal spaces, but with differing temperatures natural ventilation is more efficient. It is important to note that the temperatures in the naturally ventilated flat were between 15.5°C and 20°C in winter. Nonetheless, this range of temperature does not provide an acceptable level of indoor comfort. Research suggests that an indoor temperature of lower than 18°C can have adverse physiological and health effects (Wookey, et al., 2014). The MVHR system is not limited to Passivhaus buildings, possibly becoming the major form of ventilation in new homes as the requirement to build airtight buildings rises (Cutland, 2012). Therefore, potential barriers to using the MVHR system in the UK must be overcome.

There have also been concerns over the risk of overheating in Passivhaus buildings. It has been argued that in a building with high level of insulation and airtightness, such as a Passivhaus building, internal heat gains cannot be transferred through the building envelope (Tabatabaei Sameni, et al., 2015). Furthermore, it is common to use large south-facing windows in Passivhaus buildings to minimise heating demand. This can increase the overheating risk. There are some studies that have raised questions regarding the summer performance of some Passivhaus buildings in different parts of Europe and their risk of overheating (Tabatabaei Sameni, et al., 2015). Generally, in countries with cold winters, there is more focus on heat retention than cooling and summertime comfort (J.Lomas & M.Porritt, 2016). It can be argued that Passivhaus standard also places relatively more focus on space heating rather than cooling because it was initially developed for countries with cold winters. However, due to the rising global temperatures, concerns regarding summertime comfort is escalating even in the UK with mild summers. It is predicted that by 2040, hot summers in the UK will be the norm (J.Lomas & M.Porritt, 2016). Thus, more attention should be paid to the summer performance of the buildings. It should be noted that Passivhaus has a specific requirement to prevent overheating.

Based on Passivhaus criteria, temperature in the living area must not exceed 25 °C for more than 10% of the annual occupied hours (Tabatabaei Sameni, et al., 2015). A number of studies investigated the feasibility of achieving this criteria in the UK. Most of these studies argue that overheating depends either on the occupant behaviour or building design and components (Tabatabaei Sameni, et al., 2015) (J.Lomas & M.Porritt, 2016) (Vogiatzi, et al., 2015) (McLeod, et al., 2013) (Mlakar & Štrancar, 2011).

It has been discussed that the possibility of using natural ventilation in summer months is an important factor in prevention of overheating in Passivhaus buildings. It should be pointed out that although it is necessary to use MVHR system in Passivhaus buildings, it is possible to occasionally switch off the system and open the windows. The use of natural ventilation as an occasional alternative to mechanical ventilation depends on the size of windows, whether they are operable, to what angle they can be opened, the height of the dwelling from the ground, the density of the area, etc. (Tabatabaei Sameni, et al., 2015) (J.Lomas & M.Porritt, 2016). Another important factor is the use of efficient shading. Without shading elements, particularly on south-facing windows, there is a high risk of overheating in Passivhaus dwellings (McLeod, et al., 2013) (Mlakar & Štrancar, 2011). According to the research by Lavafpour & Sharples (2015), using a tilted façade is an effective method to eliminate the risk of overheating in UK Passivhaus buildings. In general, avoiding excessive solar gains is crucial to minimising the overheating risk. Occupant behaviour can also significantly affect the indoor temperature. For instance, some occupants may not be willing to open the windows due to security considerations or noise concerns, or they may prefer to open the windows only during the daytime (J.Lomas & M.Porritt, 2016). The occupants can reduce the risk of overheating and discomfort by increasing their reliance on natural ventilation during summer. According to Vogiatzi et al. (2015), by taking overheating mitigation measures, such as using solar shading, reduction on the g-value of windows, and using night time ventilation in summer, and taking into account occupant behaviour Passivhaus buildings will perform well during the predicted hot summers in future.

It is worth noting that overheating and discomfort in summer were not serious concerns in Wilmcote House refurbishment. Based on PHPP calculations, the annual frequency of overheating (temperature above 25 °C) was expected to be 1.3%. Prior to the refurbishment, the building occupants had not reported any dissatisfactions with the temperature of their homes in summer. It was not part of the refurbishment scheme to change the size and location of the existing windows; however, they would be replaced with high-performance Passivhaus windows. Thus, solar gains inside the maisonettes would not increase. To minimise the risk of overheating, the architects proposed the installation of vertical fins next to the windows facing west. Furthermore, the windows (except kitchen windows) were proposed to be operable; thus, it would be possible to use natural ventilation to remove internal gains in summer.

It is worth mentioning that the Code for Sustainable Homes and the Zero Carbon Policy are no longer in use. The government abandoned the Zero Carbon Policy in 2015 to "speed up house building and not add extra costs and bureaucracy" (Mark, 2016). Nevertheless, it can be argued that around a decade of using these policies has already decelerated the adoption of Passivhaus. The Zero Carbon Policy in particular could have disincentivised Passivhaus adoption because its fabric energy efficiency target was three times below the level required by Passivhaus. It was generally less challenging for building owners to comply with the Zero Carbon Policy requirements, such as the less stringent fabric criteria and use of allowable solutions (McLeod, et al., 2012). In general, UK policies such as the Zero Carbon Policy have placed a greater stress on carbon emissions. They mainly use carbon ($kg/m^2.yr$, kilograms per square metre per year) as the metric to assess building performance. On the other hand, Passivhaus focuses on energy consumption. The target performance of a Passivhaus is energy, expressed in Kilowatt hours per square metre per annum ($kWh/m^2.yr$). With no limits for carbon emissions, there were some doubts over the appropriateness of using Passivhaus in terms of meeting UK carbon targets (Willars, 2010).

It should be considered that certified Passivhaus buildings in the UK must verify compliance with both Passivhaus requirements and UK building regulations, leading to additional time, effort and cost (Cutland, 2012). Furthermore, compliance with UK policies is measured by SAP software that was developed for buildings with poor insulation and great amounts of heat loss. It underrates the effect of insulation and airtightness by assuming large amounts of heat gain for low energy buildings. Therefore, SAP cannot accurately predict the actual energy use of Passivhaus buildings (Gale and Snowden Architects, n.d.). PHPP, the tool used for modelling and assessing the performance of buildings against Passivhaus criteria, uses a similar basis for energy calculation, including additional details in certain calculations such as thermal bridging. Additionally, it considers other elements such as the energy consumed by appliances. PHPP, however, is considered to be a more accurate tool for estimating the performance of the building than the SAP methodology (Cutland, 2012). For this reason, some architects believe it is more effective to work with PHPP. Nevertheless, using PHPP requires training, a high level of data entry, and additional calculations (Cutland, 2012) which might make it challenging to work with (Lynch, 2014).

One of the major studies on the adoption of Passivhaus in the UK was carried out by Henrietta Lynch. In her research, "Passivhaus in the UK: The Challenges of an Emerging Market", she focuses on early Passivhaus adopters in the UK "to identify barriers to the uptake of the Passivhaus standard" (Lynch, 2014). The research provides the opinions of Passivhaus pioneers in the UK and investigates three early UK Passivhaus projects alongside two in Germany. The main conclusions from this study are that the challenges are cultural and connected to both social and technological limitations, such as the installation of an MVHR system, construction skills and training, and the existing legislation in the UK. Lynch (2014) suggests that the development of superinsulated buildings in German-speaking countries can be partly linked to the higher value placed on education and skills training than in the UK, and partly to their more consistent legislation.

Based on a report by Intelligent Energy Europe called 'Passive House Solutions', the construction quality of housing and the capabilities of UK labour (in 2006) may prevent the high level of detailing necessary to meet the Passivhaus airtightness requirement (IEE, 2006). Lynch (2014) argues that up-skilling the construction industry is necessary to deliver Passivhaus. While there is a potential to do this, it can take significant time due to the scale of training required and a lack of provision for achieving this. As an architect with considerable practical experience in Passivhaus projects in the UK, Justin Bere believes that architects must engage in significant teamwork with builders to cope with potential workmanship issues (Bere, 2013). As mentioned earlier, one of the reasons the Zero Carbon Hub dismissed Passivhaus was their doubt over the buildability of Passivhaus buildings. Nevertheless, as suggested by Lynch (2014), the competence of UK labour should be increased to build low energy buildings whether they aim for Passivhaus, Zero Carbon Policy, or alternative low energy standards.

Furthermore, Lynch (2014) points out that UK construction procurement types in relation to delivering Passivhaus buildings must be reviewed because there is not sufficient evidence to show which procurement methods are more suitable to be used in Passivhaus buildings. The study recommends that the delivery of Passivhaus buildings should be tested against common procurement methods used for large-scale developments such as 'design and build'. Another important challenge specified by the study is the lack of Passivhaus components such as

Passivhaus windows. This means that products would be imported from EU countries at extra expense. The lack of local certified components in the UK can indicate that there is also a lack of skills to install the components. For instance, Bere Architects decided to employ German manufacturers to explain the method of installing their Passivhaus windows to the construction team at Ebbw Vale. This indicates a requirement to use the technical support of German manufacturers and builders (Lynch, 2014).

Another important concern regarding using Passivhaus in the UK is the level of cost uplift. Additional research and development, the learning process, lack of indigenous components, and the extra care required to deliver high fabric performance are some of the factors contributing to the cost uplift of UK-based Passivhaus (Lynch, 2014). Nevertheless, the additional initial costs will pay back over time through savings in energy consumption in the building. Therefore, the assessment of additional costs depends on the perspective of the investors and whether they prioritise long-term or short-term savings. In his analysis of Passivhaus building costs, Galvin (2014) suggests that the economic viability of a Passivhaus building is a construct in the investor's mind rather than a fact. For instance, it depends whether they consider long-term savings or whether they focus on short-term ones. He points out the challenges of carrying out a clear cost assessment due to its dependence on ambiguous factors such as future fuel prices and the specific heating consumption of the household. According to Lynch (2014), to contribute to a broader understanding of the cost-effectiveness of Passivhaus in the UK, financial incentives should be provisioned, like those available to Passivhaus projects in Germany. For instance, the KfW Bank in Germany offers low interest loans to Passivhaus product developers, training and supply chain. KfW is the most important promotional bank of Germany which supports private individuals as well as enterprises, social organisations, municipalities, etc. Environmental sustainability and public welfare are two major targets of this bank. KfW generally promotes the energy efficiency of the existing buildings. It provides grants or loans for full energy efficient refurbishment schemes or funds single refurbishment measures such as insulation of walls (Anon., 2018). The Passivhaus case studies carried out by Lynch (2014) indicate that they were supported by the local authorities in those particular areas, but this type of support is not available in all locations; therefore, specific financial programs should be developed to support Passivhaus projects throughout the UK.

1.1.2 Challenges of tower block refurbishment in the UK

Following the review of general Passivhaus challenges in the UK, the question is how can they impact the refurbishment of tower blocks? Do tower blocks have certain properties which may make it more straightforward to upgrade to Passivhaus? Or are there certain difficulties associated with refurbishing tower blocks adding to the complications of using Passivhaus standard? Faye Scott, a researcher at the Green Alliance thinktank, has investigated "the challenges and opportunities of tower block retrofit" in her report published by Green Alliance in 2014. According to this report, technical, funding and resident liaison are the main challenges involved in the retrofit of tower blocks in the UK (Scott, 2014). The outcomes of a 2012 research project about the retrofit of the Edward Woods Estate tower blocks carried out by Katie Bates, Laura Lane and Anne Power at the London School of Economics are consistent with the findings of Scott (2014). The Edward Woods Estate tower blocks are three residential tower blocks in London refurbished in 2007. The project aimed at performance targets higher than UK building regulations requirements. The following examines these challenges and their possible relation to the UK retrofit schemes.

As explained, UK tower blocks are categorised as 'hard to treat' properties. It is not possible to upgrade 'hard to treat' dwellings "easily or cost effectively" using conventional methods such as the installation of gas central heating, cavity wall insulation and loft insulation (Dowson, et al., 2012). According to Dowson et al. (2012), it may be problematic to install external installation on high-rise blocks if they have structurally unsound walls, or if the leaseholders and owners of flats do not prefer to alter the external appearance of the block. One alternative is to apply internal insulation to individual flats, but external insulation is more effective than internal; furthermore, externally insulating the entire block in a single installation can lead to cost savings through the economies of scale. Prior to adding external insulation, all the possible structural problems in a tower block must be identified and repaired (Scott, 2014). This process can be very challenging due to the scale of high-rise blocks and their poor construction.

As discussed in the background section, a significant number of post-war tower blocks were built using the large panel system. However, the process of applying the LPS technique to buildings in the post-war period was inappropriate in many ways. This was partly the result of the clients' and the builders' priorities in reducing the completion time and expenses. Some of the common faults associated with using this method are the oversimplified connection between concrete panels, the reduction of the reinforcement required to tie the panels together, and using the minimum amount of concrete and mortar to fill the joints. In addition to ties and joints, the concrete panels were of poor quality with minimal reinforcement. This type of defect can damage the structural integrity of the building (Matthews & Reeves, 2012). Inefficient construction of tower blocks has led to serious structural issues creating challenges to refurbishment measures such as external insulation. The case study of the Edward Woods Estate tower blocks by Bates et al. (2012) suggests technical solutions to some of the structural problems made the retrofit works at some stages unexpectedly long and labour intensive.

Another complication associated with tower block retrofits is resident liaison. Scott (2014) believes that resident liaison is a necessary step to a tower block refurbishment project because it affects the lives of residents during and after completion. Some of the impact relates to the retrofit process itself, such as the limiting of both light and view from windows by scaffolding, and the noise caused by the retrofit works. Bates et al. (2012) reports that the Edward Woods Estate tower blocks retrofit had disproportionate effects on different groups of people. Residents with regular working hours were less impacted, but those with night shifts, parents with young children, and ill residents were more affected by noise and dust. Without adequate communication, the negative impacts of the process can lead to the dissatisfaction of residents adversely affecting the progress of the project.

Another impact is introducing new technologies that the residents will need to use after the retrofit is completed. To make these technologies more effective, it is essential to make the residents realise why they will use them and what the expected benefits are. Furthermore, the residents would need to learn the methods of using any new technologies applied to the building. Therefore, it is necessary to communicate with residents extensively and to provide relevant training programmes. Considering the whole population of a tower block, liaising with all the occupants can be quite challenging. The Edward Woods tower block retrofit project encountered resident liaison challenges despite the meetings and interviews organised with the residents. One issue was that a limited number of residents were aware of the thermal efficiency targets; thus, it was a consistent requirement to explain the aims of the project and the opportunities it was going to provide for them. The research by Bates et al. (2012) suggests that the retrofit process could have been improved by finding better ways to increase resident engagement during the process and even before the beginning of the works. For instance, it could be very helpful if the residents were provided with energy efficiency advice and usage tips during the process.

Providing sufficient funding is another challenging aspect of tower block refurbishment projects. Residential tower blocks are all managed by social landlords. Any improvements to these buildings depend on the financial capability of the social landlord, with the technical complications associated with tower blocks increasing the costs of refurbishment (Scott, 2014). Energy efficiency schemes such as ECO could have provided the impetus for refurbishing tower blocks (Bates, et al., 2012) but as mentioned earlier in this chapter, the changes made to this scheme limited its effect on 'hard to treat' properties. Currently, there is no other funding scheme with the potential to significantly contribute to tower block refurbishment schemes. Therefore, the refurbishment of tower blocks and their scope entirely relies on the motives and finances of individual landlords.

A successful example of post war tower block refurbishment according to Passivhaus can be found in Germany. The sixteen-storey block in the High Street 50 Bugginger in Wiengarten, a district in Freiburg city of Germany was the first residential tower block that achieved Passivhaus through refurbishment. Similar to its adjacent buildings, the block was constructed in 1960s (Fraunhofer ISE, 2011). Over the next four decades, the building conditions seriously deteriorated. Thus, the building owner (the municipal building society of the city of Freiburg) decided to refurbish the building. One of the main refurbishment targets was to maximise the energy efficiency of the flats; therefore, the owner decided to use Passivhaus standard. The refurbishment project commenced in 2009 and was completed in 2011. Due to substandard conditions of the building fabric, it was completely removed and replaced with a new and high-performance façade designed according to Passivhaus criteria (Quiring, 2010). This had important impacts on the project. Firstly, the risk of encountering any technical challenges with external insulation of existing walls was removed. Secondly, the occupants had to be relocated. The positive consequence was that it was not necessary to liaise with the occupants during the construction stage; thus, the project could be completed faster and with fewer complications. During the refurbishment process, the construction team set up a pilot flat on the third floor of the vacant building to be visited by the tenants and the prospective renters so they could get familiar with energy saving methods utilised to achieve Passivhaus. The project was funded by different government bodies and local authorities supporting energy efficient refurbishments, such as the German Federal Ministry of Economics and Technology and the municipal housing association of Freiburg. Thus, serious challenges were not encountered in this project, possibly because the building decanting reduced the complexity of the refurbishment, and the project was allocated sufficient funding. The image below shows the sixteen-storey block in Freiburg following the completion of the refurbishment. (Quiring, 2010)

Figure 2.2. Bugginger Strasse 50, first refurbished residential high-rise building to achieve Passivhaus (www.bundesbaublatt.de, 2011).

1.2 Conclusions

The review of Passivhaus challenges and tower block refurbishment difficulties in the UK suggests that adopting the retrofit version of Passivhaus to residential tower blocks can be more challenging than conventional low-rise buildings, because common Passivhaus challenges are likely to become more complicated when tower blocks are involved. According to the existing research, the main obstacles to adoption of Passivhaus in the UK are the government policies disincentivising the application of Passivhaus, lack of sufficient construction industry skills to achieve Passivhaus, lack of Passivhaus certified components in the UK, the requirement to use MVHR system, and the uplifted costs.

The literature review reveals that social housing tower blocks have inefficient structure and fabric. Consequently, it would become difficult to upgrade their fabrics to the level required by EnerPHit. This issue can be exacerbated by the construction industry’s lack of adequate skills to meet with Passivhaus requirements. Furthermore, it is argued that the application of new technologies to tower blocks, introducing them to the residents, and training the residents to use them correctly and effectively can be problematic. Therefore, the installation of MVHR system to tower blocks can be more challenging than conventional buildings. Additionally, the literature review suggests that funding is a serious issue in any tower block refurbishment. However, it can become more critical in case of aiming for EnerPHit because of the additional costs related to compliance with the standard. The investors cannot rely on support from the government because there is no financial aid provisioned for Passivhaus projects, with the scope of general refurbishment policies planned by the government altering continuously, limiting their contribution to Passivhaus schemes. Therefore, it is not clear if using EnerPHit in tower blocks is financially viable.

Chapter 2: Methodology

2.1 Introduction

As discussed in chapter 1, there has been limited research into the application of EnerPHit to UK tower blocks. The uptake of Passivhaus in the UK was later and slower than in northern and central European countries, with Passivhaus standard first utilised in new and existing buildings in the UK towards the end of 2010. At the same time, research started on several aspects of using Passivhaus in the UK, so that gradually, an adoption of Passivhaus emerged mostly limited to low-rise buildings. As it can be understood from the literature review of this study, most of the research on Passivhaus is about the general difficulties of using the standard in the UK, rather than addressing the specific challenges of applying EnerPHit to existing high-rise buildings, such as the 'hard-to-treat' blocks of flats; consequently, there is a lack of sufficient information in this area.

The refurbishment of Wilmcote House in Portsmouth is the first - and to date one of only two projects in the UK - in which EnerPHit is used as the benchmark for tower block retrofit. Therefore, the investigation of this project provides vital insight into the application of EnerPHit to residential tower blocks in the UK. Ongoing throughout this PhD research the Wilmcote House refurbishment project is used as the main case study within this investigation. The live case study focuses on the process underlying the delivery of the project from the initial to final stage, with the analysis revealing the specific requirements and challenges related to each phase. To carry out the case study, the project documentation was reviewed and social science methods such as interviews, observation studies, and embedded research were deployed. This chapter describes the case study method, examining both its advantages and limitations. Thereafter, the case study and all the research methods used in this research are explained.

2.2 Case study methodology

This PhD research is primarily based on the single case study of Wilmcote House refurbishment. The case study research methodology has been investigated by many researchers from diverse disciplines leading to different conclusions on various aspects of this methodology. To examine the case study method, three influential books on case study research were reviewed, by Yin (2003), Stake (1995), and Merriam (1998), plus the analysis of Yazan (2015) on the different perspectives of the aforementioned authors.

Yin (2003, p.13) describes a case study as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". It addresses either descriptive or explanatory questions about the phenomenon of interest such as "what is happening or has happened?", or "how or why did something happen?" (Yin, 2012, p.5). Stake (1995, p. xi) defines case study as the "study of the particularity and complexity of a single case, coming to understand its activity within important circumstances", but he claims that it is not possible to give a precise definition due to potential dissimilarities between definitions used within different disciplines. Stake believes that qualitative research, including qualitative case study, have four prominent characteristics: they are holistic because the researcher has to study the interrelationship between the context and phenomenon (similar to Yin's definition); they are empirical considering that the researcher uses their field observations to carry out the study; they are interpretive meaning that the researcher relies on their intuition; and lastly, they are empathic because the researcher sees the experiences of the subjects from an internal perspective. According to Merriam (1998, p. xiii), case study is "an intensive, holistic description and analysis of a bounded phenomenon such as a program, an institution, a person, a process, or a social unit". Thus, she recognises a wider possible range of phenomena available for study selection. Merriam (1998) explains the distinctive characteristics of the case study as being particularistic, descriptive, and heuristic, because this method focuses on a particular phenomenon, yielding a deeper description of the subject, and clarifying the reader's knowledge of the phenomenon. (Yazan, 2015)

The authors have shown different approaches towards the case study method. Yin, a social scientist, has a positivistic approach. Crotty (1998) finds objectivity, validity, and generalisability to be the three fundamental notions in a positivistic approach to research. According to Crotty (1998), if a researcher thinks that the findings of their research will yield established facts, positivism is the epistemology orienting the research. On the contrary, focusing on educational research Stake and Merriam believe that constructivism should inform and orient case study research. This means that rather than discovering facts, the researcher constructs knowledge through meanings and understandings derived from their experiences and reflections (Merriam, 1998). Merriam (1998, p.6) claims that "the key philosophical assumption upon which all types of qualitative research are based is the view that reality is constructed by individuals interacting with their social worlds".

Based on their epistemological commitments, the methodologists have different views towards methods of data gathering, data analysis, and data validation. Yin stresses the importance of the literature review, and including the existing theory about the case prior to data collection. He believes the researcher should identify the research questions, designing the process of the case study at the start of the research. He suggests that the structured design should be precisely followed. According to Yin (2003, p.20), the case study design is “the logical sequence that connects the empirical data to a study's initial research questions and, ultimately, to its conclusions”. He emphasises using multiple sources of evidence to gather data, believing that data analysis “consists of examining, categorizing, tabulating, testing, or otherwise recombining both quantitative and qualitative evidence to address the initial propositions of a study” (Yin, 2003, p.109). He finds it necessary to apply various analytic procedures such as the triangulation of various sources of evidence to enhance the validity and reliability of the research (Yazan, 2015).

Stake and Merriam are less prescriptive about the process of case study research. Stake does not specify a clear point for starting data collection and analysis, suggesting a flexible design allowing the researcher to make changes at later stages in the research. He advises on developing a number of research questions to help structure the process of gathering data through “observation, interviews and document review” (Stake, 1995, p. 20). He suggests preparing a plan for gathering data that includes “definition of case list of research questions, identification of helpers, data sources, allocation of time, expenses, intended reporting” (Stake, 1995, p. 51). He argues that data analysis is “a matter of giving meaning to first impressions as well as to final compilations”, claiming that “analysis essentially means taking our impressions, our observations apart” (Stake, 1995, p.71). According to Yazan (2015), Stake finds the main source of data to be the researchers’ impressions, with the data analysis an attempt to make sense of their significance. Merriam (1998) proposes a similar and complementary definition for data analysis, describing it as “the process of making sense out of the data. And making sense out of data involves consolidating, reducing, and interpreting what people have said and what the researcher has seen and read – it is the process of making meaning” (Merriam, 1998, p.178). Merriam suggests the use of different techniques for validating data and ensuring its reliability, such as triangulation, long-term observation, participatory research, the disclosure of researcher bias, and an explanation of the investigator’s position with regards to the study. (Yazan, 2015).

As can be understood from these discussions, the methodologists have different perspectives on certain aspects of the case study method. The case study investigation used in this research does not completely rely on one particular approach; nevertheless, it is closer to Merriam and Stake's constructivism, mainly because an interpretative rather than analytical approach has been adopted in the review of the data. The aim of this research is to examine the application of EnerPHit to UK tower blocks by reconstructing and critically appraising the process underlying the delivery of Wilmcote House. Thus, the 'case' is the 'project process' studied within its real-life context. One of the most important components of the real-life context is the building and its specific conditions, influencing the client's aims and objectives, the architects' design scheme, and the contractors' works on site. Another significant element is the building owner's perspective of the project, their financial capability, and their level of involvement in the project. The performance of the other project parties, such as the architects and the contractors, and their communication and collaboration with each other are similarly critical components. In general, all the people involved in the project process, such as the building residents, are parts of its real-life context.

In terms of case study design, the literature review and the research questions have helped structure the interviews and observations. The methods are applied to investigate the three main stages of the project process: decision making, design, and construction. Each stage is examined through applying particular qualitative methods appropriate to that stage. For example, document review and interviews were the major methods utilised for the retrospective reconstruction of the project development completed within the two years prior to the start of this research. Even though the main framework of the case study was designed following the literature review, it was not initially possible to precisely plan all the stages. This is because the case study was carried out on a live project affected by unpredictable factors faced over the course of the project. A post-occupancy evaluation was considered at the beginning, but was excluded from the case study because the Wilmcote House refurbishment was not completed within the timeframe of this PhD. The delay in the completion of the project was due to unforeseen problems encountered at the construction stage, meaning more interviews and site observations were planned to reveal and examine these complications. In general, four main research methods were used in this study: document review, interviews, embedded research, and observation studies. The data collected via these methods has been analysed, compared alongside each other, and interpreted to assess validity, and particularly, to compare the statements given by different stakeholders during the interview.

2.3 The case study

There is no consensus about the number of cases required to be investigated to undertake effective research. According to Darke et al. (1998, p. 281), the right number of cases "depends on the focus of the research question". While carrying out multiple case studies facilitates "theoretical replication" and cross-case comparisons, single-cases allow for deep investigation and thorough description (Darke et al., 1998, p.276). To the best knowledge of the author, only two tower block refurbishment projects in the UK have been targeting EnerPHit during the course of this research (2014-2018): Wilmcote House in Portsmouth and Cedar Court tower blocks in Glasgow.

The design stage of the Wilmcote House project started in 2012 and construction commenced in 2014. However, the plan to refurbish the Cedar Court blocks was made public in 2015 and construction was expected to start in 2016 (Collective Architecture, 2015). Therefore, Wilmcote House was the only tower block being refurbished to EnerPHit when this research commenced; consequently, it was specified as the main case study to focus on the project process and to carry out a high level of investigation and analysis at each stage. Cedar Court blocks refurbishment was not selected as the second case study because it would not be possible to investigate the full project process within the time frame of this research. Additionally, the geographical distance between Wilmcote House and Cedar Court blocks would make it challenging to carry out both live case studies simultaneously. In addition to the live case study of Wilmcote House, the research makes references to two other projects, the [REDACTED] and [REDACTED] refurbishment, and the Edward Woods Estate tower blocks refurbishment, to make cross-case analysis possible and elucidate the findings of the Wilmcote House case study.

Located in Portsmouth and owned by Portsmouth City Council, Wilmcote House is a high-rise social housing building consisting of three interlinked tower blocks constructed in 1968. By 2010, Wilmcote House underwent no major refurbishment; additionally, the main building elements did not function adequately (ECD Architects, 2012). The council decided to refurbish the building and employed ECD Architects as the project consultants (Groves, 2015). The architects had been previously involved in tower block refurbishment projects such as the refurbishment of the Edward Woods Estate tower blocks in London. They were familiar with the Passivhaus standard, but they had not attempted to use it in a tower block project. In 2012, two years after the release of EnerPHit, it became the basis of the design proposal developed for the Wilmcote House refurbishment by ECD Architects (ECD Architects, 2012). They appointed consultants to assess the structure and the airtightness of the building and to evaluate the effectiveness of utilising different heating systems. Following the completion of the consultant assessments, the architects prepared the full refurbishment design based on achieving the EnerPHit standard. The council and the architects decided to use a standard building contract procured via the traditional method, so that the architects were responsible for the design of the refurbishment scheme without the involvement of the contractors; following the completion of the design process, the contractors took over the project and began the construction stage. The selected contractors had previously never carried out an EnerPHit project, so they appointed structural engineers, site architects, and Passivhaus consultants to assist them at both the tendering stage and during the construction process. The diagram below shows the connections between the stakeholders.

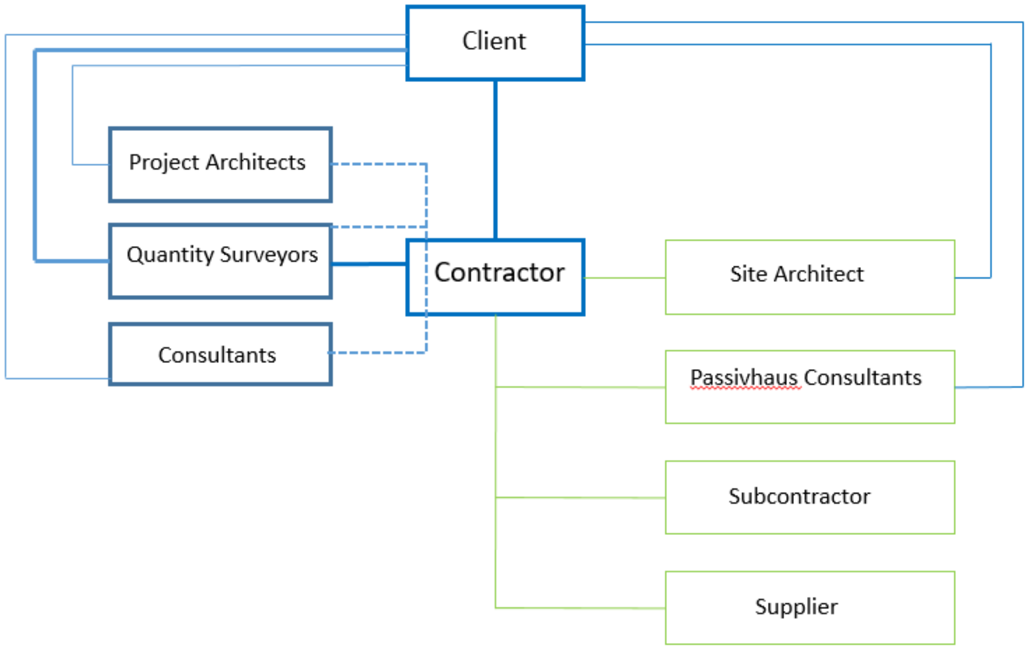

Figure 2.1. Connections between the stakeholders.

Based on the traditional procurement method, the project architects held no responsibility for the construction stage, but continued to regularly visit the site. Also, the project teams including the client, the architects, the project managers, the Passivhaus consultants, the site architect, and the contractors had monthly site meetings to discuss the progress of the works. Importantly, none of the stakeholders had any previous experience with EnerPHit. They worked separately on different stages of the project and did not collaborate on the full process. Consequently, their understanding and knowledge of the project were mostly based on the specific stage of the process they were involved in. Conducting interviews with stakeholders participating along the various stages of the project, such as the development of aims and objectives, design, tender, and construction provided the opportunity to become aware of divergent perspectives, and to compare them with each other in order to have a more accurate assessment of the challenges of the project process.

During the construction phase of Wilmcote House, [REDACTED]started to consider the improvement of two other post-war tower blocks located [REDACTED], subsequently appointing ECD Architects to investigate options such as deep refurbishment. The council was particularly interested to upgrade the blocks to EnerPHit level, and thus, ECD Architects prepared a refurbishment proposal based on EnerPHit requirements. The structural engineers appointed by ECD Architects revealed that the blocks had serious structural issues that could not be solved without first decanting the building (ECD Architects, 2015). These issues added to the complications and expenses of complying with EnerPHit. Following the assessment of the feasibility studies carried out by ECD Architects, [REDACTED] decided not to proceed with the project. Because these two similar projects led to different outcomes, the analysis and comparison of this project with the Wilmcote House refurbishment provide vital information about the crucial factors that affect the decision making and the design process when applying EnerPHit to UK tower blocks.

In addition [REDACTED], the research looks at the refurbishment of the Edward Woods Estate tower blocks, the three 24-storey post-war social housing blocks located in London. It should be noted that all three refurbishment schemes were designed by ECD Architects. Like the Wilmcote House refurbishment, the Edward Woods Estate tower blocks refurbishment was initiated to improve energy efficiency in the blocks, provide thermal comfort for the residents, and to alleviate fuel poverty (Pearson, 2014). ECD Architects aimed for a greater level than specified by UK building regulations. The project was started in 2007 and completed in 2011, before the release of the EnerPHit standard. However, the architects claim that they would have considered using EnerPHit if the project had taken place after its release (Sarchett, 2016). In fact, ECD Architects took the same approach towards the refurbishment of both the Edward Woods Estate tower blocks and Wilmcote House, but used different benchmarks. Even though the refurbishment of the Edward Woods Estate tower blocks was not based on EnerPHit, the analysis of factors leading to the client's decision to refurbish the blocks significantly contributes to an understanding of the decision making process in the Wilmcote House project. In other words, it can help to understand the reasons why Portsmouth City Council decided to use the EnerPHit standard, and generally, the conditions under which the client is more likely to use EnerPHit in a tower block refurbishment. The following section explains the qualitative methods used to study each case. The following diagram illustrates the timeline of the projects mentioned above.

[REDACTED]

Figure 2.2. Timeline of projects.

2.4 The qualitative research methods (sources of evidence)

This research aims to study and analyse all the stages of the Wilmcote House refurbishment process. The [REDACTED] and [REDACTED], and the Edward Woods Estate tower blocks refurbishment projects are similarly examined for the purpose of data analysis and data validation. Various qualitative methods are applied to investigate the projects based on their time frames and the nature of the project stages. According to Yin (2003), some of the sources of evidence used by case study researchers can be archival records, interviews, documentation, observations, and participant observation. Most of these methods are used in this research. It is important to note that this research started in 2014, three years after the Edward Woods Estate tower blocks project reached completion and exactly before the commencement of the Wilmcote House construction stage. Therefore, document review and interviews were used to investigate past events during the Edward Woods project, and the decision making and design stages at Wilmcote House. Comparatively, the construction stages of the Wilmcote House and the [REDACTED] and [REDACTED] projects were ongoing during this research; therefore, it has been possible to use additional methods such as observation and embedded research. The four major qualitative research methods utilised to carry out case studies are explored subsequently.

2.4.1 Document review

One of the most important data collection methods used in this research is document review. As explained by Yin (2003), documents are used to corroborate evidence with other sources. If a document is contradictory, the topic must be further investigated. Another advantage of document review is that it can lead to the discovery of new questions regarding the research topic. The first step in implementing the Wilmcote House case study was to review all the documents available online, in newspapers and magazines. This led to the formation of the initial questions about the case, which were then asked in the first interviews with the architects, client, contractors, and other teams. Following the initial investigations based on public documents, the documents specifically produced by the project teams were reviewed. These documents came in different forms, including the project's aims and objectives developed by the client, the tender documents, the structural analysis, the airtightness study, the heating options, the architects' feasibility studies and design proposal, the cost studies, the minutes of meetings between the client and the architects, and the project studies by the site architect and the contractors. The review and analysis of the documents contributed to unravelling the decision making process, the design process, and the construction program planned by the contractors. It was not possible to collect all of the necessary detailed project data through interviews, so the document review complimented the interviews in reconstructing the full project process. Furthermore, they were used as a base against which the statements given at the interviews could be assessed.

The data on the Edward Woods Estate tower blocks project was collected through the document review. As this project was completed years ago, there was an extensive level of public information available on different project aspects, such as project objectives, costs and sources of funding, the project program, and the challenges encountered on site. The accuracy of the collected data was later checked with the architects. With regard to [REDACTED] and [REDACTED], the document review method was used to analyse the feasibility studies, including the structural and airtightness analysis, and the design proposals.

2.4.2 Interview

Interviews play a critical role in the investigation of the Wilmcote House project. According to Kvale (2007), the interview is not only a spontaneous exchange of views; it is a professional interaction, seeking to obtain thoroughly tested knowledge through a careful questioning and listening approach. Therefore, he implies that although the interview should aim to be unprompted, it should have a clear direction and produce knowledge. Yin (2003, p.106) similarly emphasises the spontaneity of the interview, arguing for "guided conversations rather than structured queries". He suggests that the interviewer should follow their own line of inquiry asking conversational questions that serve the investigation, with a fluid flow of questions. Yin (2003) describes two types of case study interviews: in-depth and focused. In an in-depth interview, the interviewer asks the interviewee about the facts of a specific topic, and their own opinion on different matters, so that it is possible to ask the respondent to share their own insights into particular occurrences. Yin (2003) points out that an in-depth interview can occur over a period of time rather than in a single conversation. The respondent may suggest other sources of evidence and other persons that could be interviewed. Yin (2003) suggests that the interviewer needs to use other sources of evidence to avoid being overly dependent on a single interviewee. The focused interview is another type of interview in which the interviewer focuses on certain questions despite remaining open-ended. This type of interview is typically used to corroborate particular facts that have been previously established (Yin, 2003).

Both types of interview have been used in the Wilmcote House case study. The case study was designed to include at least one in-depth interview with the key members of the project followed by necessary number of focused interviews. This process is based on "grounded theory" methodology. "Grounded theory is a general methodology for developing theory that is grounded in data systematically gathered and analysed" (Strauss & Corbin, 1994, p. 273). As explained by Strauss and Corbin (1994), the ongoing interplay between data collection and analysis leads to theory evolution during the research. The process of developing theory from interviews started with collecting data from in-depth interviews with the Wilmcote House stakeholders. The data from different interviews was then compared and analysed, so that the outcome of the analysis informed the design of the focused interviews. The data collection, comparison, and analysis process were repeated with focused interviews that led to theory building. The first round of interviews were as follows:

- Interview 1: was conducted with Architect A, a project architect at ECD Architects, on 21 May 2015.
- Interview 2: was conducted with Architect B, a project architect at ECD Architects, on 3 December 2015.
- Interview 3: was conducted with maintenance manager A at Portsmouth City Council on 9 March 2016.
- Interview 4: was conducted with design manager A at the contractor's team on 6 June 2016.
- Interview 5: was conducted with project manager A, a member of project managers' team, on 10 June 2016.

- Interview 6: was conducted with Architect C, a project architect at ECD Architects, on 17 June 2016.

During the first interviews, conversational and open-ended questions were asked. Only a small number of questions including the main research questions were designed prior to the interview. These questions are as follows:

1. What is your role in the project?
2. Have you been previously involved in an EnerPHit project?
3. How would you describe the differences between an EnerPHit project and a conventional project?
4. What are the challenges of achieving EnerPHit in the Wilmcote House project?
5. In your opinion, how could the challenges be overcome?
6. How do you see the future of using EnerPHit in tower block refurbishments?

The target of these questions was to explore the challenges of and workable solutions to EnerPHit from the perspective of the different project participants, conceivably influenced by their roles and level of knowledge regarding EnerPHit. The next step was to analyse the data collected from the interviews. To analyse the data, the 6 steps for data analysis defined by Kvale (2007) were reviewed. Based on the study by Kvale (2007), the first step occurs when the interviewee spontaneously discusses their experiences and feelings in relation to the topic. There is limited interpretation at this stage. The second step is when the interviewee themselves find new meanings from their descriptions. In the third step, the interviewer interprets the descriptions of the interviewee and reacts to it; for instance, they may reply by saying ‘I did not mean that…’or ‘I was trying to say that…’ This can continue until both sides reach an agreement over a particular interpretation. In the fourth step, the interviewer analyses the recorded interview and develops the interview meanings. The fifth step is to re-interview the respondents about the interviewer’s interpretations from the data analysis. At this stage, the interviewee has a chance to give their opinions on the interviewer’s interpretations and elaborate on their initial descriptions. The sixth step can possibly be to extend the interpretations to action. This means that interviewees can act on their new insights obtained from the interview.

The Wilmcote House case study interviews include all the steps described by Kvale (2007) except for the sixth step. It was initially planned to analyse the Wilmcote House project and use the findings for improving the process of the [REDACTED] and [REDACTED] refurbishment. Nevertheless, this project did not proceed and thus there was no such opportunity to include step 6. Another difference came from step 4, as the re-interviewing was not based entirely on the analysis of a particular interview, but was the result of simultaneously analysing all of the participant interviews. The focused interviews were conducted with the project architects, the contractor and their consultants. The number of focused interviews increased as more problems were encountered on site, to which the project teams had conflicting explanations. Therefore, knowledge was created from the analysis of both in-depth and focused interviews, comparing the outcomes of different interviews, and interpreting the findings. The focused interviews were as follows:

- Interview 7: Architect A was re-interviewed on 3 July 2016.
- Interview 8: Architect B was re-interviewed on 18 December 2016.
- Interview 9: Architect B was re-interviewed on 16 January 2017.
- Interview 10: Contractor's design manager A was re-interviewed on 3 May 2017.
- Interview 11: A member of Passivhaus consultants' team and the site architect appointed by the contractor were interviewed on 3 May 2017.
- Interview 12: Architect A and B were re-interviewed on 17 November 2017.

2.4.3 Observation studies

As explained by Yin (2003), as a case study happens in the natural environment of a case, an opportunity is created for direct observation; thus, the researcher can evaluate specific behaviours at particular periods of time in the field. For instance, the researcher can observe behaviours of participants in a meeting, a classroom, etc. Direct observations can be made on a field visit while collecting data from other sources of evidence, such as an interview (Yin, 2003). Simple observations made in the field can reveal key facts about the research topic. With regard to the Wilmcote House case study, two types of observation were made during site meetings between the project participants, and during site visits. Taking part in a number of monthly meetings held between the key project members led to a better understanding of the project progress, challenging issues, and the interactions between the project members. It is necessary to mention that the author was solely an observer and did not have an active role in site meetings. In addition to these meetings, the site visits accompanied by different project participants created the opportunity to inspect the building, and to observe the progress of the works and any problems directly. The data collected through the application of this method was used to validate the data gathered from interviews, particularly when there were inconsistencies between the responses of different interviewees. One of the major areas where the interviewees had disagreements was the causes of the problems during the construction stage.

2.4.4 Embedded research

This method was used during the design process of [REDACTED] and [REDACTED]. Embedded research can be defined as the undertaking of an explicit research role by an outside academic within an organisation for the purpose of identifying and executing a "collaborative research agenda". The relationship between the individual and the organisation is a mutually beneficial one, providing the researcher with access to data owned by the organisation, while in return delivering academic knowledge and approaches to creating structural policies and procedures for the organisation (McGinity & Salokangas, 2014). The researcher and stakeholders collaborate to define the problems, produce knowledge about these problems, learn and use social research methods, and interpret the outcomes of actions established by their learnings (Greenwood & Levin, 2007). The learning process can take place through meetings, team building sessions, focus groups, search conferences, etc. (Carroll, 2004)

This method was not used for Wilmcote House case study because the design stage of the project was completed when this research commenced. Thus, the author did not have an active role in Wilmcote House project and no conflict of interest arose while carrying out this case study. After ECD Architects became aware of this research, they agreed to assist the author with data collection on Wilmcote House project. They informed the author that [REDACTED]was considering to refurbish [REDACTED] and [REDACTED] and offered employment to the author to assist them with carrying out the feasibility study of the project. The architects and the author planned to use the embedded research method to study the refurbishment process of [REDACTED] and [REDACTED], to define the problems related to the design process, and explore the reasons behind them to develop solutions for prevention. The outcome of the research would be the development of effective methods and procedures for application in future projects. As the project did not proceed following the feasibility stage, the original targets of the embedded research method were not achieved. The involvement of the author remained limited to preparing the feasibility report under the instructions of the architects. Nevertheless, the four-month employment period provided the author with the rare opportunity to examine the initial stages of a tower block refurbishment based on EnerPHit.

Working in the same environment with the architects led to better access to the project data; furthermore, it facilitated communication with the architects on many occasions so as to explore their perspectives around distinct project aspects, alongside the times that interviews were conducted. Using this method contributed to the data analysis and data validation of the design process of the Wilmcote House case study.

2.5 Research ethics

The main ethical consideration of this research is to protect the anonymity and confidentiality of the interviewees and the data they shared. To protect anonymity, the identity of the interviewees are not disclosed. To ensure confidentiality of the data is protected, the author has sought either verbal or written consent from the interviewees. Prior to the interviews, all the interviewees were provided with "participant information sheet", prepared according to the research ethics guidance of the University of Kent. The participant information sheet provided information about the research and its purposes, so the interviewees could decide if they wanted to answer the interview questions. The interviews were recorded with the consent of the interviewees. Through verbal or written consent, the interviewees gave permission to the author to analyse their answers and use them in the research project. Nevertheless, the author is required by the client and the architects to ask for their permission before the publication of the data acquired from the interviews and project documents.

2.6 Research limitations

One limitation of case study based research is the low level of generalisability; single-case is particularly criticised for having minimum generalisability value (Yin, 2012). Regarding this research, limited generalisability is partly associated with the nature of the research area, as the application of EnerPHit to a tower block will always be affected by project specific contextual factors. Nevertheless, the framework of the thesis leading to the production of the findings can be applicable in other cases. Another important argument against case study research is that it may prove biased. Nevertheless, the risk of bias is not directly related to the case study method, instead it is linked to some qualitative methods utilised in case study research, such as the interview. According to Darke et al. (1998), the processes of collecting and analysing data in case study research are subject to the effects of a researcher's background and characteristics, extensively depending on a researcher's understanding and interpretations of events; thus, the validity of the research findings may be limited. A risk of bias in this research results from its significant reliance on interviews. As argued by Yin (2003), the interview method can be

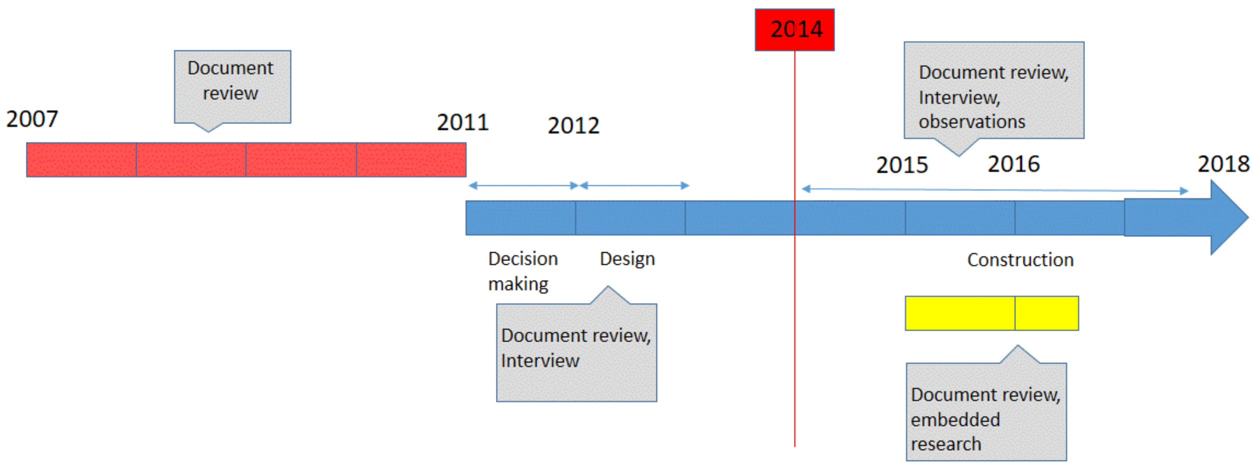

Figure 2.3. The timeline of case studies and research methods used by author.

prejudicial due to “poorly articulated questions”, and “response bias”; furthermore, it can be prone to inaccuracies resulting from poor recall. To minimise bias this research compares statements given by different interviewees, using alternative sources of evidence to assess their accuracy, such as document review and observation.

In addition to the general limitations of the case study method, some shortcomings specifically relate to the Wilmcote House case study. Firstly, due to the pioneering nature of the project, there was a sensitivity around the sharing of data. Secondly, the project took significantly longer than initially scheduled. Although most of the construction stage had finished, the project was not completed at the due time of this research limiting the potential analysis during the project’s final stage. Furthermore, some key participants from both the architects’ and the contractors’ teams left the project, and as a consequence, it was too challenging to arrange interviews with them. Generally, the busy work schedules of the project teams led to difficulties planning interviews and site visits. The following figure shows the timeline of the projects and the major research methods the author utilised to examine each project. The red line marks the beginning point of the research.

Chapter 3: Decision-making process (prior to appointing architects)

3.1 Introduction

The Wilmcote House refurbishment project started with Portsmouth City Council's decision to refurbish the building. Following this decision, they commissioned ECD Architects to develop the refurbishment design. ECD Architects proposed two refurbishment schemes, one was based on the EnerPHit standard, and the other aimed for a performance level slightly above UK building regulations. After examining both options, the Council chose to proceed with the EnerPHit option. Thus, using EnerPHit to upgrade Wilmcote House was the result of the decisions the client made at two distinct stages. The circumstances surrounding the client's decision to meet EnerPHit occurred after the engagement of the architects, and warrants its own investigation that is covered in the next chapter. The sole focus of this chapter is an examination of the client's decision to refurbish the building prior to the appointment of the architects, and so will not be discussing their decision to adopt the EnerPHit standard. The purpose of this chapter is to reveal the most significant factors in Portsmouth City Council's decision to refurbish Wilmcote House and the most serious challenges they encountered in committing themselves to deep retrofit solutions. This was a critical stage considering that during recent decades many tower blocks in the UK were demolished rather than refurbished; therefore, it requires extensive investigation. To shed further light on the findings from the Wilmcote House case, comparisons are made with the Edward Woods Estate tower block refurbishment that was designed by the same architects although aiming for different standards. The Wilmcote House case study indicates that the type of client, type of resident, building location and cost, and funding are some of the determining factors in a client's decisions regarding the future of their tower block stock.

3.2 Type of client

In similarity to all of the other social housing tower blocks, a social landlord owns Wilmcote House. The question is: How does being a social landlord affect the client's decisions regarding the future of their residential tower blocks? Bates, Lane and Power (2012) argue that in terms of planning and organising a project, it is more straightforward to refurbish a tower block owned by a social landlord compared to a tower block with privately-owned flats, because the social landlord is the only responsible party for the refurbishment of all the flats allowing the whole refurbishment to be carried out under a comprehensive programme with the same building teams and resources. This is a very important factor in achieving EnerPHit because it is a stringent standard, requiring careful planning at all stages and the design of all the details.

The investigation into the refurbishments of Wilmcote House revealed that varied factors affected the client's plans for the building, such as their broader housing policies, financial status, responsibilities towards residents, and commitment to government targets. The way they prioritised these factors had a significant role in shaping the project goals. In the case of Wilmcote House, the client was more focused on the residents' comfort and long-term benefits rather than reducing the costs of the project. During an interview, maintenance manager A at Portsmouth City Council (2016) explained that their targets were to increase the quality of residents' lives and the lifespan of the building. This was an uncommon approach towards social housing, reflecting an exceptional level of commitment from Portsmouth City Council towards their social housing tenants. This is one of the reasons why the refurbishment of Wilmcote House was such an exceptional case.

Portsmouth City Council owns and manages Wilmcote House, deciding to refurbish the building in 2011. The Council's strategic plans for the future of Portsmouth in the years between 2010 and 2015 were reviewed, so as to understand its housing policy and the Council's level of commitment to the refurbishment option at the time of the project launch. According to this document, Portsmouth City Council aimed to achieve the UK government's Decent Homes standard in their social housing stock. As discussed in chapter 1, Decent Homes was one of the standards that were introduced by the government for the purpose of raising the standard of social housing, placing pressure on public authorities to take the improvement of their building stock more seriously. Social housing tower blocks became affected by the Decent Homes standard alongside other social housing stock. Some blocks underwent refurbishment to achieve this level, while a number underwent demolition because of the expense of upgrading them to the Decent Homes standard (Williams, 2011). By 2010, 93% of Portsmouth City Council's houses had attained this; after 2010, improving the quality of housing remained one of their main priorities.

The strategic plan also outlined the Council's targets to improve their stock, incorporating government environmental targets. As explained in chapter 1, to tackle climate change one of the most important environmental targets is the reduction of CO_2 emissions. In comparison to a private building owner, local authorities can have a greater role in meeting these targets due to the scale of their responsibilities, as the government and Climate Change Committee have acknowledged. According to Climate Change Committee member Professor Julia King, **"**local authorities need to show leadership and recognise their wider role in supporting local emissions reductions” (Committee on Climate Change, 2012). Overall, the government requires councils to commit to carbon reduction targets and cut CO_2 levels from their buildings, practices, and vehicles. Councils are also expected to undertake carbon reduction projects, putting into practice government policies such as the Green Deal (Portsmouth City Council, 2011). One of the first steps of the government in recognising the role of local authorities was agreeing on a Memorandum of Understanding (MoU) with the Local Government Association. The initial target of the MoU was that each local authority would report the amount of its greenhouse gas emissions (Committee on Climate Change, 2012).

Additionally, introduced by the government in 2010 the CRC Energy Efficiency Scheme was devised to ensure the reduction of carbon emissions from large private and public-sector organisations, including city councils. Under this scheme, the participants are required to purchase allowances for each tonne of electricity and gas related carbon emission, bought from either the government or the secondary market. Based on this scheme, organisations can lower their costs if they reduce their carbon emissions, or face penalties if they fail to surrender adequate allowances (Carbon Trust, 2016). The UK Low Carbon Transition Plan[11] particularly influenced Portsmouth City Council, aiming to achieve a zero-carbon rating in both new and existing buildings by 2050. Therefore, increasing energy efficiency and reducing carbon emissions were two of the major objectives driving the refurbishment (Portsmouth City Council , 2011).

Nevertheless, there is a lack of adequate short-term goals and regulations set by the government for the achievement of their climate targets. As a result, local authorities are not obliged to commit to one specific set of rules, particularly in regard to improving existing stock. Most government standards such as the now abandoned Code for Sustainable Homes and the Zero Carbon Policy related to new buildings, rather than existing ones. Consequently, a social landlord’s decisions will be influenced by their specific approach towards their existing stock. For instance, some may be more committed to tackling climate change, protecting the environment, and social issues, while others might focus on the potential financial benefits. Landlords such as Portsmouth City Council who prioritise the environment and their resident communities are less likely to demolish their existing stock. According to the strategic plan of Portsmouth City Council, their general policy is to maintain their stock rather than replace it

[11] Read more about UK Low Transition Plan at: www.gov.uk/government/uploads/system/uploads/attachment_data/file/228752/9780108508394.pdf

with new properties. In fact, a constant feature of urban life in Portsmouth is repair and improvement, carried out by both public and private owners. The Council substantially invested in both the redevelopment of old neighbourhoods and the maintenance of their rented stock (Portsmouth City Council , 2011).

Investigating Portsmouth City Council's strategic plan illuminates their decision to carry out a deep retrofit on Wilmcote House. Wilmcote House was one of the social housing blocks in Portsmouth which had not achieved the Decent Homes standard at the end of 2010, and thus, was in a poor condition. Since its construction, the building had only undergone minor refurbishment works, so that by 2010 some of the main elements of the building were coming to the end of their serviceable life (ECD Architects, 2012). This led to difficulties for the residents in sufficiently heating their properties due to poor levels of insulation and the operational cost of the inefficient heating system. Most of the residents subsisted on lower incomes, and therefore, were at risk of fuel poverty (Buckwell, 2012). In 2010, suffering from a lack of comfort and high energy bills, a group of residents expressed their dissatisfaction, making their voices heard to local politicians (High-rise ambitions, 2015).

At this stage, Portsmouth City Council started to investigate the situation of the building and explored options for its improvement. In fact, the Council's commitment to meeting the demands of the residents became the starting point of the refurbishment project. The decision to implement a deep retrofit matched with the Council's strategic plan between 2010 and 2015 to result in energy saving, reducing carbon emissions as part of government's climate change tackling target. The EnerPHit option later chosen estimated a potential reduction in annual space heating and hot water demand by 90%; nevertheless, the Council had to quadruple their budget to be able to undertake a deep retrofit. In comparison with deep retrofit according to UK building regulations, using EnerPHit would be 8.8% more expensive (ECD Architects, 2012). Thus, the Council's decision was affected by an elevated level of commitment to their tenants and government policies, resulting in the reinforcement of their initial targets through an increase to the original project budget. The combination of these factors led to the unconventional refurbishment of Wilmcote House. To clarify this, comparisons are made with the refurbishment project of the Edward Woods Estate tower blocks that were also designed by ECD Architects, but aiming for different targets.

The tower blocks in the Edward Woods Estate were in a comparable situation to Wilmcote House in terms of the physical condition of the buildings. As a result, the residents of these blocks also suffered from poor living conditions and high energy bills. Hammersmith and Fulham Council own the blocks, and similar to Portsmouth City Council, were committed to reducing their impact on climate change. The Council was in favour of improvements to existing housing stock or developments on existing housing land because they found regeneration more sustainable than renewal and transformation (Hammersmith and Fulham Council, 2011). Thus, they preferred to refurbish the Edward Woods Estate tower blocks, but unlike Portsmouth City Council, did not prioritise the comfort of their residents. In fact, their target was to achieve a balance between differing priorities, such as cost-efficiency and contributing to the neighbourhood. The retrofit of the tower blocks was part of a bigger regeneration scheme carried out by Hammersmith and Fulham borough council over the whole Edward Woods Estate and its surrounding areas (Breyer Group, n.d.). The aim of the scheme was to regenerate one of their poorest neighbourhoods, and being a part of this area, the tower blocks had to be improved accordingly. To evaluate the condition of the buildings the residents were surveyed, with the outcome of this investigation revealing how poor their living conditions were. The Council decided to refurbish the blocks with the aim of improving the residents' living conditions, increasing energy efficiency, alleviating fuel poverty, reducing CO_2 emissions, and enhancing the local environment by rejuvenating the blocks' appearance (Bates, et al., 2012).

In 2007, when the project was in its design stage, the Climate Change Act 2008 had not yet been passed meaning that there were no clear legally binding carbon targets at this time. However, the Council was committed to the Decent Homes standard, and subsequently, the refurbishment of the Edward Woods Estate tower blocks conformed with bringing them up to this level. It was anticipated that the energy bills of the flats would fall by around 70% after refurbishment (Bates, et al., 2012). The client in the Edward Woods Estate project sought a balance between immediate financial savings and improving the residents' lives. With different project priorities, Portsmouth City Council aimed to maximise the energy efficiency of Wilmcote House, later agreeing to spend around £100,000 on each flat to upgrade them to EnerPHit level; whereas, the landlord of the Edward Woods Estate tower blocks pursued less ambitious energy efficiency targets at a cost of approximately £30,000 per flat (Breyer Group, n.d.).

3.3 Type of residents

Initial interviews with ECD architects and the client revealed that the residents of Wilmcote House were all tenants, mostly on low incomes. Portsmouth City Council is the sole owner and manager of Wilmcote House, an unusual situation because most social housing tower blocks are occupied by both tenants and leaseholders. The change in the type of occupant occurred after the Right to Buy[12] scheme encouraged social housing residents to buy their homes, resulting in some tower block tenants buying their flats and becoming leaseholders. Those residents of a tower block who bought their flats under Right to Buy, in fact, bought the right to live in their homes and become leaseholders; however, the freeholder (social landlord) would remain in charge of the building management. In this arrangement, the freeholder makes the decisions in regard to both day-to-day maintenance of the building and the need for larger refurbishment programmes, and thereafter the leaseholders are required to pay their share of service charges to cover the costs. In many projects, the costs associated with major refurbishment works have been found too high by the leaseholders, resulting in dissatisfaction and complaints. Some leaseholders feel that their landlords had historically neglected the maintenance of their tower blocks, leading to leaseholders paying the price via high service charges and the buildings requiring later costly refurbishment programmes. In 2014, following increased complaints, the government finally placed a cap on leaseholder service charges (Wilson & Bate, 2015).

Thus, in a tower block with leaseholders, the landlord must consider the affordability of any major refurbishment works to prevent conflicts with its residents. In order to avoid imposing unnecessary charges on leaseholders, all refurbishment works need to be justified, which can be a barrier to the adoption of deep retrofit solutions such as EnerPHit. At the Edward Woods Estate tower blocks, 62 out of 528 homes were occupied by leaseholders and so minimising refurbishment costs was a priority (Breyer Group, n.d.). On the contrary, being the sole owner of Wilmcote House, Portsmouth City Council did not have to consult with residents over the financial side of the project and thus had more freedom with the project costs. This was reflected in interviews with the client team in which they emphasised that they merely consulted with the tenants with regard to the design aspects of the project, but not the financial side, resulting in greater improvements to the tenants' lives. Therefore, it can be argued that

[12] See introduction chapter.

there is a higher chance of EnerPHit adoption to social housing tower blocks without leased flats.

3.4 Location of the building

Maintenance manager A at the Council (2016) explained that the Council was not interested in selling Wilmcote House to the private sector because it would not have been profitable considering the low property prices in Portsmouth. The demolition of Wilmcote House would not be an appropriate option either because it was one of a few buildings in the area that provided three-bedroom apartments. These were in high demand because of their greater suitability for families with children. Furthermore, according to maintenance manager A, any decisions made regarding Wilmcote House had to be adapted to other tower blocks in the area. Maintenance manager A (2016) explained: “If we demolished Wilmcote House, we had to demolish all the tower blocks in the area”. The Council could not afford to rebuild and replace all of the blocks; additionally, the tenants’ communities would be destroyed. Thus, the market value of the properties, housing demands, and the surrounding buildings in the area were some of the factors that the client considered while deciding to refurbish Wilmcote House. The factors related to the location of the building are investigated in this section.

3.4.1 Market Value

The UK government has promoted homeownership since Margaret Thatcher’s government introduced its Right to Buy policy. In 2011, the Conservative government of David Cameron decided to make the Right to Buy more attractive by raising the discounts on this scheme (Wilson, 2014). One purpose of promoting Right to Buy was to handle the UK housing shortage by spending the money made by selling social houses on new housing (Stone, 2015). Wilcox, Perry, and Williams (2015) argue that the promotion of Right to Buy has led to the decline of social rented housing, with housing stock in some areas decimated as a consequence of forcing councils to sell their most expensive stock (Stone, 2015). The government has cut the funding provided to social landlords (Wilcox, et al., 2015) to be used on social housing refurbishment schemes to encourage them to sell their stock to the private sector, thus reducing social housing. Maintenance manager A explained that Portsmouth City Council was also under pressure from the government not to maintain Wilmcote House. However, considering the low house prices in Portsmouth particularly compared with London, the Council did not have any financial incentive to demolish, rebuild, and sell the flats to the private sector.

To shed more light on this, it should be noted that the construction and sale of new flats was part of the Edward Woods Estate refurbishment project. This seemed to be a profitable solution considering the location of the estate, leading to the client building twelve penthouses on top of the blocks. In 2009, when the project started on site it was hoped that each of the penthouse apartments would be sold to the private sector for up to £500,000, collectively totalling £6,000,000 (Bates, et al., 2012). This is a considerable amount taking into account that the budget for the whole project was around £16,000,000. The following tables show the prices of houses with differing numbers of rooms in both Somerstown and the London Borough of Hammersmith and Fulham where Wilmcote House and Edwards Woods Estate are located respectively.

Table 3.1. Average asking prices for properties in Somerstown c.(home.co.uk, 2016).

Number of bedrooms	September 2006	June 2016	Change
4 Bedrooms	£374,271	£413,823	+11%
3 Bedrooms	£252,119	£289,315	+15%
2 Bedrooms	£175,282	£185,294	+6%
1 Bedrooms	£116,851	£110,715	-5%

Table 3.2. Average asking prices for properties in Hammersmith and Fulham (home.co.uk, 2016).

Number of bedrooms	September 2006	June 2016	Change
4 Bedrooms	£797,834	£1,961,933	+146%
3 Bedrooms	£675,066	£1,605,845	+138%
2 Bedrooms	£393,246	£1,025,622	+161%
1 Bedroom	£264,542	£655,883	+148%

The figures in the tables come from 2006, a year before the Edward Woods project started, and 2016. It is clear from the tables that house prices in Somerstown are significantly lower than the prices in Hammersmith and Fulham. In addition, the prices in Somerstown have not changed considerably within the ten-year period, in contrast to Hammersmith and Fulham where there has been a significant rise in all categories. To have a better estimation of new flat prices in Somerstown, the average price of different property types in this area is also investigated in the following table. The red-marked areas on the table and the graph above show the data related to flats. Based on this table, the average price of flats in 2006 and 2016 was less than £150,000, and according to the graph, there was no significant increase in these values between these years. Thus, the average price of flats in Somerstown is less than one-third of the average prices in Hammersmith and Fulham in 2009.

Table 3.3. Average property asking prices in Somerstown. (home.co.uk, 2016).

Type of property	September 2006	June 2016
Detached	£750,000	£495,000
Semi	£325,000	£444,998
Terraced	£289,950	£367,500
Flat	£134,973	£140,000
All	£164,995	£155,000

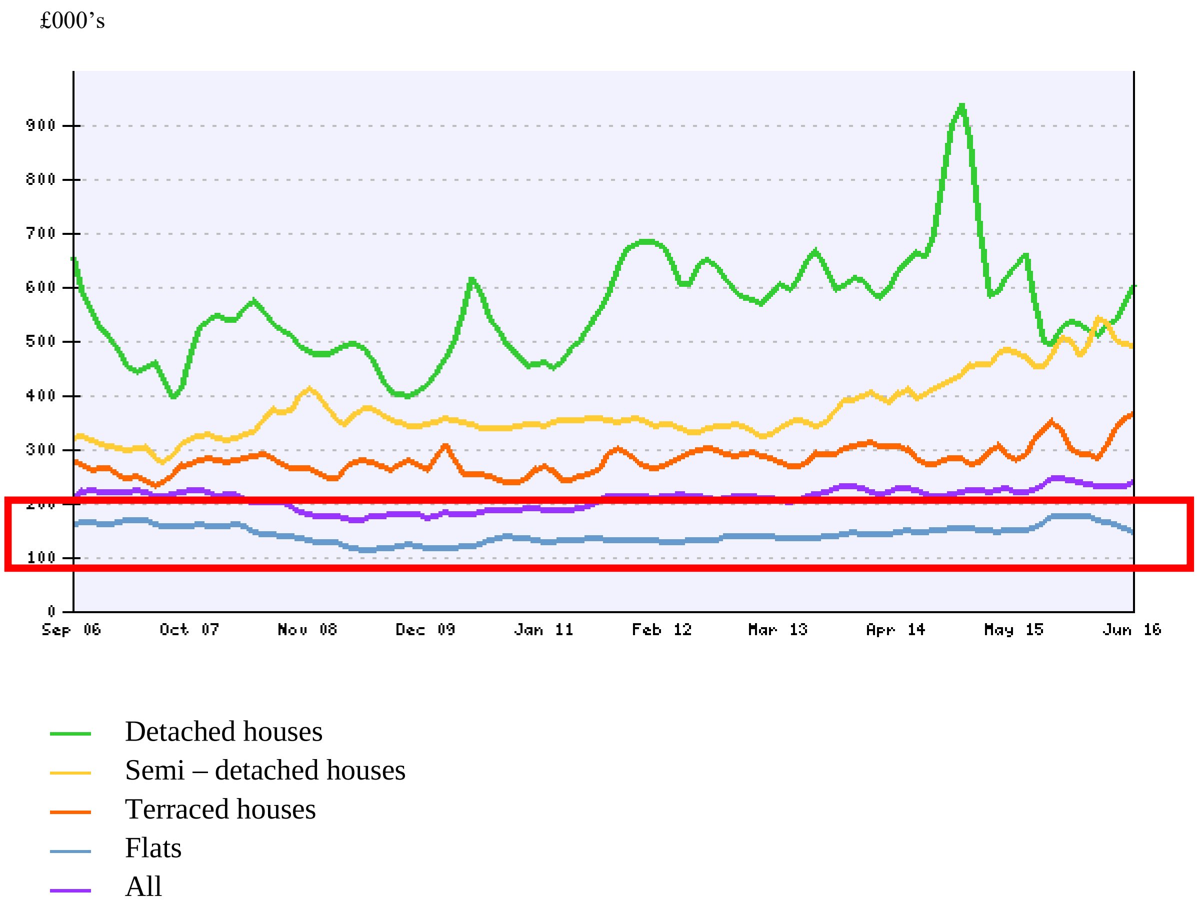

Figure 3.1. Somerstown average property asking prices by type from 2006 to 2016. The red box highlights the average prices of flats, the lowest in the chart (home.co.uk, 2016).

It should be noted that the figures in table 3.3 and figure 3.1 show the average prices of each property type with differing numbers of bedrooms; considering that flats generally have a lower number of bedrooms compared to other property types, their average prices are the lowest.

3.4.2 Housing demands

Wilmcote House is located in an area with both a dense population and a shortage of affordable housing. As discussed by maintenance manager A at the Council, the three-bedroom flats in Wilmcote House were particularly under demand in the area as Portsmouth has very high urban density and an increasing population. According to a report by the Office for National Statistics, in 2010 Portsmouth had a density of 5,000 people per sq.km, making it the most densely populated unitary authority outside of London where the average density is 4,900 (Causer & Park, 2010). According to Portsmouth City Council (2011), there is significant diversity in household incomes, with a concerning number of people living in poverty and unhealthy conditions. Despite the relatively low house prices, one-fifth of households do not have the sufficient income to engage with housing market without accessing cheaper rents or housing benefit assistance. Therefore, the demand for homes with affordable rents is significant and ever growing.

Another critical issue for consideration is the rising size of households in Portsmouth, with a need for larger properties. A considerable number of social housing tenants currently live in one-bedroom apartments despite requiring 2 to 3 bedrooms. There is a shortage of larger dwellings in Portsmouth, and as a result, although people from outside Portsmouth are attracted to move into the city due to its lower house prices, there is also an outflow of the existing population to nearby boroughs in the hope of finding larger properties (Portsmouth City Council , 2011). Containing three-bedroom maisonettes, Wilmcote House contains some of the area's most in-demand dwellings, being a part of the social housing stock able to provide relatively larger properties. Therefore, the demolition of this building would not be in the best interest of the people in the area. During an interview with project manager A at Keegans (2016), the Wilmcote House refurbishment project managers, he referred to housing demands as the main factor that convinced the client to reject the demolition of Wilmcote House. He explained that due to the shortage of three-bedroom properties in the area it would be challenging to relocate the residents because there were not enough available properties of the same size for decanting.

3.4.3 The building neighbourhood

As pointed out by the client, the decision to refurbish Wilmcote House was not merely based on its specific situation; the client needed to consider the future of other tower blocks in the area as well, taking the same approach towards all the blocks. Steve Groves, asset manager for Portsmouth City Council pointed out: "In terms of our long-term strategy, I think it's wrong to just evaluate Wilmcote House on its own, that's just one high-rise block and we've got a dozen other high-rise block that also exceed 11 storeys, so what we do if the case is right for demolishing one, do we demolish all the other blocks? That's when it becomes unaffordable" (Groves, 2015). It can be concluded from the interview with the client that the Wilmcote House refurbishment functioned as a pilot project that could provide a model for the regeneration of other blocks, reflected in the client's decision to investigate the feasibility of refurbishing [REDACTED].

Research into tower block projects in the UK during the last three decades suggests that generally if there is more than one tower block in the area, there is a high probability that similar decisions will be made across the board, meaning that all may be demolished, refurbished, or sold to the private sector. For instance, Nottingham City Council decided to demolish all five residential tower blocks in the Lenton area of Nottingham because they similarly concluded that the buildings were in such a condition that the cost of their refurbishment would exceed that of demolition and rebuilding (Nottingham City Homes, 2014). Another example is Oxford City Council's decision to maintain and refurbish the Blackbird Leys' five tower blocks. Considering their budget constraints, the Council decided to raise all the blocks to the same level so that they would all meet the Decent Homes Standard (Somerville, 2016). Similarly, the impact of the building site neighbourhood is recognisable in the Edward Woods Estate refurbishment plans. As explained earlier in this chapter, the refurbishment decision was part of a regeneration scheme covering the whole estate, with the rejuvenation of the blocks to help promote the neighbourhood being one of the aims of the project. This meant that the landlord took into consideration the situation of the surroundings of the building site while deciding to refurbish the blocks.

3.5 Costs

One of the most important stages in the client's decision-making process regarding the Wilmcote House project was the calculation and comparison of the costs of different options including demolition and rebuilding, refurbishment, and the carrying out of essential repairs. Calculations undertaken by Portsmouth City Council showed that the demolition and rebuilding of Wilmcote House was likely to be significantly costlier than the refurbishment option (Buckwell, 2012),and as discussed earlier, the estimated costs of these options affected the client's ultimate decision. Reviewing the client's report on the evaluation of different options revealed that cost estimation was a convoluted process. With regard to the demolition option, it was not possible to identify an exact potential duration for the decanting process as this would depend on the time required to secure appropriate new homes for the residents. The new homes would need to fit the myriad requirements of the residents; therefore, a lack of suitable homes in the area could extend the length of the decanting period. This would result in higher rent loss and disturbance allowance; thus, the total costs associated with demolition option would increase (Buckwell, 2012). Portsmouth City Council estimated that it would take 18 to 24 months to decant all the blocks; this estimation was based on both the experience of previous projects such as the decanting of an 18-storey tower block in Portsmouth called Horatia House, and a review of the number of three-bedroom properties let in the prior two years, due to all the flats in Wilmcote House containing three-bedrooms. Based on this evaluation, the Council predicted that the total costs of decanting, demolition, rebuilding, rent loss, and disturbance allowance could reach £20million (Buckwell, 2012).

However, the assessment of refurbishment costs involved complications and uncertainties. There were measurable costs such as the price of materials or technical services; however, this option was not merely assessed according to its initial costs, but was justified by its estimated future savings. The amount of energy saved exists only as a predicted figure showing how the owner and the residents would benefit by a reduction in future spending. According to Crawford et al. (2014), this figure was not necessarily achievable in reality if the actual performance of the building became worse than expected or as a result of the rebound effect[13] and thus, it would be difficult to calculate exact reductions in energy bills. Furthermore, the uncertainty of future fuel prices complicates this calculation even further. Portsmouth City Council had initially calculated the refurbishment costs to be around £3m, significantly lower than the costs of demolition and rebuilding. Following their consultation with ECD Architects and their commitment to deep retrofit, ECD Architects estimated the costs of deep retrofit options to be between £12m and £13m, while expecting around £750 per dwelling per annum savings in energy bills (ECD Architects, 2012). Even though the retrofit costs were higher than the client's initial expectation, they remained lower than the demolition option; furthermore, the savings achievable from retrofit options conformed with the client's main objectives in terms of improving the residents' lives.

3.6 Funding

As discussed in the previous section, Portsmouth City Council found it financially workable to increase their initial budget by around four times to carry out a deep retrofit. Four years later, [REDACTED] decided that they could not afford the costs of a similar deep retrofit in two other tower blocks, [REDACTED] and [REDACTED][14]. The question then arises, "How capable is the Council to fund large-scale retrofit projects?" The literature review suggests that generally funding remains one of the main challenges of tower block refurbishment projects (Scott, 2014). The research shows that public clients have access to a broad range of borrowing resources which offer them certain flexibilities and freedoms to pay back their loans. For instance, local authorities can borrow from central government through the fixed rate loans

[13] Rebound effect in this context is the rise in residents' energy consumption following a refurbishment project. This results from residents heating their homes at higher levels to increase their comfort after their homes become more energy efficient. Reference is needed here.
[14] This decision is analysed in chapter 4.

offered by the Public Works Loan Board (PWLB).[15] With these loans, the rate of interest remains the same for the duration of the loan. Apart from central government, a council can additionally borrow from other councils (United Kingdom Debt Management Office, 2015). Furthermore, funding is available for the public sector to borrow and use for energy efficiency improvements. Salix Finance Ltd., established in 2004, is an independent company dedicated to this purpose, providing interest-free loans to the public sector to invest in the reduction of carbon emissions and the increasing of energy efficiency (Anon., 2006). The project architect A (2015) explained that Portsmouth City Council was able to borrow from central government at low interest, relying on their long-term asset management strategy.

In spite of the various available sources, social landlords might encounter problems with providing sufficient funding. One reason is that there are inconsistencies with government policies and schemes. For instance, the government initiated the Green Deal to encourage landlords to carry out sustainable refurbishments, but later changed this policy and limited obtainable funds. Evidently, this had an adverse effect on many projects under progress; furthermore, it may also discourage owners from relying on any similar future schemes. Another problem results from the borrowing caps imposed by the government in April 2012. The caps restrict the sum of money local authorities can borrow to spend on council housing. The limit relates to the specific debts of the councils; anything left within the limit after deducting the debts is called headroom. Based on this policy, the amount councils can borrow depends on their available headrooms. Imposing the caps limits the overall borrowing power of all councils, additionally leaving very little or no borrowing power for councils with high debts (Perry, 2014). This policy can encourage councils with low headrooms to sell their stock or minimize their spending on improving them.

Following the restrictions imposed on their borrowing from the government, local authorities required alternative sources of funding which could prove quite challenging. One alternative source of borrowing could be banks, however, they may not be willing to lend because of the financial risks of sustainable refurbishment projects and the uncertainties regarding their future savings (Swan, et al., 2013). Future policies, borrowing mechanisms, or possible changes in

[15]"The Public Works Loan Board (PWLB) is an independent and unpaid statutory body, which originated in 1793 and became established on a permanent basis in 1817. Since 1946 it has consisted of up to twelve Commissioners appointed by the Crown. The functions of the Commissioners are to consider loan applications from local authorities and other prescribed bodies and, where loans are made, to collect the repayments. The PWLB has operated within the United Kingdom Debt Management Office since July 2002." (United Kingdom Debt Management Office, 2015)

prices of materials and systems required to carry out refurbishment programmes may change the affordability of these projects. According to Swan et al. (2013), social housing providers can secure loans based on their land and housing assets in the future; therefore, they may not be able to fund future projects if they sell their assets now to afford current projects. This is one prediction for the future, but it is possible that landlords may find alternative routes of funding.

In order to fund the Wilmcote House project, the Council relied mainly on their own income and borrowing power rather than external resources. In an interview with architect A (2015) at ECD Architects, he explained that Portsmouth City Council had a high headroom and a 35-year asset management strategy. It is worth mentioning that Wilmcote House had initially attracted £700,000 ECO funding, later reduced to £300,000 because of the changes made to the scheme (Architect B, 2015). Considering that the total project budget was £13m and only £300,000 was provided by ECO, it can be concluded that Portsmouth City Council had relatively high financial power, otherwise, they may have been unlikely to be able to afford the project. For instance, the funding for the Edward Woods tower blocks came from different sources. The complete budget spent on the project was around £16m: around one third of the funding (£5.24m) was from the GLA (Greater London Authority) energy saving funding; around £0.6m was funded by CESP which was effective at the time of the project; around half of the funding (£8.62m) came from Housing Revenue Account capital funding and capital receipts; and the remaining £1.67m was provided from the residual funding of a previous scheme (Bates, et al., 2012).

Analysing the various funding sources of the Edward Woods Estate tower blocks refurbishment shows that this project had a higher dependence on external sources than the Wilmcote House refurbishment. At least one-third of the capital came from sources not normally available to all social landlords, one of these being CESP funding which was only available for a limited time and is no longer effective, and the other source the GLA energy saving funding available only to buildings in London. It was possible that the lack of these two sources might change the scope of this project. In other words, the different means of funding for this project cannot merely be explained by the financial power of the client, but also reflect the effective use of available opportunities.

3.7 Review of Wilmcote House refurbishment project prior to appointing project consultants

The factors investigated above, including type of client, resident, the location of the building and costs, and funding can explain Portsmouth City Council's decision to refurbish Wilmcote House and demonstrate the client's capabilities to carry out an EnerPHit refurbishment. In fact, the decision to achieve EnerPHit was only made after consultation with the architects, as prior to this stage, the Council had only decided to refurbish the building. The influence of the architects on changing the scope of the project, choosing EnerPHit as the project benchmark, and the architects' evaluations on the feasibility of complying with EnerPHit requirements are explored in the next chapter. Before the investigation of the next stage of the project, the client's decision to refurbish Wilmcote House is reviewed.

Portsmouth City Council started the investigation of the Wilmcote house situation by evaluating three options: demolition and rebuilding, continuing the building maintenance with no essential improvements, and refurbishment. The demolition option was rejected due to the excessive costs of decanting and rebuilding, and the negative impact on its residents' lives. If the building were demolished it would have a detrimental effect on the community of residents, the tenants could take a long time to start living in an improved environment, a similar density may not be achieved after rebuilding, and all the residents may not come back once more to live in the building. The demolition process may negatively affect the surrounding area to the point that disturbance allowances would need to be paid; furthermore, the Council would face significant rent loss during the demolition and rebuilding process. Steve Groves explained: "We were able to demonstrate that financially, it wasn't a viable option. It is not just about the cost of demolition, although that is a significant factor, you have to factor in the cost of rebuilding and the indirect cost of rebuilding and the indirect cost of decanting, your rent loss can be over a number of years"; "Then there is disturbance allowance and before you know it you are talking about 20m pounds to demolish and rebuild and that is not withstanding other issues such as can you get the same density again if you are rebuilding on that same site" (Groves, 2015).

Moreover, this option would result in the destruction of one of the few buildings offering the most sought after 3-bedroom properties in the area (Buckwell, 2012). Lastly, it would exemplify the broader policy of the Council towards all their tower block stock, something financially impractical for the Council due to the existence of a considerable number of social housing tower blocks in the area and the excessive costs of their demolition and rebuild. According to Steve Groves: “If you focus on new-build to improve the energy efficiency of your stock, it is only a small proportion of the whole housing stock for us in Portsmouth. We could never keep pace with demolishing and rebuilding to meet our housing demand as opposed to refurbishing our existing stock” (Groves, 2015).

The next option, continuing the maintenance without undertaking improvements, was similarly rejected due to the detrimental effect on residents’ living standards, and prohibitive costs during the remaining 15-20 years of estimated life for the building if major refurbishment was not undertaken. However, the landlord would still need to pay for the maintenance during this period. Due to their commitments, the Council could not ignore the uncomfortable living conditions and high energy bills of the residents; therefore, they would need to spend a considerable amount of their maintenance costs on improving a building almost at the end of its life (Buckwell, 2012). Thus, Portsmouth City Council decided that refurbishment was the most appropriate option to improve Wilmcote House and proceeded with appointing consultants to carry out this work. According to Portsmouth City Council, the objectives of the refurbishment works were the resolution of the structural problems; extending the life of the building by at least 30 years through repairs and protection; improving residents’ comfort, safety, and affordability; reducing greenhouse gas emissions; and reviving the building, making it adaptable to modern lifestyles (Portsmouth City Council, 2012). In order to achieve these objectives, the Council planned to remedy the external structure of the building, replace the windows, upgrade and install PV panels to the roof, and plan a new gas CHP. Some potential extra works, such as enclosing communal walkways, were also mentioned in the brief (Portsmouth City Council, 2011).

3.8 Conclusions

The chapter reveals that Portsmouth City Council’s decision to refurbish Wilmcote House was influenced by factors such as the client’s approach, the location of the building, the costs of the project, and the financial capability of the client. The differences between Wilmcote House and the Edward Woods Estate tower blocks projects, particularly the market value of the properties and the financial status of their landlords, explain why Wilmcote House had a better potential to receive an EnerPHit refurbishment. The chapter suggests that social landlords choose to retrofit their tower block stock based on their commitments to their residents and government targets. Being highly committed to improving the living conditions of the tenants, the landlord of Wilmcote House was reluctant to demolish the building and relocate the residents, preferring instead to improve the conditions of the existing building.

Another key factor which influenced the decision of the clients was the location of the buildings. According to the case studies, a block located in an area with high market value has a greater chance of a landlord deciding to make a profit from selling the flats to the private sector, than spending their budget on improving the flats occupied by social housing tenants. On the contrary, in areas with low house prices, owners do not have a financial incentive to sell their flats, and therefore, it is more probable that they will opt for the refurbishment of their social housing stock. This is one of the reasons why Portsmouth City Council chose to carry out a deep retrofit on Wilmcote House.

The case studies show that the need to serve the specific housing demands of an area can encourage a client to maintain and improve their tower blocks. For instance, Portsmouth City Council was interested in keeping the three-bedroom flats of Wilmcote House because this was a most in demand type of property type of property in the area. It was also revealed that decisions regarding the future of tower blocks were influenced by the potential effects on the neighbourhood and other local tower blocks. Portsmouth City Council believed that the same solution should be used to improve all their tower blocks. If Wilmcote House were to be demolished and rebuilt all of its surrounding blocks would need to be similarly transformed, but the client was not capable of meeting the costs of this option. On the other hand, Hammersmith and Fulham Council felt obliged to refurbish the Edward Woods Estate tower blocks to contribute to the rejuvenation of the neighbourhood. Lastly, the clients compared the costs of these options and evaluated them alongside their finances. Portsmouth City Council relied on their relatively high financial capability to retrofit Wilmcote House, while Hammersmith and Fulham Council required additional external financial sources. Consequently, the former decided to comply with the stringent EnerPHit standard, while the latter aimed for more conventional retrofit solutions based on more typical building regulations.

Chapter 4: Decision-making process (After appointing architects)

4.1 Introduction

The Council's decision to adopt EnerPHit in Wilmcote House was the result of a two-stage process. The previous chapter reviewed the first stage, focusing on the client's decision to adopt a deep retrofit approach. This chapter aims to shed light on the second stage which was the client's decision to select EnerPHit as the benchmark for the project. While the first stage comprised the client's own analysis of their targets, policies, and the situation of Wilmcote House, the project architects played a significant part in shaping the views, principles, and investigations resulting from the second stage. This chapter explores why the architects proposed a refurbishment scheme according to EnerPHit criteria and how they investigated the feasibility of this scheme. The findings show that the architects' proposition to utilise EnerPHit was related to their knowledge of the standard, their background, and their approach towards refurbishment projects. To understand the limits of the building and to assess the viability of achieving EnerPHit criteria, such as U-value targets and airtightness, the architects and their consultants assessed the structural conditions of the building and tested the existing airtightness level. Furthermore, they consulted the tenants to inquire as to their views regarding the scheme. Based on the outcomes of these investigations, the architects developed refurbishment solutions. The case studies show that this was a critical stage of the project because it resulted in the client's decision to use EnerPHit in Wilmcote House, while rejecting the adoption of this standard in the [REDACTED].

4.2 Approach of Project Architects

The investigation of Portsmouth City Council's consultation with the project architects shows their influence on the client's decision-making. This impact depended on several factors, such as their background and previous experience, their approach towards refurbishment projects, and their knowledge of new standards and technologies. ECD Architects convinced the client to extend the scope of their refurbishment agenda, initiating one of the main steps on the path leading to the use of the EnerPHit standard. ECD (Energy Conscious Design) Architects has considerable experience in sustainable projects. The company is committed to sustainability principles, with a policy of taking under consideration social, environmental, and economic factors. Subsequently, the team's design process from the initial to final stages was affected by this policy.

This approach to energy efficiency suggests firstly, the reduction of energy demands; secondly, the use of renewable energy; and lastly, the supply of energy in an efficient way (ECD

Architects, n.d.). ECD Architects explain that: “Whether refurbishment or new build construction, our projects are undertaken with a fabric first approach which extensively improves the building thermal envelope with internal and external insulation, insulated doors and windows” (ECD Architects, 2017). In order to reduce energy demand, they aim to achieve thermal insulation standards beyond building regulations. They originally offered BREEAM and Code for Sustainable Homes consultancy, but after becoming familiar with Passivhaus started to offer Passivhaus design to their clients alongside other standards. In the initial interview with ECD Architects, they claimed that they had become acquainted with Passivhaus towards the end of the 2000s. Architect A (2015), explained that he became aware of the standard “through a former colleague who is a trained Passivhaus designer”, later having “a few workshops on what Passivhaus is about”. He stressed that ECD became interested in using Passivhaus because “it is a very good, rigorous methodology, and we can apply it to both new and existing buildings to ensure their energy performance (the actual energy consumption in use) is more closely related to what is predicted. Therefore, there is not a performance gap as there is in many buildings. Passivhaus provides a rigor that we can enforce through the contract on site”.

Several city councils and housing associations have been among the clients of ECD Architects and they have experience with the refurbishment of social housing. Moreover, they were involved in the retrofit of the Edward Woods Estate tower blocks before they were appointed to design the Wilmcote House refurbishment. Even though both projects were tower block refurbishments, ECD did not consider the EnerPHit standard for Edward Woods. Ian Sarchett and Richard Ferraro (2016) at ECD explained that the company was not familiar with the Passivhaus standard in 2007 when their engagement with Edward Woods started; furthermore, the EnerPHit standard did not come out until 2010. Additionally, architect A (2015) believes that the client in the Edward Woods tower blocks project might not have accepted to pay the costs required to achieve EnerPHit. Regardless of the performance benchmark, ECD’s design targets for this project were to improve the energy efficiency of the building, reduce the residents’ energy demands, and create for them better living conditions.

Portsmouth City Council appointed ECD Architects through a competitive tender. Steve Groves, the asset manager, explained: “We recognized as a council that we did not have the expertise to do that sort of scheme to a high-rise block, so we went out to tender for consultants and that is when we first started getting working with ECD Architects” (Groves, 2015). After

ECD Architects were appointed as the project consultants of the Wilmcote House refurbishment, they changed the client's initial scope for the project. Following their initial investigations, ECD realised that the building was facing serious problems, such as poor energy efficiency, a deteriorated façade and internal spaces resulting from water penetration, condensation and mould growth, thermal bridges and air leakage, a poor visual image of the building, substandard communal areas (ECD Architects, 2012), and "there was much anger about how much people were paying on fuel bills" (Architect A, 2015). Therefore, they convinced the client that improving Wilmcote House should not merely concentrate on enhancing the heating system, as it was necessary to boost the efficiency of the building fabric in order to address the different problems plaguing the building (Anon., 2015). This was based on their general approach of minimising energy use by maximising the efficiency of the building fabric. Following their consultation with ECD Architects and Keegans, the sister company of ECD later appointed as quantity surveyors, Portsmouth City Council decided to reconsider their initial plans and increase the previsioned budget.

In the first interview with ECD Architects, one of the initial questions was: why did ECD propose to upgrade Wilmcote House according to EnerPHit standard? To answer this question, architect A (2015) explained that they had initially proposed two retrofit options: "one option was to insulate to the level required by building regulation system and then provide a communal heating system, and another option was to superinsulate the building to reduce energy consumption massively and to get to such a point that heating was negligible". They presented these options to the client at the feasibility stage, where the client decided and selected the superinsulated option.

According to architect A (2015), as ECD started to develop this choice, they realised that EnerPHit was the logical standard to apply because of its fabric first approach and emphasis on superinsulation. He pointed out that the client was not aware of the EnerPHit standard requiring ECD to familiarise them. ECD's EnerPHit proposal for Wilmcote House addressed environmental, social, and economic advantages conforming to their commitment to sustainability principles and the client's responsibilities towards people and government targets. From an environmental point of view, the objective was to reduce carbon emissions related to poor energy efficiency while preventing the deterioration of facade and internal environment. In terms of social, economic, and health benefits, the plan was to minimise thermal bridges and air leakage in order to prevent draughts and mould growth, resulting in the improved comfort of residents and a reduction in their energy bills. Finally, from an economic perspective, the target was to prolong the life of the building, reducing the maintenance costs related to poor building fabric (ECD Architects, 2012).

The feasibility report prepared by ECD Architects shows that they appointed consultants to investigate the structure, airtightness, and heating system of Wilmcote House. Based on the results of investigations, they developed the retrofit proposals. After the client selected the EnerPHit scheme, the architects presented the results to the residents to receive their feedback on their design solutions. Thus, the consultants' investigations on the building revealed the viability of achieving EnerPHit and shaped the architects' proposal, while the consultation with the residents helped the architects to assess their proposal from the residents' perspective. The investigations that affected the architects' proposals are examined in the remainder of this chapter. Without this examination, it would not be possible to understand ECD Architects' solutions for the refurbishment of Wilmcote House.

4.3 Structural assessment

ECD Architects appointed Carter Clack to examine the structure of Wilmcote House. They explained in their feasibility report that their intention was to understand: "can the building fabric support the additional loadings imposed by the thermal insulation systems proposed?" (ECD Architects and Keegans, 2015). The structural assessment revealed that applying external insulation to the building was not possible via conventional methods. As mentioned in the literature review, installation of external insulation on high-rise blocks can be often problematic (Dowson, et al., 2012). It should be noted that external insulation is one of the most significant factors for achieving EnerPHit, and thus, any challenges in this area can be an obstacle to meeting the standard. With regard to Wilmcote House, Carter Clack developed a special solution to add insulation to the building. Discussed later in this section, the solution made achieving EnerPHit possible, but at the same time created complexities with carrying out the project.

Nonetheless, the outcomes of the structural assessment resolved another significant issue: it revealed that it was possible to carry out the proposed refurbishment works while residents resided in the property. This was critical to the financial feasibility of the project; if it were necessary to decant the building, the gap between the costs of the retrofit options and the demolition and rebuilding option would be significantly smaller. In addition, the residents would lose their community. Therefore, the retrofit options would become less justifiable. This was the case with [REDACTED] and [REDACTED], the two tower blocks that [REDACTED] considered refurbishing according to EnerPHit. The extensive structural problems detected through the investigations showed that the blocks could not be refurbished while the residents occupied them, and thus, the client decided not to refurbish these buildings. Therefore, the building structure was a determining factor in the viability of the project, making the structural assessment a crucial developmental stage. Consequently, this section focuses on the process of the assessment to reveal: What is the method of assessing the building structure? Which structural features are being evaluated? What are the conditions that necessitate decanting a building prior to a building refurbishment? To find answers to these questions the general structural requirements of high-rise buildings are examined, and the structural evaluations of both Wilmcote House and [REDACTED] and [REDACTED] are analysed. It should be mentioned that the main purpose of this section is to provide an insight into the general process and the evaluation methods; however, the details of the assessment process are outside the scope of this research.

The main requirements of building structures can be found in building regulations document A. These requirements refer to: Loading, Ground Movement, and Disproportionate Collapse (Ministry of Housing, Communities & Local Government, 2013). The summary of each requirement definition can be found in the box below.

Box 4.1: Structural requirements of buildings (Ministry of Housing, Communities & Local Government, 2013)

1. Loading:

The building should be constructed so that combined loads (dead, imposed and wind loads) are sustained and transmitted by it to the ground safely and without impairing the stability of the building.

2. Ground movement:

The building should be constructed so that ground movement caused by different reasons such as swelling, shrinkage, etc. will not impair the stability of any part of the buildings.

3. Disproportionate collapse:

The building should be constructed so that in case of an accident the building will not be subjected to a collapse to an extent disproportionate to the cause.

When assessing the structure of a building, including a tower block, it should be tested against these three criteria. The third requirement of avoiding disproportionate collapse holds specific importance to tower blocks. It was included in the UK building regulations following the 1968 disproportionate collapse of Ronan Point (British Constructional Steel Work Association, 2016). Following the partial collapse of Ronan Point, the building suffered a gas explosion and the destruction of a load-bearing wall (Concrete Construction, 1969). This accident discerned the significance of assessing the structural resistance of buildings against disproportionate collapse caused by accidental loads, such as in the case of an explosion.

Similar to Wilmcote House, Ronan Point had been built using the Large Panel System (LPS)[16]; however, the post-disaster analysis of Ronan Point had found the structure of the building to be poor and insufficient to withstand even a small explosion. The inappropriate joints between floors and walls were found to be the exact reason behind the accident. In fact, the structure did not maintain a continuous link providing mutual interaction of the components under overload (Concrete Construction, 1969). Other tower blocks built by the same technique prior to 1968 were therefore exposed to similar risks. As discussed in the literature review, the lower costs and faster construction period that resulted from the use of the Large Panel System initially made it popular in post-war UK, however, it was soon discovered that the application of this method throughout the country had been in many ways defective, leading to a risk of disproportionate collapse (Matthews & Reeves, 2012). To prevent the disproportionate collapse of buildings, UK building regulations have identified certain robustness levels for various consequence classes of buildings. The requirements involving residential tower blocks are explored in Box 4.2.

[16] A description of the Large Panel System can be found in introduction chapter, under the background section.

Box 4.2: Disproportionate collapse regulations for tower blocks

The consequence class categories of buildings included in building regulations Part A is defined based on different criteria, such as the height of the building and its population. Blocks of flats with between four and fifteen storeys belong to consequence class 2b, and residential blocks with higher than fifteen storeys belong to consequence class 3. For consequence class 2b buildings, loading and ground movement requirements mentioned in Box 4.1 should be met; furthermore, effective ties both horizontal and vertical should be provided. For consequence class 3 buildings it is necessary to undertake a systematic risk assessment taking into consideration all the normal and abnormal hazards. Alternatively, it can be checked if a building remains stable upon the notional removal of each supporting element including columns, beams, or a length of load-bearing wall. The removal of these elements at each floor should not result in a collapse of more than 15% of the area of the floor or 100 square metres; additionally, the collapse should not extend to more than the immediate adjacent floors. If the notional removal of supporting elements lead to a collapse with a higher extent, these elements have to be designed as key elements. A key element must be powerful enough to sustain an accidental load of $34KN/m^2$ from either vertical or horizontal directions. It should be assumed that the accidental loads act consecutively with other loadings such as wind. (Ministry of Housing, Communities & Local Government, 2013)

According to Stuart Matthews and Barry Reeves at BRE (2012), explosions in LPS buildings involving a piped-gas supply can be considerably more destructive than explosions in those without. It was discovered that overpressure of $17\ KN/m^2$ is a reasonable evaluation criterion for the cases where an internal gas explosion occurs without the involvement of a piped-gas supply. However, if there is a piped-gas supply in any part of the block, or in case the building has a poorly-ventilated zone - such as a basement where there is a possibility of gas accumulation from an external source - overpressure of $34KN/m^2$ should be considered as the assessment criterion.

Thus, it is concluded from the structural requirements of tower blocks that the following factors should be examined to assess their structural stability:

- The general stability of a structure based on loading and ground movement requirements;
- The quality of building materials and joints;
- The quality of construction works;
- The adequacy of vertical and horizontal ties between supporting elements;
- The possible hazards, such as internal explosions which the building may become exposed to, explored according to a risk assessment of building;
- Identification of key elements and their capability to sustain an accidental load of $34KN/m^2$ for blocks with gas pipes and loading of $17KN/m^2$ for blocks without gas pipes.

The review of ECD Architects' feasibility report for the Wilmcote House and the [REDACTED] and [REDACTED] refurbishment projects showed that the structural engineers used a specific process to analyse the factors above, assessing the structural stability of the buildings. According to this document, they initially reviewed all the data available from previous structural surveys and then inspected the building directly to check the quality of exposed elements (desk study and visual inspection). Following the initial investigation, "future life and likely works" were evaluated by the architects and energy specialists to assess the effects of any improvement plans in terms of appearance and thermal efficiency on the building structure (ECD Architects and Keegans, 2015). At this point, the architects developed their design concepts. As previously explained, their first EnerPHit option proposal was to wrap the building with insulation. Architect A (2015) explained that the investigations had revealed that: "the building was very poor in terms of fabric"; thus, covering the fabric with insulation would maximise energy efficiency. However, as can be seen from the following image, the building had either open walkways or balconies on each floor.

Figure 4.1. Courtyard facade of Wilmcote House.
Photo by James Traynor (2013)

It was necessary to enclose the balconies and walkways to insulate the fabric externally and to minimise thermal bridges. With open walkways and balconies, the building would be more exposed to the external environment; therefore, the amount of heat loss would be higher than in a compact building with a lower surface area. Furthermore, according to ECD Architects' feasibility report, the surface of the access walkways differed in level and there were drainage issues; thus, it was not practical to install external insulation on these surfaces. The alternative was to insulate the ceiling of the living areas below. However, this would result in thermal bridges at the slabs, with the precast structure remaining exposed, and as a result, the expected heating demand related to this scheme would be higher. Enclosure of walkways and balconies was one of the issues that the structural engineers had to investigate carefully. It was necessary to clarify: Would the building structure remain stable if the balconies and walkways were enclosed? And if not, were there any feasible solutions to stabilise it? To answer this, the investigation needed to be broadened beyond basic inspections and observations to reach a deeper level.

After completing their initial investigations, the structural engineers identified possible vulnerable areas demanding further inspection and analysis, such as the ties between panels. At this stage, "field works" began and the structural engineers carried out their own survey conducting a more in-depth investigation, such as opening up some sections of the structure to check the condition and details of different elements, and update previous surveys and available data. Based on this survey, a deeper analysis was performed, including a risk assessment and "appraisal" based on BRE structural assessment methodology[17] for existing multi-storey LPS residential blocks. Testing the capability of key elements to resist disproportionate collapse is a part of this stage. Finally, a "report" was prepared to explain the crucial issues that needed to be resolved to carry out the proposed works, and any associated costs. This report was discussed and "developed" with the client to achieve the most appropriate method for undertaking structural works (ECD Architects and Keegans, 2015). The outcomes of this process indicated the extent of works required to achieve the project targets and whether it was possible to keep the building occupied throughout the works. The structural assessment of the Wilmcote House and [REDACTED] and [REDACTED] tower blocks had different results. This was one of the reasons why [REDACTED] decided not to use deep retrofit solutions for [REDACTED].

4.3.1 Wilmcote House structural assessment

This section explains the most important findings regarding the structure of Wilmcote House to clarify why it was not necessary to decant the building during the refurbishment process. Additionally, the findings reveal structural challenges in terms of meeting EnerPHit requirements. A summary of Wilmcote House's structural condition and the initial investigations carried out by Carter Clack are explored in Box 4.3.

[17] In the UK, BRE produced a handbook for use by structural engineers, providing a structural assessment methodology for existing multi-storey LPS residential blocks. This handbook is the outcome of case studies and structural tests on some LPS buildings with the support of a number of local authorities, and structural engineers including Carter Clack who were involved in both the Wilmcote House and [REDACTED] and [REDACTED] refurbishment projects. Technical information about the structural assessment and recommendations to improve the structure are explained in this handbook, which could be of use as a reference to assess and develop solutions for LPS tower blocks in the UK (Matthews & Reeves, 2012).

Box 4.3: Structural analysis of Wilmcote house

Wilmcote House comprises three interlinked residential blocks, each eleven storeys high. The blocks were built as a concrete prefabricated structure by Reema Ltd in the late 1960s, with only the ground floor slab built in-situ with beams supported by piled foundations. All the three blocks contain maisonettes on upper floors, and alternate floors have a deck access open walkway at the rear. The upper level of each maisonette extends over the walkway on the lower floor. The links between the blocks adjacent to the gable walls contain the staircase and lift shafts. The main load bearing element of the buildings are the cross walls (ECD Architects, 2012).

At the initial stages, the drawings and information were provided to Carter Clack by Portsmouth City Council, including the previous surveys, investigations, tests and recommendations for remedial action. The actions previously recommended were mostly about repair of concrete, dry pack, walkway panels, and re-fixing the angles to the gable end walls installed in 1975 to strengthen the joints of these poorly built, load bearing walls. In terms of disproportionate collapse, it was advised that some key elements could only resist overpressure of 17 KN/m^2. (Carter Clack Consulting Engineers, 2012)

After reviewing the available data, Carter Clack started their own exploration, with the council providing four empty maisonettes in Wilmcote House to be used for the undertaking of these works. Detailed cutting and exploratory works were carried out in four days using the investigation company Martech. In order to determine its strength, cores were taken from the concrete and smashed in the laboratory, and some reinforcement was also cut from the structure to be similarly checked. Additionally, the quality of the wall panels, the floor construction, and the joints between the elements were investigated. The disproportionate collapse test was performed by simultaneously applying a load of 17 KN/m2 to the ceiling, floor, and walls. (Carter Clack Consulting Engineers, 2012)

Following these tests Carter Clack provided the results of their investigations and their recommended remedial actions. These recommendations address the general structural issues of the building and also the specific design solutions proposed by the architects such as enclosing the walkways which are explained in this chapter.

The structural report by Carter Clack showed some structural weaknesses mainly relating to the external layer of the building. There were problems with the quality of materials, and joints and ties between the elements. For instance, some of the outer wall panels were built from unreinforced concrete. This could result in the fracturing of this layer if the external insulation proposed by the architects were applied via conventional methods, such as using adhesives or mechanical ties. Thus, it was recommended that to complete the insulation an external steel grillage of channel sections be installed to the structure at each floor. With regards to the risk of disproportionate collapse, the testing of different elements indicated that the joints between some elements might cause local collapse; however, overall the blocks just complied with the requirements for limiting disproportionate collapse. When enclosing the balconies and extending the living rooms, the additional loading would need to be supported by the foundations; otherwise, the extra load would be added to the outer face of the structure, which was too weak to carry this load. Therefore, Carter Clack recommended the use of a steel framework which would be carried to the ground floor and the columns supported by the existing piled foundations. The frame would be bolted to the existing concrete walkway structure, facilitating the insertion of a new composite steel[18]. In order to infill between the elements, a grillage of channel sections could be utilised (Carter Clack Consulting Engineers, 2012). The following image shows the steel grillage installed on the courtyard façade.

Figure 4.2. Steel framework and grillage on the rear façade of Wilmcote House (ECD Architects, 2016).

[18] The steel beams are connected to concrete slab so they act as a single unit (composite action). The advantage is that concrete is strong in compression, while steel is strong in tension (Adluri, 2011).

It is concluded from the review of investigation outcomes that the structure of the building was in a relatively acceptable situation, with no serious obstacle or lack of feasible solutions for achieving EnerPHit. The major complication regarded enclosing the walkways and its consequences. As pointed out before, enclosing the walkways and creating a seamless façade were essential to preventing thermal bridges and minimising heat losses, two of the main requirements of EnerPHit. The nature of the recommended remedial works completely related to the external layer of the building, making it possible to carry out the works while the residents occupied the building. [REDACTED] was hoping that the structural assessment of [REDACTED] would have comparable results in terms of any flaws being restricted to the building exteriors. During an interview with architect A (2016), he explained that the client and the architects expected that the Wilmcote House refurbishment would be more challenging than the refurbishment of other tower blocks because of its more complicated form and layout, particularly the uneven courtyard façade with open walkways and balconies. On the contrary, they believed that the refurbishment of the [REDACTED] and [REDACTED] blocks would be much simpler due to their simple box shape. Nevertheless, the structural assessment of [REDACTED] and [REDACTED] showed more serious structural flaws which would necessitate decanting the blocks prior to refurbishment, increasing the estimated costs significantly. Consequently, [REDACTED] decided not to refurbish the buildings, but instead to carry out essential repairs. But, why did these apparently simpler blocks require more extensive structural improvements? To answer this question, the next section examines the structural assessment of [REDACTED] and [REDACTED].

4.3.2 [REDACTED] and [REDACTED] structural assessment

[REDACTED] and [REDACTED] are two 18-storey tower blocks in the [REDACTED] built in 1966 using the Bison precast concrete panel method. Each building has 136 flats containing a 50:50 mix of two-bedroom and one-bedroom units (ECD Architects and Keegans, 2015). As can be seen from the following image, the blocks have a simple box form.

[REDACTED]

Figure 4.3. [REDACTED] (commons.wikimedia.org, 2010).

During the construction stage at Wilmcote House, [REDACTED] commissioned ECD Architects to produce an EnerPHit refurbishment proposal for [REDACTED] and [REDACTED], comparing its feasibility to other options including demolition and rebuilding, refurbishment according to building regulations, and maintenance and repair. [REDACTED]. In the feasibility studies of [REDACTED] and [REDACTED], ECD applied the same process as in the Wilmcote House project. This meant that one of the initial stages of the study was the structural investigation. As explained in the feasibility report, ECD Architects were considering two distinctive design options to achieve EnerPHit in [REDACTED] and [REDACTED]. The first option was to install insulation using traditional systems such as mechanical ties, while the second option was to use a prefabricated panellised overcladding scheme adding a lightweight cladding panel finish to the buildings. The main reason for proposing the use of a prefabricated system was to achieve a faster installation process, limiting disruption to the residents, and working within a smaller site compound (ECD Architects, 2016). The investigation team had previously worked on the Wilmcote House project, resulting in similar structural assessment methods being deployed in both cases. Information as to the specifics of these methods can be found earlier in this chapter.

Contrary to the initial expectations of the client and the architects, the structural report by Carter Clack showed that the existing [REDACTED] and [REDACTED] structures were in an exceptionally poor condition, even compared to other Large Panel System buildings constructed during the same time period. This was believed to be the result of inferior quality control and mediocre workmanship (ECD Architects, 2016). Unlike Wilmcote House, the structural problems of [REDACTED] and [REDACTED] were both external and internal. According to the report, there were serious issues with the quality of concrete, reinforcement, and joints on the external layer of the buildings. The external panels had minimal reinforcement and were inadequately re-bolted to the internal layer.

Figure 4.4. Close up of cracked brickwork and spalling joint filler (ECD Architects, 2015).

Similarly, these panels exhibited signs of corrosion to the reinforcement, compounded by variable chloride levels with some high values detected that potentially could result in the rapid corrosion of the reinforcement[19] (Wilde Carter Clack Limited, 2015). Furthermore, the report revealed significant internal problems; for example, there were elevated levels of chloride in some locations, and the reinforcement of the internal layer of the outer walls was corroded. Carter Clack suggested that extensive external and internal improvements[20] would be required; otherwise, the blocks would be at the risk of disproportionate collapse. Due to the extent of the internal works, it would be necessary to decant the blocks. The following images show some of the problems related to the external envelope of [REDACTED] and [REDACTED].

Figure 4.5. Spalling at base of panel in [REDACTED] (ECD Architects, 2015).

[19]The level of chloride in the concrete and the depth of carbonation are critical in old concrete buildings. These and the environmental factors affect the rate of corrosion of the reinforcement. When it starts to corrode, the reinforcement expands and splits off the concrete cover. Further corrosion leads to a reduction in bar size. (Wilde Carter Clack Limited, 2015)

[20] The external and internal defects identified by Carter Clack's structural report (2015) suggested that it was necessary to stabilise upper floor walls, undertake remedial work to dry pack, re-bolt the external layer of main elevations, carry out concrete repairs, provide protection against corrosion by using systems such as sacrificial anodes, and design appropriate cladding or overcladding.

The structural report highlighted another critical issue: it would be quite challenging to apply external insulation to the building regardless of whether using the overcladding or cladding option. Based on the report, if insulation were added to the external layer of the building using a traditional method, there was a risk of continued corrosion to the reinforcement of the concrete panels behind the overcladding, resulting in serious damage to both the reinforcement and the panels. Additionally, it would be necessary to remove the overcladding to do the corrosion test in the future. Another option suggested was the removal of the external leaf and the addition of new cladding, which could be a more appropriate solution in terms of efficiency because removing the external leaf eliminated the risk of corrosion due to the high levels of chloride in this layer. Overall, taking out the external layer would facilitate the remedial works to the structure. However, this option would be costlier, with the removal of the panels involving a higher level of risk (Wilde Carter Clack Limited, 2015).

According to the report by the quantity surveyors Keegans, the cost of achieving EnerPHit in each of the blocks following the decanting of the building would be around £25m (Keegans, 2016). This meant that the average cost for each flat would be around £184,000, higher than the average selling price of a flat with the same number of rooms in [REDACTED] [21]. By comparison, in the Wilmcote House project, the average price for a three-bedroom flat refurbishment based on EnerPHit was around £117,000. Thus, an EnerPHit-based refurbishment of [REDACTED] and [REDACTED] would be significantly costlier than the Wilmcote House refurbishment. Following these assessments, [REDACTED] decided not to refurbish [REDACTED] and [REDACTED].

4.4 Airtightness

The feasibility report prepared by ECD Architects showed that prior to the development of the Wilmcote House refurbishment design proposals another important investigation related to the airtightness of the building. The result of this investigation was particularly important for assessing the feasibility of the EnerPHit proposal, as this option had a significantly more stringent airtightness target compared to that contained in the building regulations proposal. In a European climate, the Passivhaus airtightness target is ≤ 0.6 air changes/ hr @ n50; while a slightly more relaxed target of ≤ 1.0 air changes/ hr @ n50 is required to meet EnerPHit (Passivhaus Trust, 2010). On the other hand, UK building regulations have no set airtightness

[21] See the Market Value section in chapter 3.

standard to be met through retrofit projects. There is a threshold of 10 $m^3/hr/m^2$ @ 50 Pa for newly built homes (Anon., 2013).

According to the Chartered Institution of Building Services Engineers (2000), at $5m^3/h/m^2$ the air permeability meets the "Good Practice" standard, while $3m^3/h/m^2$ is "Best Practice". It should be mentioned that the EnerPHit standard has a different method of measuring and expressing the airtightness level than UK building regulations and thus the targets mentioned above cannot be directly compared[22]. However, to have a better comparison between the units used by each method, it can be explained that a building with lower than 0.6 air changes/ hr @ n50 as required by Passivhaus is highly airtight and cannot rely on natural ventilation; whereas, for the buildings measured by the UK Building regulations method, an air permeability of lower than $3m^3/h/m^2$ would make providing acceptable air quality challenging if relying on natural

[22]The Passivhaus standard measures the Air Change Rate (ACH) @50Pa, or to put another way the number of times the volume of air within the building is changed in an hour. The Passivhaus methodology takes into account the volume of air required to be heated. Therefore, it excludes the internal walls and floors. The building regulations require airtightness to be measured as Air Permeability, in m^3 $/h/m^2$@50Pa (the q50 measurement), the air leakage per square metre of building envelope. The ATTMA (Air Tightness Testing and Measurement Association) TS1 standard defines the building envelope as everything within the air barrier line; this can be anywhere inside the building envelope (Encraft Limited, 2015).

ventilation alone. Thus, the airtightness required by UK building regulations is far below the EnerPHit requirement.

Carrying out an airtightness test on Wilmcote House revealed how far the existing airtightness of the building was from the EnerPHit target, necessitating solutions to achieve it. The sub-

Box 4.4: Airtightness Tests

The airtightness of a building can be defined as its resistance to air leakage through the skin of the building. The most common way to measure this resistance is via the 'blower door test'; placed in an airtight covering, a large fan or "blower" is installed in an exterior door opening to supply or extract air from the building (Straube, 2014). It should be noted that usually during the test all the exterior doors and windows are kept closed and intentional openings providing ventilation such as trickle vents and extract vents are sealed. This is because the result of this test should only relate to uncontrolled air leakage through unintentional openings, such as cracks in the fabric. Furthermore, all internal doors should be left open so that all internal spaces can be treated as one space. The fan is then turned on and its flow is increased until the building reaches a pressure of 50 Pa. At this point, the air flow of the fan and the pressure difference between the inside and outside of the building is recorded, with this data used to calculate the total airflow of the building. In order to calculate air permeability expressed as $m^3 .h^{-1}.m^{-2}$ @ 50 Pa as required by UK building regulations, the total airflow is divided by the envelope area; whereas, for Passivhaus the airflow is divided by the volume of the building exposed to the test to achieve an air change rate expressed in h^{-1} @ 50 Pa (The Air Tightness Testing & Measurement Association, 2010). The gross volume of the building (total volume of interior spaces) is not considered for this calculation; in fact, the volume occupied by intermediate floors, window reveals, suspended ceilings, partitions, and internal walls must be discounted. Additionally, according to the Passivhaus air tightness testing protocol, both of the positive and negative pressure measurements of the test should be repeated at ten pressure intervals. The final airtightness parameter of the building is determined via the average value calculated from the results of these ten tests (Encraft Limited, 2015).

consultants assigned by ECD Architects, Aldas, undertook airtightness tests on Wilmcote House. The feasibility report suggested that the tests should be carried out on a number of flats. Although the flats might exhibit different airtightness levels, it would be extremely time-consuming to test every single one. Therefore, a number of units were selected as samples, with each treated as an individual dwelling and separately tested. The common methods used to test the airtightness of a building and the requirements of Passivhaus airtightness testing are explained in Box 4.4.

In their report on the airtightness of Wilmcote House, Aldas explained that they planned to test three empty maisonettes to determine both their air permeability and air change rates. These tests were in accordance with the requirements of BS EN 13829 used to test air permeability as required by UK building regulations (Jennings, 2012). At this point, the airtightness test based on the German standard DIN 4108-7 specified by Passivhaus was not undertaken; however, it was still possible to measure air change rates through dividing the airflow by building volume, although this would not follow the Passivhaus testing protocol specified in Box 4.4. The reason for this was that at this stage, the purpose of the tests was not to check the Passivhaus compliance of the dwellings, but to assess the general airtightness level of the building. The air leakage tests were performed using blower doors (Retrotec 3000-series) mounted in the main entrance doors of the available maisonettes. During the tests, all external windows and doors were closed, internal doors were left open, vents were closed, and extractor fans were sealed (Jennings, 2012). The tests results are shown in the following table.

Table 4.1. Air Leakage Test Results of Sample Flats in Wilmcote House (Jennings, 2012).

Sample Flat	Air Change Rate	Air Permeability
Flat No. 65	3.38 ACH^{-1} @ 50 Pa	3.11 $m^3/hr/m^2$ @ 50 Pa
Flat No. 88	3.09 ACH^{-1} @ 50 Pa	2.85 $m^3/hr/m^2$ @ 50 Pa
Flat No. 96	2.81 ACH^{-1} @ 50 Pa	2.59 $m^3/hr/m^2$ @ 50 Pa

The test results show that all of the sample flats not only complied with the airtightness requirement of UK building regulations, but displayed high standards compared to existing buildings in the UK[23]. It was realised during the tests that some air leakage was related to window sections and balcony doors; therefore, in one of the sample maisonettes (No.65) an

[23] According to BRE research undertaken on dwellings in the UK of different types, sizes, ages, and constructions, the air permeability of the buildings varied between 2 and 29 $m^3/h/m^2$@ 50 Pa (Stephen, 1998).

extra test was undertaken following the temporary sealing of the balcony doors, the window head vents, and the window sections. The purpose of this test was to determine the effects of improving these openings on the overall airtightness of the unit. The additional sealing of the elements improved the test result for flat No.65 from 3.11 $m^3/hr/m^2$ @ 50 Pa to 2.57 $m^3/hr/m^2$ @ 50 (Jennings, 2012). This result indicated that it was possible to achieve the 'Best Practice' standard defined by CIBSE through window replacement. Likewise, air leakage levels below 2.57 $m^3/hr/m^2$ @ 50 would necessitate the use of extract ventilation (ECD Architects, 2012). The relatively low air leakage levels and air change rates of the sample flats showed that achieving the airtightness requirement of EnerPHit was feasible in Wilmcote House. According to ECD Architects' feasibility report, replacing the fenestration would not be sufficient to reduce air change rates to the EnerPHit level. Further improvements to fabric would be required, in particular on the rear façade with its open access walkways and balconies. To comply with the EnerPHit airtightness target, it was necessary to use proprietary membranes, grommets, and tapes, alongside enclosing the open walkways and balconies.

4.5 Consultation with Residents

Following their investigations of Wilmcote House, ECD Architects developed two different refurbishment schemes, leading to the client selecting the EnerPHit proposal. It is important to note that initially, the architects had only proposed an EnerPHit-based refurbishment; their consultation with the residents necessitated the development of the second proposal. As pointed out by architect A (2015), the client and the architects decided to consult the tenants about their improvement plans for the building because some of these plans would directly affect their lives. He explained that consultation with residents about the design solutions through surveys and consultation events was a step that they generally took in tower block refurbishment projects. Their purpose was to find the most practical and sustainable solutions, believing that the support of all stakeholder groups, including the residents, and their input into design ideas could ensure a longer life for the buildings, building greater resilience to possible changes that might occur in the area over time. ECD Architects argue that if local residents feel they own the design ideas, there is a greater chance that the project will find long-term success (ECD Architects and Keegans, 2015). According to the report by ECD Architects, Portsmouth City Council held a resident consultation event to receive their feedback on their initial retrofit proposal. As explained in the feasibility report, some of the most important aspects of this proposal included the enclosure of balconies and walkways; the extension of living rooms on the top floors of the maisonettes to create an even façade; the re-roofing of the building; and the replacement of the fenestration. Members of both the council and ECD Architects presented the proposal to the tenants present, representing nearly half of all of the flats. The attendees were asked to show their level of support for the presented strategies by filling in a questionnaire and writing their comments. A list of these strategies and the response of the residents are shown in the following table (ECD Architects, 2012).

Table 4.2. List of strategies presented to Wilmcote House residents and their responses (ECD Architects, 2012).

	Area of Improvement	Yes	No	Not Sure	Left Blank
1.	Improve the energy efficiency of the building and modernise the external appearance.	96%	0%	4%	0%
2.	Re-roof the building with insulation, external downpipes (removing internal gutters) and a long-lasting durable roof finish.	93%	0%	7%	0%
3.	For the street face of Wilmcote double-glazed windows, external insulation with a render finish and coloured feature fins.	98%	0%	2%	0%
4.	For the courtyard face of Wilmcote remove balconies, extend living rooms, enclose walkways with double-glazing and create new external facades.	69%	9%	22%	0%
5.	Enlarge internal property hallways and living rooms.	72%	9%	15%	4%
6.	Install an efficient heating system that may include new radiators fed from a communal boiler and solar thermal collectors.	94%	2%	2%	2%

Shown in the table above, the outcome of the resident consultation indicates that most of the objectives found support amongst the residents; however, some negative reviews were received about the proposal for the enclosure of balconies and walkways, and the enlargement of the living rooms. According to ECD Architects, the concerns over enclosing the balconies regarded losing the outside spaces used for drying clothes and smoking. Regarding the enclosure of the walkways, residents were worried about possible loss of daylight, a sense of claustrophobia, and losing the space for smoking (ECD Architects, 2012). Negative comments about these objectives are understandable considering their immediate impact on the daily activities of the residents. Additionally, these impacts were more perceptible to them; for instance, the effect of removing the balcony space would be more tangible to the residents than the impact of re-roofing the building with insulation.

During an interview, architect B (2015) explained that following the assessment of resident consultation and recognising the negative views on enclosing balconies and walkways, they decided to develop another refurbishment proposal with open walkways and balconies. However, this proposal did not meet EnerPHit due to the problems with external insulation and minimising thermal bridges discussed earlier in this chapter. Therefore, the second proposal aimed for UK building regulations. Nevertheless, as explained before, the Council chose the EnerPHit proposal. To address the residents' concerns, the architects decided to convert the enclosed balconies into sunspaces. Consequently, the balconies were enclosed but contained windows, so that when the residents entered the sunspaces they could open the windows to get fresh air, smoke, or dry their clothes. The balconies would be separated from the living rooms through glass doors. The following image shows the new courtyard façade proposed by ECD Architects.

Figure 4.6. The proposed rear façade of Wilmcote House (ECD Architects, 2012).

4.6 Conclusion

It can be concluded from this chapter that a project's architects can play a significant role in the selection of EnerPHit as a benchmark for a tower block refurbishment. Their choice to use EnerPHit will depend on their knowledge of the standard and their commitment to low-energy design. The Wilmcote House case study showed that they investigated the structural condition and the airtightness level to assess the viability of achieving EnerPHit. Comparing the Wilmcote House refurbishment project with the [REDACTED] and [REDACTED] refurbishment revealed that all three blocks suffered from serious structural problems creating challenges for reaching the EnerPHit level. Even though it was possible to develop solutions to overcome these challenges, in the case of [REDACTED] and [REDACTED], the solutions were too costly due to the inferior construction of the blocks. Furthermore, the internal structural issues of [REDACTED] and [REDACTED] meant that it was not possible to refurbish the blocks while the residents occupied the buildings, significantly increasing the refurbishment costs. Thus, the client found it financially unrealisable to refurbish these blocks. [REDACTED].

The structural inefficiencies of Wilmcote House meant that it was only possible to achieve EnerPHit if the building façade were modified, and unconventional insulation methods were utilised. The changes to the façade would affect the lives of residents following the completion of refurbishment works. The consultation with the residents revealed that although some of them had some concerns about certain aspects of the scheme, they were mostly supportive of the EnerPHit proposal. Overall, the nature of the structural and airtightness improvements combined with residents' opinions shaped the architects' eventual design proposal. The next chapter examines the details of the architects' refurbishment proposals and explains in what ways the EnerPHit strategy was different from the proposal based on building regulations.

Chapter 5: EnerPHit proposal vs. building regulations proposal (fabric and heating system)

5.1 Introduction

As explained in chapters 3 and 4, Portsmouth City Council ruled out the demolition and rebuild of Wilmcote House, instead deciding to refurbish the building. Following their consultation with ECD Architects, the Council were convinced to follow a deep retrofit approach. ECD Architects developed two retrofit options: Option 1 specified a 'good practice' retrofit, slightly exceeding the latest building regulations as of 2011 to anticipate the future 2013 updates, and option 2 specified an 'advanced practice' retrofit significantly surpassing the aforementioned building regulations to comply with the EnerPHit standard (ECD Architects, 2012). Ultimately, the client chose the EnerPHit option over the building regulations plan. The aim of this chapter is to explain the differences between the proposals and to clarify why the Council decided to adopt EnerPHit. The choice not only affected the fabric design but also had implications for the choice of heating system. It should be noted that these two elements are key factors for minimising heating/cooling demand, maximising airtightness, and reducing primary energy consumption, the main targets of Passivhaus standard. Thus, the first part of the chapter focuses on the fabric design details of each option, identifying their differences, and explaining the reasons behind these variances. The second part of the chapter investigates the heating system specified in each proposal, clarifying the factors that affected the selection of the heating system. The investigation reveals that the heating system was a critical component of the proposal, significantly affecting the client's decision.

5.2 Fabric design

As mentioned in the previous chapter, the fabric of Wilmcote House was poor, resulting in issues of air leakage, condensation, and mould growth. In interviews, architect A (2015) explained that in the flats the indoor temperature was very low in the cold months due to its inefficient building fabric. Thus, the tenants had to rely extensively on inefficient heaters to warm their homes. Consequently, the tenants either utilised the heaters and paid high bills, or were unable to afford their use and suffered from a cold indoor environment. Accordingly, ECD Architects decided that improving the fabric was the first priority (Architect A, 2015). It is understood from the proposals included in ECD Architects' feasibility report that fabric improvement was prioritised in both options.

Option 1, 'good practice', aimed to upgrade the fabric to the level required by UK building regulations. Evidently, this would reduce the heating level, but not significantly. To reduce the tenants' energy bills it would be necessary to change the existing electric heating system and switch to one using gas, the less expensive form of energy. Option 2, 'advanced practice', aimed to maximise the fabric energy efficiency according to EnerPHit targets. This was expected to minimise heating demand to a level where it would no longer be critical to switch to another fuel source. In terms of fabric design, both options would have involved replacing the roof and windows, and overcladding the façades. However, the fabric elements of the EnerPHit proposal required higher performance because EnerPHit takes a fabric-first approach requiring significantly higher airtightness, low U-values, and a thermal bridge-free envelope. Compliance with these requirements is vital to meeting the low heating and cooling demands of EnerPHit. Consequently, the EnerPHit proposal was specified with its higher level of insulation, extra parge coat[24], installation of Passivhaus windows, and enclosure of access walkways at the courtyard façade. Overall, it would be a greater challenge to upgrade the courtyard façade to the EnerPHit level than the street façade, as the latter was a typical even frontage with windows. The courtyard façade was considered to be a complex and unconventional tower block façade with open walkways, balconies, and an uneven surface, complicating the improvement of its performance according to EnerPHit criteria. The following images show the plan of Wilmcote House and the street and courtyard façades.

[24] Parge coat can be used in a Passivhaus/EnerPHit project to create an airtight layer which is necessary to comply with the airtightness requirements.

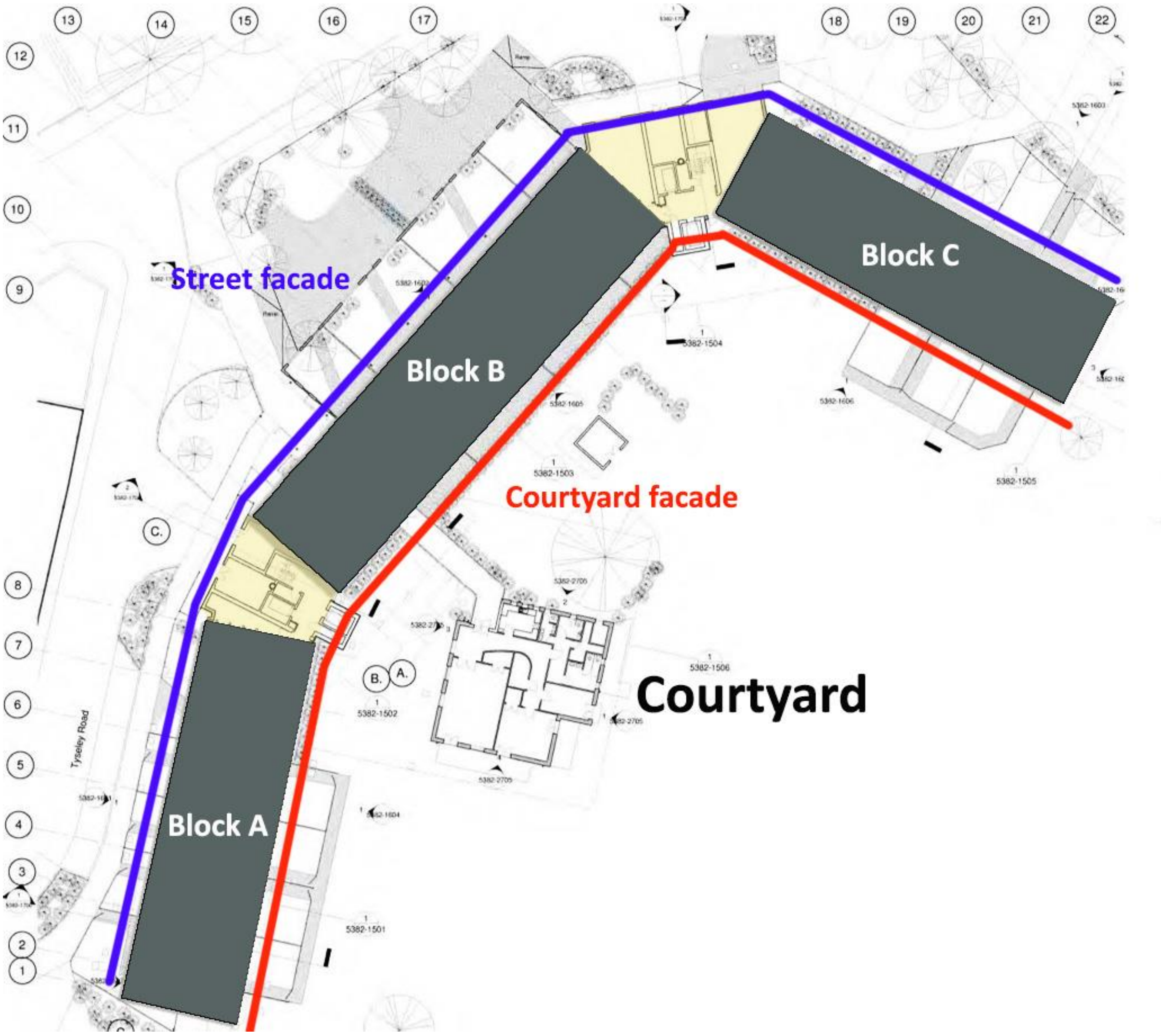

Figure 5.3. The plan of Wilmcote House (ECD Architects, 2012).

Figure 5.2. The photos on the left and the right show the street façade and the courtyard façade, respectively (ECD Architects, 2013).

Reviewing ECD Architects' feasibility report reveals that both options proposed converting the existing balconies into sunspaces to keep the continuity of the insulation layer. It was proposed that the balconies should be enclosed by adding a new skin, and bi-fold windows would be placed in the new walls so that they could be temporarily opened for drying clothes or any other purposes. The sunspaces would be separated from the living rooms with new double-glazed partitions with patio doors (ECD Architects, 2012). However, the building regulations option kept the access walkways open and followed the maisonette lines, insulating the walkway façade, the underside of walkways, and the underside of the extended living rooms (ECD Architects, 2012). As discussed in the previous chapter, there were two main reasons why it was essential to enclose the balconies and walkways in order to comply with EnerPHit: the airtightness tests revealed that without enclosing these spaces the stringent airtightness requirement of EnerPHit would not be met; furthermore, it was not feasible to install external insulation on the surface of walkways; therefore, thermal bridges could not be prevented. The enclosure of open spaces would alter the courtyard façade considerably. As seen from the images taken from the building, the existing courtyard façade was uneven because on the lower floors the width of access walkways extending out from the frontage was larger than the extension of the balconies and the living rooms on the upper floors. ECD Architects aimed to enclose the open spaces and to create an even façade; thus, the living rooms and balconies (which would later become sunspaces) had to be extended to reach the same width as the walkways beneath. The schematic 3D models show the alteration of the courtyard façade.

Figure 5.3. The uneven courtyard façade of Wilmcote House (ECD Architects, 2013).

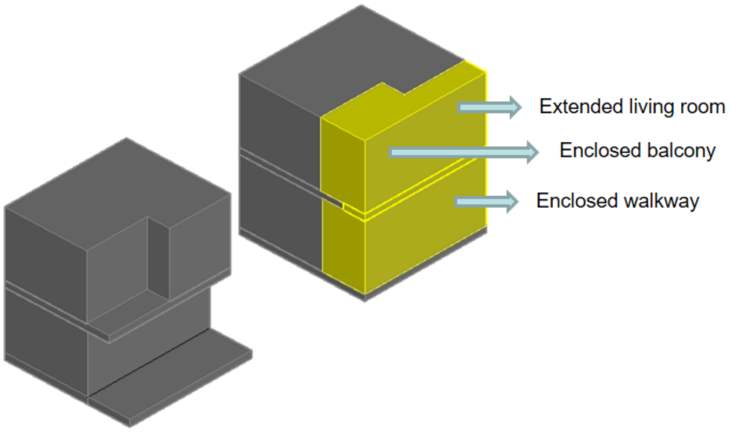

Figure 5.4. The proposed changes to the courtyard façade (EnerPHit option).

5.2.1 External wall overcladding

Details of the overcladding system proposed in the building regulations and EnerPHit options are included in Box 5.1 and 5.2. Due to the differences between the street and courtyard façades, the former being a typically simple façade with windows and the latter being a more complicated façade with walkways and balconies, ECD Architects proposed two different overcladding systems.

Box 5.1: Overcladding system design for street façade (ECD Architects, 2012):

Option 1 (good practice):

- Silcoplast silicone render, including top coat, base coat, and reinforcement mesh, on;
- 30mm dual density Rockwool Rockshield insulation, mechanically and adhesively fixed to;
- 8mm fibre-cement particle sheathing board, mounted on;
- 100M20 lightweight steel grillage, incorporating 100mm Rockwool Flexi insulation between channels, and finally;
- 40mm Rockwool Flexi insulation to fill the void between the steel and the existing wall.

Option 2 (advanced practice):

- Silcoplast silicone render, including top coat, base coat, and reinforcement mesh, on;
- 100mm dual density Rockwool Rockshield insulation, mechanically and adhesively fixed to;
- 8mm fibre-cement particle sheathing board, mounted on;
- 100M20 lightweight steel grillage, incorporating 100mm Rockwool Flexi insulation between channels, and finally;
- 40mm Rockwool Flexi insulation to fill the void between steels and the existing wall, and;
- Nominal 10mm parge coat to the existing surface to provide a continuous air barrier.

Box 5.2: Courtyard façade design (ECD Architects, 2012):

Option 1 (good practice):

- Rockpanel Woods cladding board, on;
- 50mm battens, on;
- 50mm dual density Rockwool Duoslab insulation between 50mm timber studs, mechanically and adhesively fixed to;
- 8mm fibre-cement particle sheathing board, mounted on;
- 100M20 lightweight steel grillage, incorporating 100mm Rockwool Flexi insulation between channels, lined with;
- Taped 18mm OSB3 sheathing, 50mm timber battens, with 50mm Rockwool Flexi insulation in between, and;
- 12.5mm plasterboard and skim finish.

Option 2 (advanced practice):

The specifications for option 2 are exactly the same with only one difference: 100mm Rockwool Flexi insulation placed in between 100mm timber battens, which is twice the amount proposed in option 1.

It is understood from the external wall overcladding build-up on the street façade (included in Box 5.1) that the main components of this system for both the building regulations and EnerPHit options were the insulation layers, the steel grillage, and the finishes. The two options had two specific differences. The first related to the extra parge coat layer included in the EnerPHit option. The purpose of proposing this layer was to meet the airtightness requirements specified by the EnerPHit standard. The second related to the level of insulation; the thickness of Rockshield insulation recommended by the EnerPHit option was more than three times the thickness required in the building regulations proposal. This relates to the different U-value requirements of the two benchmarks. As can be seen in tables 5.1 and 5.2, the target U-values of all the different building elements for EnerPHit are higher than those for building regulations.

Table 5.1. U-value targets of the EnerPHit standard (Passive House Institute, 2015).

Standard	Building Elements	Target U-values (W/m^2.K)
EnerPHit	Roof, Wall, Floor	≤ 0.15
	Windows and Doors	≤ 0.8

Table 5.2. U-value targets of UK building regulations 2013 (Department for Communities and Local Government, 2016).

Standard	Building Elements	Target U-values (W/m^2.K)
UK Building Regulations 2013 (Existing Buildings Part L1 B)	Roof	0.18
	Wall	0.30
	Floor	0.25
	Window	1.6
	Door	1.8

Therefore, to achieve EnerPHit the same insulation material at a higher thickness was specified. The building regulations option with 178mm of insulation was expected to achieve an overall external wall U-value of 0.18 W/m^2.K; whereas, the EnerPHit option proposed an overall insulation of 248mm and an expected U-value of 0.15 W/m^2.K. Figure 5.5 indicates the difference in the levels of insulation applied to the external walls in both proposals. It should be noted that there was another difference relating to the minimisation of thermal bridges, one of the main requirements of EnerPHit. The EnerPHit proposal specified thermal break pads to be applied to the building to avoid thermal bridges (ECD Architects, 2012).

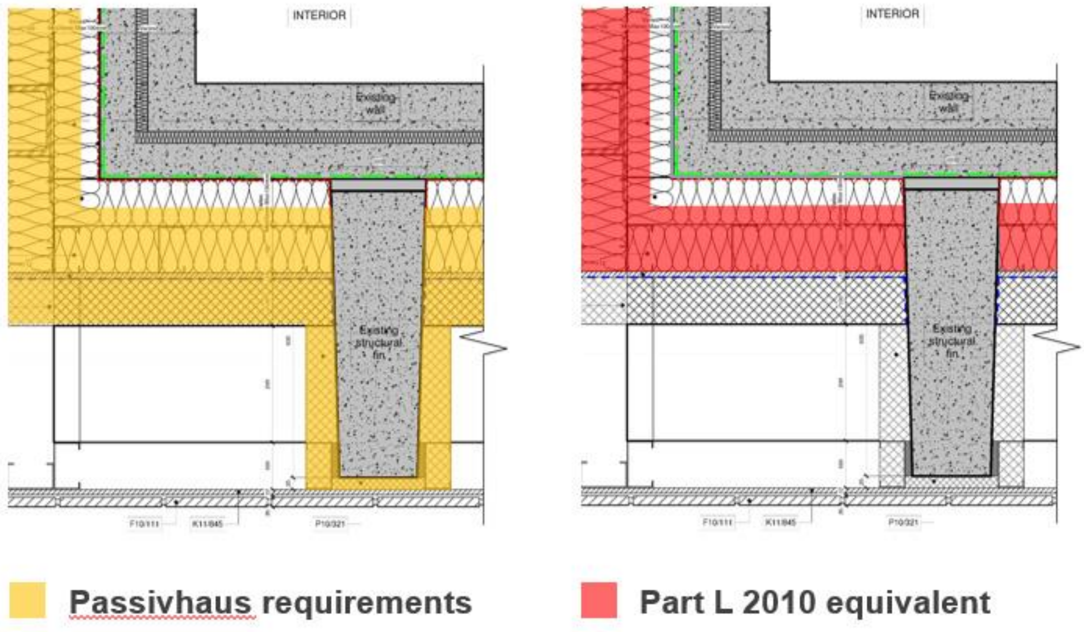

Figure 5.5. Comparison between the insulation options for the external wall (ECD Architects, 2015).

The overcladding build-up devised by ECD was based on Rockwool insulation materials and systems. Research into their project history demonstrated that ECD had specified Rockwool insulation systems in their previous tower block refurbishment project, the Edward Woods Estate tower blocks. As discussed in chapter 3, this project had similarities with the Wilmcote House refurbishment project, with ECD Architects taking a fabric-first approach on both occasions. Thus, the Edward Woods project involved a fabric upgrade as well. Rockwool provided the blocks with insulation systems suitable for high-rise refurbishment. Following the completion of the project, Rockwool worked in partnership with the London School of Economics (LSE) to carry out research on the project outcomes, for the purpose of providing learning opportunities for social landlords considering undertaking large scale, energy-efficient refurbishment schemes (Snaith, 2016).

Due to Rockwool's involvement in high-rise refurbishments and their previous partnership with ECD Architects, one of the main alternatives investigated for the Wilmcote House refurbishment was Rockwool's insulation solutions. Subsequently, ECD developed its fabric upgrade designs based on Rockwool systems. As seen from Box 6, Rockwool Rockshield was specified in both proposals, while Rockwool Duoslab would be specifically utilised for the courtyard façade in the EnerPHit scheme because of its suitability for application behind a rain screen cladding system (Rockwool, 2009). The questions then arise: Why were these insulation systems specified? What were the most important selection criteria? According to Rockwool, Rockshield and Duoslab systems both have high resistance to fire (Rockwool, 2016); a crucial factor when it comes to overcladding tall buildings. Generally, it is believed that providing fire safety for tall buildings is more challenging than compared to low-rise buildings. One reason is that more time is required to escape from the upper floors of a tall building, considering that usually the lifts and escalators cannot be used in the event of a fire. The source of fire may be either internal, spreading to other floors through its openings, or it can be external, entering the building through the cladding. Either way, cladding can greatly affect the spread of fire in a tall building (Rockwool, 2016). In the UK, there have been a number of fires which spread through tower block cladding systems after refurbishment. The most recent and well-known example is the Grenfell tower fire in June 2017. The research revealed that the building cladding did not have an acceptable fire safety rating (Jessel, 2018). Following the recognition of the role of external cladding in spreading the fire, guidance documents and test procedures were developed to evaluate the fire performance of external walls of tall buildings (Holland, et al., 2016). These documents and tests are explained in Box 5.3.

Box 5.3: Fire safety tests and guidance documents for tall buildings (Rockwool, 2016):

In 1988, the BR 135 document was published following an increased use of thermal insulation in the refurbishment of multi-story residential tower blocks. This document addressed the fire performance of thermal insulation used for external walls of multi-story buildings. Initially, a full-scale fire test was unavailable, and so the recommendations included in the document relied on a single-faced large-scale test. However, several serious fire incidents occurred during the review of BR 135 resulting in a reconsideration of the test methodology. Along with the development of new design solutions, it was concluded that a full-scale test was required to understand the fire performance of the whole system. Consequently, the new test method was developed and published in 1999.

The second edition of BR 135 was published in 2003 following the review of the 1999 test method. In addition to this document, a full-scale test from BRE Fire Note 9 was produced, titled "BS 8414-1: Fire Performance Of External Cladding Systems – Part 1 Test Method for Non-Loadbearing External Cladding Systems Applied to the Face of the Building". Part 1 can be applied to systems fixed to a solid substrate such as masonry.

Therefore, the Part 2 system was also developed for systems fixed to a structural system framework, as these two systems react differently to fire and so require particular methods to test them. This test was produced in 2013.

The UK building regulations also require the use of a cladding system which does not spread fire. The investigation of different fire events in tall buildings showed that the external cladding can spread the fire through the cladding materials or via the cavities, the Approved Document B of the building regulations for England and Wales required that: "The external envelope of the building should not provide a medium for fire spread if it is likely to be a risk to health or safety. The use of combustible materials in the cladding system and extensive cavities may present such a risk in tall buildings". However, a number of construction projects that had been completed at the time did not comply with BR 135 or the Approved Document B. Thus, a technical guidance was published by the Building Control Alliance (BCA) outlining the process for buildings over 18m in height. The guidance includes options for complying with BR 135 and Approved Document B. The first option is about using materials with low combustibility for all cladding elements including insulation and the internal and external layers. According to the second option, the client should provide evidence that the whole cladding system they propose to use has been assessed based on the fire tests in BS 8414 Part 1 or 2. If the actual fire data is not available option 3 must be complied, requiring a desktop study report prepared by a qualified fire specialist. In case none of these options are suitable, a "holistic fire-engineered approach" must be taken.

The utilisation of Rockshield, a type of stone wool insulation[25], would comply with the fire safety requirements specified under the "British and European standard for the fire classification of construction materials" (BS EN 13501-1: 2007), as the stone wool insulation can achieve a rating of A1 or "non-combustible" (Rockwool, 2016). Similarly, Rockwool Duoslab was classified as non-combustible (Rockwool, 2009). Aside from fire safety, Rockshield and Rockwool were selected for their expected high thermal performance protecting the fabric against the wind, water penetration, and condensation (ECD Architects, 2012). Table 5.3 shows the U-values for different levels of insulation thickness. It is clear from

[25] "Stone wool is manufactured from basalt rock, a volcanic rock. Stone wool insulation consists of layers of bonded, water-repellent-treated multidirectional stone-wool fibres formed into a resilient batt using a resin binder" (Rockwool, 2016).

the table that if Rockshield was the only insulation product used for the overcladding, a thickness of 10cm would be required to meet the UK building regulation U-value target of 0.30 (W/m^2.K), while at least twice this thickness was required to achieve EnerPHit.

Table 5.3. U values for Rockshield construction (Rockwool Ltd., 2013).

Insulation thickness (mm)	U value (W/m^2.K) Rockwool Dual Density
50	0.51
90	0.33
100	0.30
140	0.22
180	0.18
200	0.16

Steel grillage was another key component specified in both options. As explained in chapter 4, the existing structure of Wilmcote House was insufficiently strong to carry the external insulation to be installed to the building. Therefore, based on the recommendation of the structural engineers Carter Clack, ECD Architects proposed an external steel grillage of channel sections. The steel grillage would be installed to the structure on all floors, and as the following image suggests, insulation (Rockwool Flexi insulation) would be incorporated between the grillage channels.

Figure 5.6. Insulation between the grillage channels. (Photo by author, 2016)

The finishing system was the final, most external layer of the overcladding system specified for the street façade. As explained by ECD Architects, the external skin of the building could be finished with either render systems or rain screen systems. Rain screen systems are comprised of panels on a carrier system. They may result in a lower thermal performance of the insulation (ECD Architects, 2012) and can be more expensive than render systems (Searle, 2014). Render systems are generally made using mesh, base coats, and a coloured top coat. With regard to the Wilmcote House street façade, the target was to specify a suitable and low-cost finishing. ECD Architects found the render finished insulation to be the most cost-effective finish system. According to ECD Architects (2012), when applied to the insulation the silcoplast silicone render system would allow the vapour to move from the structure to the outside air; additionally, it would improve the shedding of water and remove dirt from the façade due to its silicone and marble content. However, one of the factors under consideration for the courtyard façade was the aesthetic upgrade of the fabric. Architect A (2015) pointed out that one of their targets was to improve the appearance of Wilmcote House by adding modern features to its façade. Thus, they specified Rockpanel Wood board which is available in a range of different colours, complementing its non-combustible classification (Rockwool, n.d.). The colourful boards would add variety to the façade and modernize its appearance (ECD Architects, 2012). The following image illustrates the courtyard façade proposed by ECD Architects.

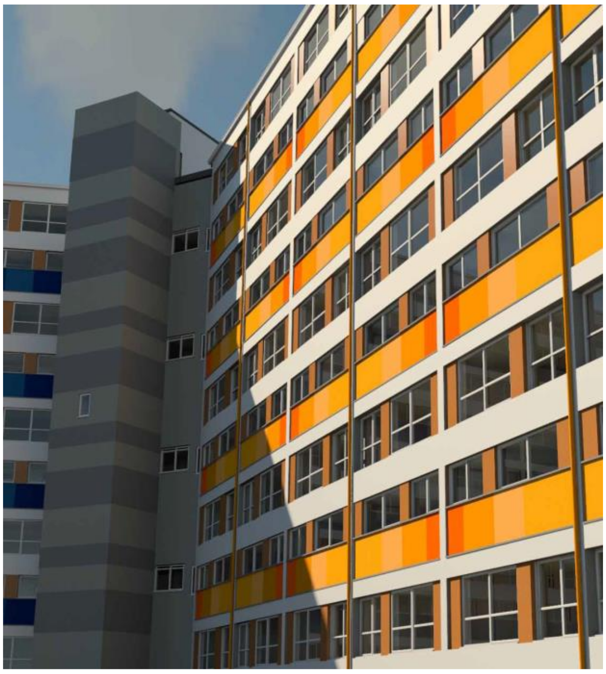

Figure 5.7. A visualisation of the courtyard façade (ECD Architects, 2012).

According to the cost study by ECD Architects and the quantity surveyors Keegans, the price of the external walls specified for the EnerPHit option was around £144,000 higher than what was required for the building regulations option (ECD Architects and Keegans, 2015).

5.2.2 Window specifications

The upgrade of the windows was an important part of the fabric design in both refurbishment proposals. ECD Architects found replacing the existing windows of Wilmcote House essential to achieve the project targets of reducing the energy demand and improving the tenants' living conditions. Generally, windows play a critical role in the thermal efficiency of the building fabric. Without an energy efficient design, they can lead to a significant level of heat transfer at the building envelope resulting in energy waste (Hee, et al., 2015). Furthermore, windows with low thermal performance are highly likely to have internal cold surfaces when the outside temperature is low, causing condensation and mould growth (Roulet, 2001). Mould growth is believed to have negative effects on human health and is associated with illnesses and health problems such as the common cold, cough, rhinitis, and fatigue (Koskinen, et al., 1999). Thus, the design of a window affects the level of energy demand, the occupants' health, and the physical condition of a building.

The original windows of Wilmcote House were single-glazed and metal-framed. Later, they were replaced with uPVC double-glazed windows, which at the time of the Council's decision to refurbish the building had deteriorated, providing an inferior performance (ECD Architects, 2012). In an interview with the ‘Local Authority Building & Maintenance journal’, Steve Groves, an asset manager from Portsmouth City Council, explained that: “The analysis we did of our repairs demand highlighted over a two-year period that 80% of residents had reported problems with their windows and a third had reported condensation” (Groves, 2015). According to LSE’s interview[26] with a sample of 15 interviewees, two-thirds of them reported that they had issues with damp and mould, and had a family member with health issues whose condition deteriorated in the cold and damp environment (Rockwool, n.d.).

The inefficiency of the windows was one of the major reasons behind these problems. ECD Architects proposed the replacement of the windows in both refurbishment options; nevertheless, the proposed windows had slightly different specifications based on the requirements of each option. According to their feasibility report, ECD Architects proposed triple-glazed PVCu windows with 5-chamber frames for the EnerPHit option. The glazing units would be argon-filled, low-e coated, and equipped with warm edge spacers. The windows would be installed within the steel framework that would carry the external wall insulation. Following the installation, the windows would achieve a minimum U-value of 0.8 $W/m^2.K$. The windows suggested for the building regulations proposal had similar specifications except that they were double-glazed. The windows would be positioned outside the existing wall, in the depth of the new insulation for a better thermal performance. This was estimated to achieve an overall U-value of 1.4 $W/m^2.K$. The windows designed for both options were inward opening, making it possible to overlap the frames with external insulation (ECD Architects, 2012). To clarify why the EnerPHit option had an additional layer to that detailed in the building regulations, the specific EnerPHit requirements in terms of window performance are investigated.

Generally, the Passivhaus standard places significant emphasis on the performance of the windows as they play a critical role in compliance with two important aspects of Passivhaus: minimising heat transfer, and creating a comfortable environment. To achieve the minimum heat transfer, Passivhaus/EnerPHit specifies a U-value requirement of maximum 0.8 $W/m^2.K$ in a cool and temperate climate. To assure residents’ comfort, the average temperature of the interior surface of the window should not be more than 3 degrees lower than the outside

[26] LSE and Rockwool carried out research on the Wilmcote House refurbishment to assess the social outcomes of the project.

temperature in the winter design day (Feist, 2006). To meet these requirements, Passivhaus windows are generally triple-glazed. Both proposals specified low-e coating, 5-chamber frames, and modern technologies such as warm edge spacers to address the client's objective to avoid existing problems, such as condensation (ECD Architects, 2012). As discussed by Jelle et al. (2012), because the overall performance of the window is affected by all of its components it is not adequate to merely consider its glass. Window frames and spacers - the component that holds the layers apart in windows with more than one layer of glazing - are two important components affecting the main causes of condensation, the level of heat transfer and the existence of thermal bridges (Gustavsen, 2008). Specified for the Wilmcote House windows, warm edge spacers are materials with low thermal conductivity, avoiding heat loss around the window edge so that the temperature of the internal edge does not reduce, staying warm (Song, et al., 2007). By avoiding heat loss from the internal perimeter of the window, the warm edge can contribute to preventing condensation.

In an interview with architect A (2016), he noted that although low-e coating was specified in both proposals, it played a more critical role in the EnerPHit proposal. According to the EnerPHit proposal, the access walkways were to be enclosed, with windows to be installed along the enclosed walkways; without the low-e coating, the walkways would be at risk of overheating. ECD Architects' feasibility report revealed that on the street façade of Wilmcote House they specified coloured metal fins to be installed next to the individual bedroom windows, protecting against solar gains from the west side, and subsequently preventing overheating in the summer. It should be noted that the fins would also enliven the simple street façade, as can be seen in the image below (ECD Architects, 2012). Nevertheless, a similar solution could not be applied to the courtyard façade because the glazing was stretched at each level along the frontage. An alternative would be to cover the glazing with internal or external shading, but this would restrict the light to the public access ways leading to the maisonettes and the kitchens behind them. The application of low-e coating was found to be more appropriate because it would restrict the heat gains without compromising light penetration. The additional cost of windows in the EnerPHit proposal was estimated at around £35,000 (ECD Architects and Keegans, 2015).

Figure 5.8. Vertical fins on the street façade (www.ribaj.com, 2018)

5.2.3 Roof

The building roof was another major building component planned for upgrade by Portsmouth City Council. According to the Council's brief included in the initial tender documents, one of the required refurbishment works was the "conversion of flat to pitched roof together with roof insulation upgrade" (Portsmouth City Council, 2011). Maintenance manager A at the Council explained that the existing bitumen flat roof caused issues with heat loss and condensation. He pointed out that the Council intended to replace it with a pitched roof because water accumulation on the surface of the flat roof was likely to lead to water leakage and damage to the roof elements, requiring significant future maintenance. As explained in their feasibility report, ECD Architects considered the design of a pitched roof, but did not proceed with this option because thermal bridges are highly probable to occur in this type of roof. The reason is that the angle of the pitched roof makes it challenging to provide a continuity of insulation at the joints (ECD Architects, 2012).

Thermal bridges at the joints would be an obstacle to achieving EnerPHit; thus, the pitched roof scheme was rejected, and ECD Architects developed an alternative solution to address the drainage issue. Their proposal was to create a level platform of insulation, applying a tapered rigid insulation board following the contours of the existing roof. Afterwards, a second layer of the same insulation would be added to create falls towards the external edges of the blocks. This solution would minimise water accumulation and loading on the existing roof without creating thermal bridges and thus maximising its thermal performance (ECD Architects, 2012). Based on their feasibility report, ECD Architects recommended the same solution in both refurbishment proposals; nevertheless, an additional level of insulation was specified in the EnerPHit option to prevent thermal bridges around the roof rafters. The following drawings by ECD Architects indicate the differences between the proposed roof options. According to the cost study by ECD and Keegans, the roof specified for the EnerPHit option would cost £55,798 more than the building regulations option, due to the additional insulation applied to the roof rafters, the utilisation of parge coat, and the application of thermal break pads.

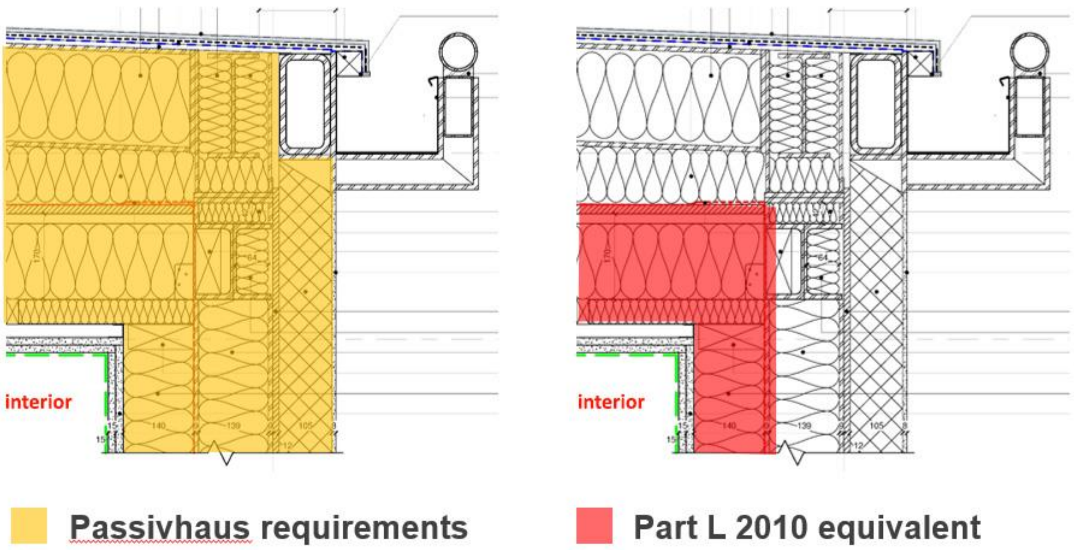

Figure 5.9. Roof insulation options (ECD Architects, 2015).

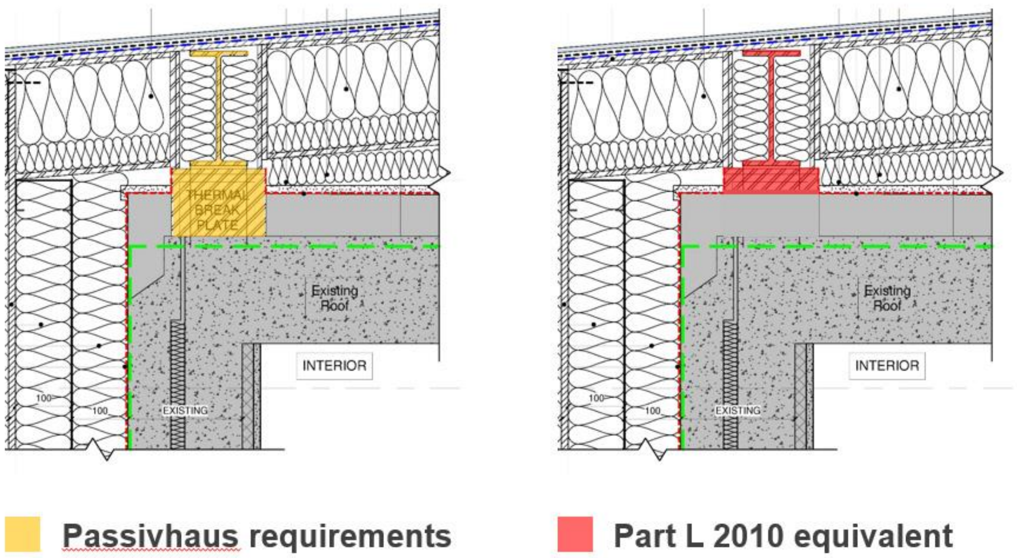

Figure 5.10. Additional thermal break pads in the roof design of the EnerPHit option (ECD Architects, 2015).

5.3 Heating system

Following the completion of the fabric proposals, ECD Architects appointed building services design consultancy NLG Associates to investigate different heating options for the Wilmcote House refurbishment. The suitability of heating options was assessed for each fabric proposal individually because they had different design specifications and thermal performance targets. Table 5.4 indicates the specifications of the existing fabric, the building regulations proposal, and the EnerPHit proposal. It should be noted that some elements of each proposal, such as the roof, were expected to achieve U-values above the target. As discussed earlier in this chapter, the EnerPHit proposal specified a higher level of insulation, parge coat, thermal break pads, and an even courtyard façade to achieve the stringent EnerPHit standard requirements in terms of U-value, airtightness, and the removal of thermal bridges. As can be seen from figure 5.11, the ‘Good Practice’ and ‘Advanced Practice’ (EnerPHit) proposals were expected to reduce the existing heating demand by around 36% and 60% respectively.

Table 5.4. Specification of existing and proposed fabrics (ECD Architects, 2012)(NLG ASSOCIATES, 2012).

Fabric specifications	Existing building	Good Practice proposal	Advanced Practice (EnerPHit) proposal
U-values (W/m^2.K)			
Roof	0.25	0.1	0.1
External wall	0.72	0.22	0.15
Glazing	1.8	1.4	0.8
Thermal Bridging (Y-value)	0.15	0.08	0.01
Air permeability (m^3/hr/m^2 @ 50 Pa)	3	3	1
Communal walkways	Open walkways	Open walkways	Enclosed walkways
Balconies	Open balconies	Enclosed balconies	Enclosed balconies

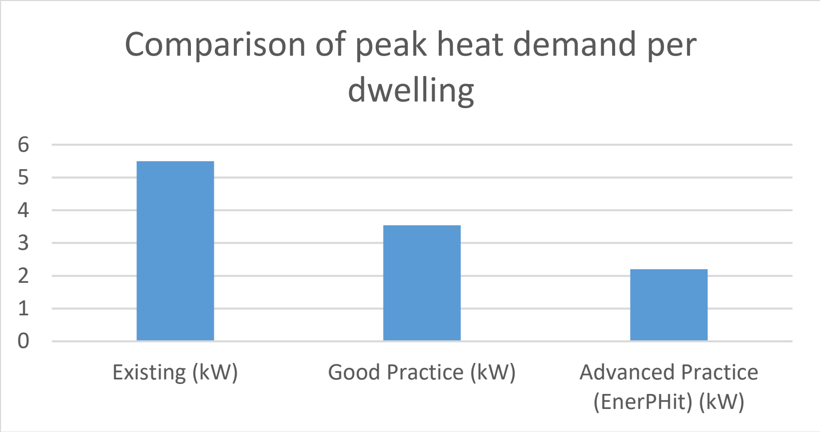

Figure 5.11. Comparison of peak heat demand (NLG ASSOCIATES, 2012).

As explained by Steve Groves at the Council, the Wilmcote House project started "with the initial demands about heating". He pointed out: "Traditionally as a council, we would have gone down the route of putting more efficient heating in, that would have been our default position and certainly was what we looked at in the early days to appease residents. That is when you start considering if there is a more efficient form of electric heating, or looking at district heating options" (Groves, 2015). According to Steve Groves (2015), they later realised that the building had other serious issues and it would be insufficient to merely upgrade the heating system. Nevertheless, they still considered the replacement of the heating system alongside the other refurbishment works. 'Planning a new gas CHP' was one of the refurbishment works included in the client's brief (Portsmouth City Council, 2011). It is understood from ECD Architects' feasibility report that both communal and individual heating systems were considered for the Wilmcote House refurbishment. Each heating option was assessed against numerous factors such as cost, the type of fuels viable to be utilised, structural limits, energy efficiency, and carbon emissions. Subsequently, the outcomes of this analysis were compared with the specific requirements and the level of energy savings related to each fabric proposal. This section examines the process of the investigation into available heating options, the analysis of each option, and the final outcomes. Furthermore, it explains how the proposed heating systems for each refurbishment proposal affected the client's final decision when choosing the appropriate refurbishment option.

The maisonettes in Wilmcote House had either electric storage heaters or an electric warm air heating system[27], and all were equipped with an electric immersion-heated hot water cylinder[28] to provide hot water (NLG Associates, 2012). It should be noted that unlike electric storage heaters, the warm air heating system does not have the capacity to store heat. Therefore, the level of heat retained within the dwelling depends on the efficiency of the fabric. According to NLG 2012, in maisonettes with a warm air heating system, the tenants needed to use the heaters at electricity peak times to warm their homes during the normal hours of the day; consequently, they were paying high energy bills.

In their Mechanical and Electrical report, NLG presented several alternative heating options, evaluating each based on annual energy usage and estimated energy bills. NLG chose one of the maisonettes as a sample dwelling to determine annual heat losses and the resulting heat demands of each heating method. Subsequently, the heat losses were calculated modelled on the existing sample maisonette[29]. By deducting the predicted space heating savings associated with fabric upgrade proposals 1 and 2 from the existing heating demands, the final amount of heat demand for each fabric proposal could be determined, and its consequent impact on heating bills. The heating methods were selected by factors identified in the CIBSE Domestic Heating Design Guide, including the availability of fuel source, the appropriate heat production and delivery strategy, and the type of heat emitter. For Wilmcote House, gas and electricity were identified as sources which could be used for an individual heating strategy; alternatively, gas, biomass, or solar energy could be consumed in a community heating strategy. Storage heaters, wet radiators, and warm air systems were possible emitter types which could be used in conjunction with the aforementioned fuel sources and strategies (NLG Associates, 2012).

It is noteworthy that the EnerPHit standard specifies a limit to a building's primary energy demand. To achieve EnerPHit, it is necessary to meet the primary energy target; thus, it is a critical factor in the design of the heating and hot water systems. In other words, these systems should be designed in a way that minimises the demand for primary energy. Generally,

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[27] This type of electric heating system is comprised of a heater and a blower fan. In the Wilmcote House maisonettes, the fan and the heaters are located in duct cupboards. When the system operates, it supplies warm air to the hall, distributing to the rooms through the louvres above the doors. A duct riser from the cupboards serves the upper floors of the maisonettes (NLG Associates, 2012).

[28] In this system, dual electric immersion elements heat the water stored in a cylinder. One of the immersion heaters operates at night on off-peak electricity, heating the water inside the cylinder to the minimum temperature, while the other immersion heater operates during the day on peak electricity to maintain the temperature (NLG Associates, 2012).

[29] SAP approved software FSAP was used to determine the annual energy usage from the various heating, hot water, and ventilation systems assessed (NLG Associates, 2012).

individual heating systems using electricity result in greater primary energy consumption and higher carbon emissions compared to individual gas heating systems, such as gas boilers and wet radiators. This is because electricity is a secondary energy generated from primary resources such as gas, coal, wind, and sunlight. In this process, the primary energy does not transform into electricity entirely, with part of it converting into heat (Kydes, 2011). Typically, around 1 energy unit of electricity is generated for every 2.5 energy units of fuel entering power stations in the UK; additionally, some energy is wasted during the transmission of electricity (Department of Community and Local Government, 2006). On average, the amount of electricity delivered to consumers totals about 30% of the primary energy resources used (Krigger, 2004). Therefore, a building's primary energy demand could be significantly reduced if gas, supplied via mains, were used to heat the building; but as discussed in chapter 4, due to the risk of disproportionate collapse, large panel system tower blocks like Wilmcote House are not permitted to use individual gas boilers[30]. Therefore, at Wilmcote House, the only individual heating source which could be utilised was electricity, despite its higher primary energy use and the risk of exceeding the EnerPHit primary energy limit. Storage heaters, an air source heat pump with wet radiators, and a Compact Service Unit with warm air system were the individual heating options investigated by NLG. These options are described in the following box.

[30] See chapter 4, regarding disproportionate collapse regulations concerning tower blocks.

Box 5.4: Individual heating system options

1. An electrical storage heater stores heat by utilising off-peak electricity usually available at night (M.Farid & M.Husian, 1990), releasing the heat during peak times.

2. Air source heat pumps (ASHP) with wet radiators:

“Heat pumps (vapour compression heat pumps) transfer heat by circulating a phase changing substance called a refrigerant through a cycle of evaporation and condensation” (Wu, 2009). An air source heat pump uses the ambient air as the source of heat (Wu, 2009). One option is to install wet radiators to circulate the hot water and heat the building. One disadvantage of an air source heat pump is that its performance decreases when the ambient temperature is low (S. Bertsch & A. Groll, 2008).

3. Compact Service Unit with warm air system:

This system integrates air source heat pumps with a mechanical ventilation and heat recovery system. However, instead of wet radiators, ducts are utilised to transfer warm air to the rooms (NLG Associates, 2012).

The result of NLG’s investigations showed that the introduction of new storage heaters and compact service units were estimated to significantly reduce fuel demand and energy bills; conversely, a compact service unit would result in a lower primary energy demand and carbon emissions. This results from the system using the heat of ambient air, recovering heat from the dwelling, so that it does not completely rely on electricity. Furthermore, it provides both heating and hot water, whereas, storage heaters merely provide heating. Consequently, electric showers would need to be installed to heat the water. Nevertheless, the storage heater was less complicated and less disruptive to install, while costing less than the compact service unit. Although it could achieve a considerable reduction in carbon emissions, the air source heat pump was the least suitable option due to its higher fuel demand and the requirement for a space outside the building to situate the fan units. As the communal walkways provided the only space available, the system would be challenging to integrate with the EnerPHit proposal, because the walkways were to be enclosed and the fan units would need to be bracketed off the courtyard façade, resulting in an aesthetically unacceptable appearance (NLG Associates, 2012). Considering its savings, ease of installation, lack of contact with the outside air, and lack of requirement for utilisation of ducts, it can be argued that an electric storage heater would be the most appropriate individual heating option to be used for the EnerPHit proposal because it would minimise the heating demand, while preventing thermal bridges. As explained by architect A at ECD, the EnerPHit fabric proposal minimised the heating demand and would be sufficient to utilise storage heaters as “an overnight off-peak top-up” (Architect A, 2015).

The Mechanical and Electrical report indicates that in addition to individual heating systems, the feasibility of communal heating options was considered for the Wilmcote House refurbishment. The communal heating system has been very popular in Northern European countries with long heating seasons (Goth, 2010). For instance, in Denmark, more than 60% of households receive heat from community heating networks (Whitehead, 2014). However, this is currently uncommon in the UK; although it has been considered more often after the setting of carbon reduction targets, with the government calling for the creation and expansion of district heating, and the Department of Energy and Climate Change (DECC) identifying community heating as necessary for “decarbonising heat supply in urban and suburban areas” (Combined Heat and Power Association, 2012). The following box explains the specifications of a communal or district heating system.

Box 5.5: Communal (district) heating system:

A communal heating system delivers heat from a centralised heat source, to many heat consumers in a number of dwellings via a pipe network. Typically, this system comprises one or more energy centres with heat sources, heat exchangers within dwellings, and a pipe network connecting them to each other. The hot water produced in the energy centre is pumped to the dwellings via the pipe network. Thus, the system meets the overall heat demands of all the individual consumers, with the larger size of load resulting in an economy of scale. The energy centre can use different fuels and technologies, such as gas boilers, biomass boilers, and Combined Heat and Power (CHP) systems. Through the efficient consumption of energy and utilisation of renewable sources, the district heating system can lead to a significant reduction in carbon emissions. From a building manager's perspective, a communal heating system offers certain benefits; for instance, it saves the capital costs related to maintenance of individual heaters. Furthermore, a manager does not need to access inside the dwellings because the energy centres are outside of the building (Wiltshire, et al., 2014).

NLG investigated different communal heating options including a CHP system running on mains gas, and CHP with biomass and backup gas boilers. The use of biomass would require substantial space for fuel storage, which was impractical as this could not be found on the site. NLG argued that it would not be necessary to constantly supply fuel to the CHP system with biomass. However, this would be challenging due to the site limits, and lastly, the system would require a high frequency of servicing resulting in higher maintenance costs. However, a gas source CHP would not lead to the aforementioned problems; therefore, it was a more viable communal heating option. The expected level of fuel savings achievable from this option was lower than with the individual heating options; nevertheless, it could result in the highest reductions in fuel bills and carbon emissions for both fabric proposals (NLG Associates, 2012) because it relied on a primary source of energy. The following table indicates the savings achieved by each heating option (except the CHP system with biomass[31]) for both fabric proposals.

[31] The projected results for this option were not available on any of the reports.

Table 5.5. Comparison between savings achieved from the heating options (NLG Associates, 2012).

Refurbishment proposals	Storage Heater	Air source heat pump	Compact service unit	Gas source CHP
Saving in heating demands				
Good practice	57.7%	50.7%	69%	22%
EnerPHit	89.7%	62.2%	79.2%	47%
Saving in energy bills				
Good practice	43%	41%	57%	66%
EnerPHit	67%	51%	68%	73%
Carbon reduction				
Good practice	39.9%	48.9%	61.9%	70.4%
EnerPHit	62.1%	57.9%	71.8%	78.1%

Consequently, a communal heating system with gas source CHP was the most appropriate option for the building regulations proposal; however, it was not possible to utilise this method with the EnerPHit fabric proposal for Wilmcote House. According to the report by NLG associates, to install the communal heating system a route had to be determined for the pipes transferring hot water from the energy centre to the maisonettes. However, the only feasible route was through the courtyard façade because the energy centre could not be located on the street side and needed to be on the courtyard side; thus, it was only practical to connect it to the building via the courtyard façade. Nevertheless, the EnerPHit proposal required the enclosure of balconies and walkways. To connect the pipes to the building, it would be necessary that they penetrated the enclosed walkways. Consequently, the Mechanical and Electrical report suggested that it would be more appropriate to specify the EnerPHit proposal with an individual heating system (NLG Associates, 2012).

As previously explained, storage heaters were considered the most efficient individual heating option that could be utilised with the EnerPHit proposal. Thus, ECD Architects' feasibility report suggested the utilisation of a gas source CHP communal heating system alongside the 'Good Practice' fabric proposal, and storage heaters alongside the EnerPHit fabric proposal. According to the feasibility report, it was estimated that the 'Good Practice' option would result in a 22% reduction in yearly heating and hot water demands, annually saving £745 per dwelling in energy bills. The EnerPHit option was expected to reduce annual heating and hot water demand by 90%, saving £750 per flat per annum in energy bills (ECD Architects, 2012). The saving in energy bills achieved from the EnerPHit proposal would almost be the same as with the 'Good Practice' option, although the EnerPHit proposal would achieve a significantly higher level of heating demand. This was because 'Good Practice' specified a communal heating system which would be supplied by gas, a primary energy source, while the EnerPhit proposal was based on a heating system utilising electricity, a secondary energy source.

5.4 Final decision of the client

According to maintenance manager A at Portsmouth City Council, the Council chose the EnerPHit option as it allowed for high savings in energy bills without the utilisation of a communal heating system. The option for meeting building regulations standard would only have achieved a high saving in energy bills if combined with a communal heating system. The EnerPHit proposal could achieve a similar level of saving using an individual heating system. Maintenance manager A explained that the Council objected to the use of a communal heating system due to the high administrative burden. They wanted the tenants of each maisonette to receive their energy bills and pay for them without any dependency on the landlord. Maintenance manager A (2016) argued that if the Council installed a communal heating system they would be responsible to collect the bills. If any of the tenants did not pay their bills, the Council would need to cover the cost. Maintenance manager A (2016) believed that it would not be fair to the other tenants if the Council paid for some of the tenants' bills. Thus, the client decided to invest in optimizing the fabric. Architect B (2016) explained that the Council decided to maintain the existing electric heaters because they believed reliance on them would be minimised by the optimised fabric. According to architect B, the Council was planning to carry out a post-occupancy evaluation a few years in the future to determine if it were necessary to replace the heaters.

It was revealed during an interview with architect B that when ECD submitted the feasibility report to the client they had not calculated the primary energy demands of the heating options; therefore, they did not know if the utilisation of electric heaters would comply with the primary energy demand of EnerPHit. Architect B (2015) explained that their calculations with the Passivhaus Planning Package (PHPP) addressed the compliance of fabric specifications against EnerPHit requirements. Architect B pointed out that after the appointment of the contractor, the Passivhaus consultants they employed calculated all the refurbishment specifications via PHPP, and realised that using the electric heating system would result in a lack of compliance with the primary energy demand specified by EnerPHit, because as a secondary energy source electricity consumes a higher level of primary energy. Thus, the client had two options to meet EnerPHit: to install a communal heating system, or to use renewable energy technologies.

Maintenance manager A (2016) explained that regardless of technical and operational challenges, the Council did not intend to utilise a communal heating system alongside the EnerPHit option because the EnerPHit fabric was considerably costlier than the alternative, and they could not justify spending more of the budget on the capital costs of a communal heating system installation solely for the purpose of achieving EnerPHit. He emphasized that the Council was interested in fully achieving EnerPHit, but it was not a priority to them. He pointed out that they were going to meet four out of the five requirements of EnerPHit and would achieve significant savings in heating demands and fuel bills; thus, it would not matter if they did not meet one requirement. According to maintenance manager A (2016), the priority of the Council was to maximise the performance of the building, not to achieve an EnerPHit certification.

Nevertheless, another opportunity to comply with the primary energy demand while using the electric heating system arose after the introduction of new Passivhaus categories (Classic, Plus, and Premium), and the release of an updated version of PHPP (version 9) containing a method for evaluating primary energy demand. This method considered energy generation via renewable energy sources. Prior to PHPP 9, the maximum primary energy demand was 120 kWh/m^{2}y, with the utilisation of renewable energy sources not taken into consideration. With PHPP 9, the calculation can be based on a scenario where the renewable energy provides all the energy demand (Bonilauri, 2016). PHPP 9 provides results for “demand for renewable primary energy (PER) per year” instead of the primary energy demand and “assessment of the annual renewable energy gains”. Based on this evaluation, the Passivhaus Classic category should meet the renewable primary energy (PER) demand of 60 kWh/(m²a) at the most without the need to generate any extra energy[32]. However, it is still possible for only the Passive House Classic category to use the previous method based on primary energy (PE) in parallel at a transitional phase. The preferred verification method can be chosen in the PHPP worksheet "Verification" (Passive House Institute, 2015). Thus, based on the new assessment method, Wilmcote House could meet the primary energy demand if adequate and appropriate renewable energy sources were utilised, such as photovoltaic panels. During a site meeting in 2016, Portsmouth City Council revealed that they would consider the utilisation of renewable technologies as a future step after project completion. Thus, the client decided to refurbish Wilmcote House according to EnerPHit criteria, without fully achieving EnerPHit at the completion of the project.

5.5 Conclusion

This chapter concludes that the EnerPHit requirements restricted both the fabric design solutions and the possibility of utilising different heating options. For the EnerPHit proposal, the specifications of the different elements of façade, such as the external walls and the roof, were based on achieving the U-value targets of EnerPHit, complying with airtightness criteria and minimising thermal bridges. To meet these requirements, the EnerPHit scheme had to account for additional insulation, airtightness layers, thermal break pads, and specific design solutions targeted to provide continuity of the insulation layer. It was not viable to upgrade Wilmcote House to EnerPHit without transforming its courtyard frontage to an even façade with enclosed communal walkways and private balconies. This restriction was specific to the EnerPHit proposal; whereas, compliance with UK building regulations did not require such significant alterations.

The selection of the appropriate heating system to be utilised together with the EnerPHit fabric proposal was affected by the structural problems of the building, the specific design of the fabric, and the EnerPHit requirements. The requirement to minimise the thermal bridges made it less favourable to select options which were in contact with ambient air, such as an air source heat pump. The enclosed walkways and balconies, a requirement of EnerPHit fabric design, made it technically challenging to connect the pipework to the building when installing a

[32] The other two Passivhaus classes introduced were Passive House Plus and Passive House Premium. A building built to Passive House Plus is more efficient than Passive House Classic because it may not use up more than 45 kWh/ (m²a) of renewable primary energy. At the same time, it should produce at least 60 kWh/ (m²a) of energy relative to the area covered by the building. In regards to Passive House Premium, the energy demand is restricted to only 30 kWh/ (m²a), with an energy generation of at least 120 kWh/ (m²a) (Passive House Institute, 2015).

communal heating system. The risk of disproportionate collapse due to the inappropriate structure of a large panel system building prohibited the use of individual gas boilers. Thus, the individual electric heater was technically found to be the most appropriate option. Nevertheless, the building regulations fabric proposal would not reduce the heating demand to the level achieved by EnerPHit; thus, this option could only reduce the energy bills significantly if it utilised a communal heating system. Between an EnerPHit fabric with electric heaters and a building regulations façade with a communal heating system, both achieving a similar level of reduction in fuel bills, the client selected the EnerPHit option because they did not want to make savings that relied on a heating system. Even though it was revealed that the use of electric heaters would result in a lack of full EnerPHit compliance, the client did not change their plans and opt for the alternative of installing a communal heating system because it would be financially unjustifiable to use alongside the EnerPHit option. The fact that ECD Architects did not expect that the utilisation of electric heaters would lead to a lack of compliance with EnerPHit indicates that to achieve EnerPHit, the fabric-first approach and questions of space heating cannot be treated in isolation. This was not fully recognised by ECD when they specified the heating system in the EnerPHit proposal.

Chapter 6: Development of EnerPHit scheme prior to contractors' involvement

6.1 Introduction

As explained in the previous chapters, the architects developed two refurbishment proposals, 'good practice' aiming for slightly above the 2010 UK building regulations level, and 'advanced practice' aiming for the EnerPHit standard. The specifications for both proposals in terms of fabric and services were included in a feasibility report presented to the client. Having compared the proposals in terms of fabric, heating systems, and their estimated savings in terms of heating and energy bills, the client decided to select the EnerPHit option. At this stage, the architects made a major decision with regard to the project procurement. They decided to utilise a Standard Building Contract with a Contractor's Design Portion, meaning that the design and construction were to take two separate stages. According to this method, the contractors would take over the project after the architects completed the design stage, but due to the Contractor's Design Portion, the contractor held responsibility for completing the architects' design prior to undertaking the construction stage. According to ECD Architects, they developed the design to the greatest degree before the contractor's involvement in the project to ensure compliance with EnerPHit (Architect B, 2016) (Architect A, 2015).

This chapter aims to investigate: Which components of the design were specified within the Contractor's Design Portion and why? In addition to the fabric and the heating system, which elements did the architects find necessary to design to ensure compliance with EnerPHit and what challenges were encountered during the design of these elements? Interviews with the architects reveal that they were particularly concerned with achieving the airtightness requirement of EnerPHit. The tender documents indicate that the project architects developed an airtightness strategy with all the necessary specifications and details to accomplish this strategy on site. Besides the airtightness element, the architects specified the type of mechanical ventilation and heat recovery system (MVHR), its location in the building, and details for its installation. The design of these elements was directly related to the potential achievement of EnerPHit; therefore, they would be superfluous to requirement if the client had selected the building regulations proposal.

6.2 Airtightness strategy

The fabric specifications explained in chapter 5 revealed that the EnerPHit proposal stipulated an additional parge coat layer, conforming to the stringent airtightness demand of EnerPHit. Nonetheless, the architects' plans to meet this requirement were not restricted to this specification alone. To ensure the contractor's compliance with EnerPHit on site, they produced a document called "Air Tightness Specification and EnerPHit Compliance" which explained their airtightness strategy, their proposed products, and the details of their application. This gives rise to the questions: What is an effective airtightness strategy? And why was this strategy essential to achieving EnerPHit in Wilmcote House? According to the airtightness guide by McLeod et al. (2014), one of the most important rules in developing an effective airtightness strategy is creating "a single, continuous and robust airtight layer", sitting on the warm side of the insulation, surrounding the heated volume. Involved in many UK-based Passivhaus projects, Bere Architects believe that in any plan or section drawing, the architects must highlight the location of the airtight layer. After specifying this, the next step should be to detail the sequence of building difficult construction junctions, using drawings and written explanations (Bere Architects, 2012). Some of the critical locations requiring greater clarification are the junctions between floors and walls, walls and ceilings, walls and windows and service penetrations.

Following the detailing, air tests should be scheduled, with at least three air tests undertaken to check the integrity of the airtight layer (Hopfe & McLeod, 2015) and to detect any defects in the airtightness before the airtight layer is covered. The initial stage arises when the doors and windows are installed, completing the air barrier; the second stage occurs after the installation of services; with the final test performed at the conclusion of the building works (Jaggs & Scivyer, 2009). According to Bere Architects (2012), it is the responsibility of the project architects to produce clear drawings with a sufficient level of detail, enabling the contractor to understand the airtightness strategy and to implement the design details on site. An 'airtightness champion' should be appointed to ensure that site operatives remain aware of the significance of airtightness. This person is required to retain the integrity of the airtight layer throughout the building and make the design team and project manager aware of any issues (McLeod, et al., 2014).

According to the interviews with ECD Architects, it would be challenging to provide one continuous airtight layer throughout Wilmcote House because the building is comprised of three blocks, connected at the stair cores (Architect A, 2015) (Architect B, 2015). It should be noted that it is crucial to have a single uninterrupted airtight layer; otherwise, air leakage will occur. For instance, if there are two noncontinuous layers instead of one continuous layer, air leakage will initially occur on the first layer and then on the second layer. This will result in lack of compliance with airtightness target (Feist, 2015). As shown in their airtightness document, ECD Architects split Wilmcote House into three thermal envelopes by leaving the two stair cores outside of the thermal zone; thus, each block had a separate airtight layer. The following drawings show the airtightness strategy developed by ECD Architects, with the enclosed walkways within the thermal zone, surrounded by the airtightness layer, indicated by the red lines. The airtight layer was an external membrane to be installed on to the existing wall before the application of external insulation (Traynor, 2013). The architects detailed a red line of airtightness on all the external details.

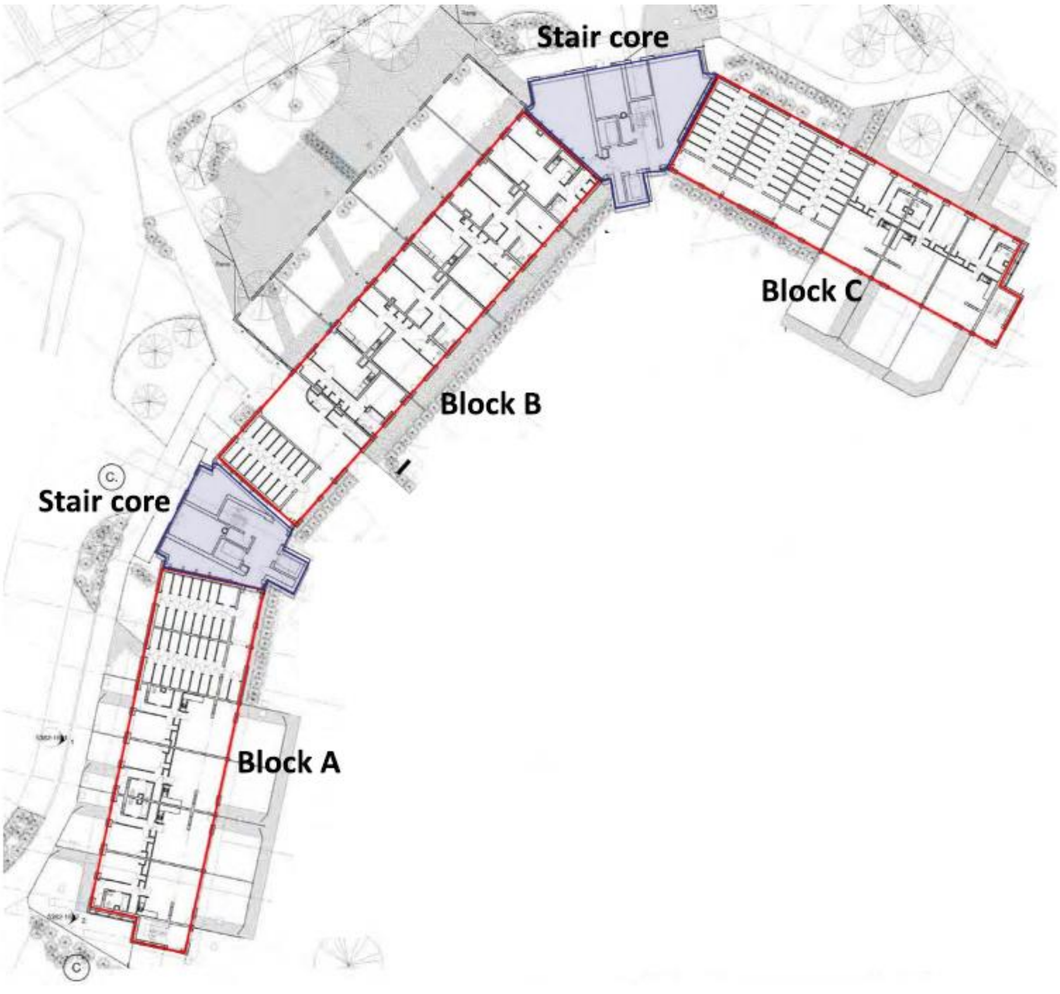

Figure 6.1. Airtight layer at the ground floor (ECD Architects, 2013).

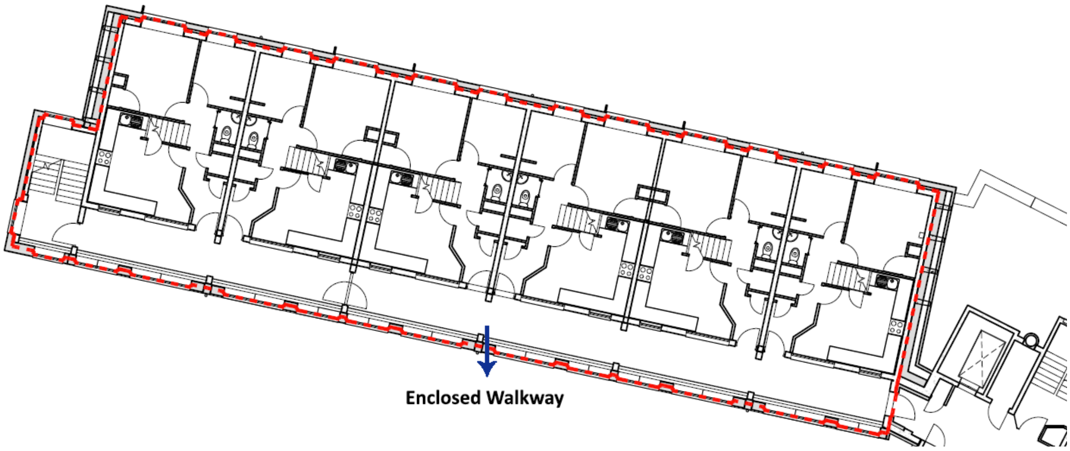

Figure 6.2. Airtight layer in a typical walkway level (ECD Architects, 2013).

In addition to the overall strategy, ECD Architects prepared details which explained measures to achieve airtightness in key locations. Type of membranes, tapes, seals and coatings were also specified. A German manufacturer, MOLL bauökologische Produkte GmbH, produced the airtightness components, that were provided by UK suppliers (Traynor, 2013).

ECD Architects emphasised the significance of compliance with the airtightness requirement through the Air Tightness Specification and EnerPHit Compliance document included in the tender documents: "Achieving acceptable air-tightness is of paramount importance when targeting the EnerPHit standard and the successful contractor must appoint an 'Air-tightness champion' from within their project team". "The contractor shall employ an independent consultant (BRE or similar) to check air-tightness at key stages (no greater than 1ACH @ 50Pa) of the project" (Traynor, 2013). The sequencing of the tests was specified as the responsibility of the contractors.

According to the tender documents, the architects required the contractors to provide a minimum of two tests; the baseline test (pre-commencement) and final air test (certification). The baseline test was to be carried out before starting work on site. This test was required to identify the existing airtightness level in order that later it would be possible to measure the amount of improvement achieved by the refurbishment works against the existing level. The final test was to be completed following the completion of works, but before the handover of the building. The number and time of tests were to be decided by the contractors. In general, they were required to plan the tests to ensure that the performance of the building was acceptable, and so that if the building failed the final airtightness test any destructive works could be avoided at a later date (Traynor, 2013). It was recommended but not required that the contractors arrange additional partial air tests during the progress of works, as arguably committing the contractors to performing additional tests might add to the challenges of the project during the construction stage. As will be discussed in the next chapter, the contractors encountered serious issues with the design of the airtightness tests due to the large scale of the project and specific issues relating to the building.

As discussed earlier, the architects' airtightness strategy specified three airtightness lines surrounding each block. Based on the tender documents, the contractor was responsible to provide the air test results "for each discrete volume within an airtightness line". Architect A (2015) noted, it was predictable that the contractors would find it challenging to test a whole volume at a time; therefore, they had to identify different test areas within each volume. The architects suggested that partial air tests could be undertaken floor by floor or completed section by section. They recommended that the appointed contractors could arrange the sequence of their works in such a way that the entire airtightness barrier at each testing section would be visible from the testing point, to detect and seal any potential leaks (Traynor, 2013).

6.3 Mechanical Ventilation and Heat Recovery system

As the alternative refurbishment proposal merely required a mechanical extraction system, the mechanical ventilation and heat recovery (MVHR) system featured as an important EnerPHit-related element of the design. According to the cost study by ECD Architects and Keegans (2015), MVHR was one of the main elements of the EnerPHit proposal that contributed to the cost difference between the two refurbishment options. Specified by ECD Architects, this element would be later reviewed by the contractor to ensure that its installation met with Passivhaus requirements. It should be noted that the MVHR system may be utilised in non-Passivhaus buildings, but it is a requirement in all Passivhaus/EnerPHit buildings. The Passivhaus/EnerPHit MVHR performance requirements include a minimum heat recovery efficiency of 75% and a maximum specific fan power of 0.45 Wh/m^3. To minimise any unwanted noise from the MVHR, Passivhaus requires the maximum MVHR sound to be no greater than 35 dB(A), and the sound transfer between rooms should not exceed 25 dB(A). Additionally, the MVHR unit must be certified by the Passivhaus Institute (McLeod, et al., 2014). Numerous factors significantly affect the potential to reach Passivhaus MVHR levels such as the heat exchanger properties, the location of the MVHR unit, the ducting system, the material and length of ducts, the insulation and the sound attenuators. It is not within the scope of this study to fully investigate all the factors affecting the system efficiency; however, the most important determinants are examined in the following box.

Box 6.1: The effects of MVHR components on system performance

a) Heat recovery efficiency and the fan power of MVHR are affected by ducting and insulation.

Ducting: is a significant component of the MVHR system. Following their study of 85 UK-based dwellings with the MVHR system, Sharpe et al. (2016) categorized their related ducting systems into three groups: flexible, hybrid, and rigid. In the first system, whole ducting is flexible regardless of material or quality; in a hybrid system, most of the ducting is rigid; however, some flexible elements have been utilised; and the rigid system is comprised of 100% rigid ducting regardless of the material type (apart from final connections to the MVHR unit). The results of the study by Sharpe et al. (2016) showed that 88% of rigid duct systems complied with their design air flow criteria; while, only 44% of flexible duct systems and 40% of hybrid duct systems met the conditions of their air flow design. These results were inadequate to assess the efficiency of a ducting system because meeting the air flow criteria can be affected by other factors such as the fan power and the installation quality. However, it suggests that rigid ducting systems tend to perform better.

Generally, designers and suppliers recommend against the utilisation of a flexible ducting system, mostly due to its association with unpredictable and relatively high air resistance (NHBC, 2013). The ducts can be installed in a branch or radial arrangement. In a branch arrangement one main supply duct connected to the heat exchanger is divided into branches to supply different rooms, and likewise, one main extract duct with subdivisions extracts air from wet areas. However, in a radial system the main supply and extract ducts from the MVHR unit are each connected to a plenum. The ducts in this system should be semi-rigid to avoid the breaks. One of the advantages of this system is that the semi rigid ducts with smaller diameters can thread between structural components and provide higher level of flexibility. In addition, the radial system reduces the sound transfer between the rooms because each room has a separate duct. Another advantage encompasses the elimination of joints in the ducts, which can adversely affect the system by increasing the air flow. In a radial system there is one continuous duct for each area; therefore, there are no joints along the ducts.

However, one major disadvantage of this system is the extra space required to place the plenums. Similarly, it requires many ducts to access the void space (Hopfe & McLeod, 2015).

Insulation: must be applied to ducts to prevent condensation and minimize heat transfer either between the ducts and unheated areas or the ducts and internal spaces of the building. The warm extract duct and the supply duct should be significantly insulated if the MVHR unit is outside of the building envelope because exposing the ducts to cold weather can result in heat loss and condensation. The level of insulation should match the building fabric insulation because they can be regarded as internal parts of the building (Hopfe & McLeod, 2015). If the unit is inside the building, both the fresh air intake and the exhaust ducts should be insulated. Ideally, the insulation of these ducts should also be identical to that of the building fabric. However, Hopfe & McLeod (2015) find this to be generally impractical, identifying the recommended insulation levels to be 50mm for ducts shorter than 2m, and 100mm for ducts longer than 2m.

b) Sound-proofing: All the factors affecting the fan power similarly impact the sound levels of the system. In fact, the higher the fan power running the system, the more noise is produced. Therefore, lower fan power contributes to sound reduction. In addition, appropriate sound attenuators should be utilised to minimise the transfer of noise and sound between rooms. There are different techniques of applying the attenuators. For instance, they can be placed on the supply and extract side of internal building areas to minimize both fan noises and cross-talk between rooms. However, in a radial system, sounds cannot travel from one room to another; therefore, it is not necessary to use cross-talk attenuators. If the plenums are sound-proof, fan noises will not transfer to the supply and extract ducts either and the requirement to use any sound attenuators on supply and extracts sides will therefore prove unnecessary. Additionally, some manufacturers provide extract and supply ducts combined with silencers and volume flow controllers (Bräunlich, et al., 2016) which makes it easier to provide sound attenuation. Thus, sound-proofing measures can depend on the type and properties of the specific ducts and ducting system.

Overall, to meet EnerPHit, all the MVHR components should be designed for maximum efficiency in heat recovery, while fan power and system noise is minimised. In an interview with ECD Architects, architect B explained that within the maisonettes, they had restrictions in terms of the size and location of the MVHR units and ducting. The MVHR unit had to be installed within the existing cupboard inside the entrance hall of each flat and the ducts would need to be installed inside existing risers. Considering that the entrance halls of flats are located on the courtyard side, the exhaust and intake ducting had to extend to the external wall of the enclosed walkway (Architect B, 2016). Regardless of the type of MVHR unit and ducting system the architects specified, the length of the ducts would increase. This in turn impacts the air resistance; the longer the ducts are, the more air resistance increases, leading to a requirement for higher fan power (Hopfe & McLeod, 2015). Therefore, it was challenging to comply with MVHR requirements in Wilmcote House. The following drawings show the extension of intake and exhaust ducts from the cupboard to the outer surface of the enclosed walkway.

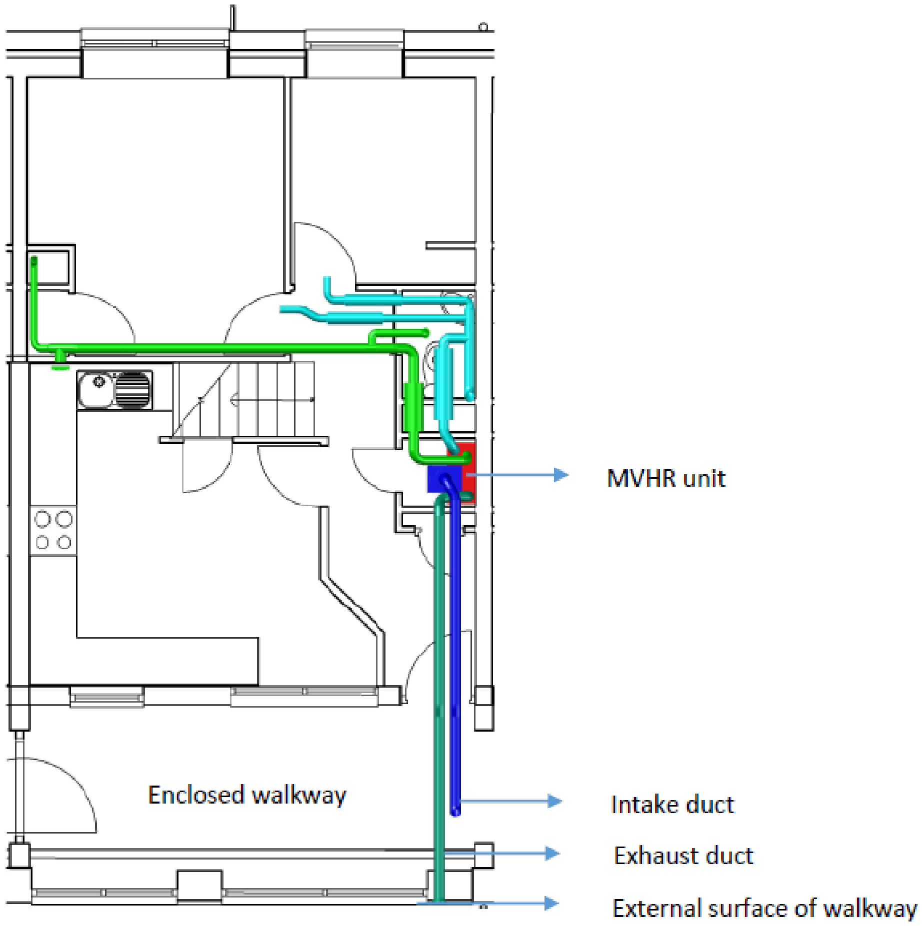

Figure 6.3. Plan drawing of MVHR system in a typical maisonette (Green Building Store, 2013.)

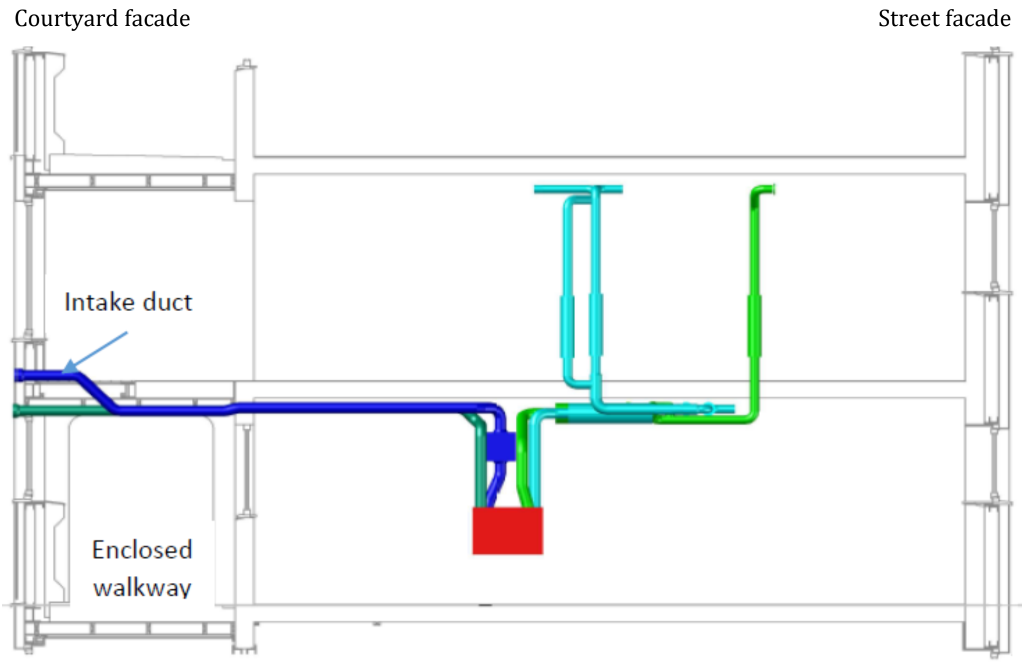

Figure 6.4. Section drawing of MVHR system in a typical maisonette (Green Building Store, 2013).

The drawings indicate that in comparison to the courtyard façade, situating the MVHR unit on the street façade would require shorter exhaust and intake ducts due to its lack of walkways, and so the inlets and outlets of the MVHR could be directly placed on the external wall of the flats rather than the walkways. However, it was not possible to position the MVHR close to the street façade for the reason that there were bedrooms on the street side, and no suitable space available to site the MVHR or the ducts. To avoid noise in the bedrooms or living room, the location of the MVHR unit should be far-removed.

According to the tender documents, ECD Architects commissioned Green Building Store, a supplier of low-energy products, to specify an appropriate MVHR system for the Wilmcote House maisonettes. The documents provided by Green Building Store included both specifications of products such as duct and duct fittings, acoustic attenuation, and installation instructions. The MVHR unit they specified for the maisonettes was the "Passivhaus certified Paul Focus 200 DC with standard PAUL cross counter flow channel heat exchanger" with a "circular spiral wound rigid duct of 100 mm and 125 mm diameter" made of galvanised steel. All joints were to be secured by self-tapping duct screws (Green Building Store, 2013). As can be seen from the above drawings, the ducting was arranged via a branch system. As the existing risers were utilised, there was insufficient space to use the radial system. The Paul Focus 200 MVHR unit is Passivhaus certified and has an electric power consumption of 0.31 Wh/m3 which complies with Passivhaus requirements. Its dimensions are 542 mm high x 752 mm wide x 355 mm deep, meaning it is suitably sized for a flat (Green Building Store, 2015), and would fit in the cupboards of the entrance halls in the Wilmcote House maisonettes (Architect B, 2016). Due to the considerable length of the ducts, it was likely that the specified rigid metal ducting would result in considerable heat transfer, reducing the efficiency of the system. A closed cell foam insulation suitable for ducts and pipes (Armaflex class 1[33]) was proposed to cover the intake and exhaust ducts from the MVHR unit to the airtightness barrier of the envelope. As the MVHR unit was to be placed within the building envelope, the insulation would need to be applied to the intake and exhaust ducts.

To meet the sound criteria cross-talk attenuation, supply and extract side attenuation and exhaust attenuation were proposed to be installed to the system (Green Building Store, 2013). According to the interviews with the architects and the site meeting minutes, there were doubts among the client and the architects over the appropriateness of this system with regard to the efficiency of the ducting system and its cost-efficiency. Nevertheless, according to the contract, the compliance of the system with Passivhaus requirements needed to be assured. Thus, the contractor had to evaluate the system performance through PHPP calculations, and to propose an alternative if the architect-specified system did not meet EnerPHit criteria. As will be explained in the next chapter, the MVHR system detailed in the tender documents did not end up being utilised. It is not clear whether this system would have complied with EnerPHit had it been installed in the Wilmcote House maisonettes. Prior to the commencement of the construction stage, the system was replaced with another option with more efficient ducting and lower costs.

It should be considered that the MVHR specifications for Wilmcote House were proposed in 2012, and MVHR technology has improved since this time. Its designers and manufacturers have been developing solutions to provide more efficient and cost-effective MVHR systems for retrofit projects. Some targets of these solutions are to produce compact duct networks, ready-made systems, and cost-effective components in order to reduce air pressure losses, power consumption, space demand, installation difficulties and project costs (Bräunlich et al., 2016). Utilising new technologies can reduce the challenges of achieving EnerPHit.

For instance, according to Rupert Daly, the architect of the second EnerPHit tower block refurbishment project in the UK[34], Collective Architecture proposed to utilise a new MVHR

[33] Find more information at www.armacell.com
[34] The refurbishment of Cedar Court tower blocks in Glasgow

system called fresh-r[35] which was advantageous in terms of unit size, heat exchanger material, and filters. The considerably small size of the unit used in this system allows it to be integrated into a window frame as shown in the following image.

Figure 6.5 The Fresh-r Window-Panel MVHR system fitted in a window pane (fresh-r.eu, n.d.).

In addition to reducing the space demand, the small unit makes it easier to install and maintain the system. Additionally, placing the unit on the outside wall reduces the use of ducts, saving on their cost and that of the coring required for their installation. With a copper heat exchanger, this system conducts heat much better than conventional systems with plastic heat exchangers; thus, it needs less power and utilises less energy. Furthermore, the filter in the system is washable meaning that it will not need replacement. Based on the project architect's calculation, washable filters can save £100k over 10 years per project, as opposed to replacing filters every six months (Daly, 2016). These technologies will simplify the utilisation of MVHR in potential future tower block refurbishments based on EnerPHit.

6.4 The Contractor's Design Portion (CDP)

According to the tender documents, ECD Architects and their consultants produced the specifications and drawings for most of the project elements; nevertheless, these were designated as part of the Contractor's Design Portion (CDP). Based on the contract between

[35] More information can be found at: http://fresh-r.eu/

the stakeholders, all work to the building envelope and construction elements (discussed in the previous chapters) would fall within the CPD package, including the MVHR installation, the air barrier implementation, and the air testing (explained earlier in this chapter). The contract made the contractor responsible for the design of all junctions and connections, the completion of design details for all CPD elements, and the integration of the CDP packages with the designs of the architects, and the structural and service engineers. Therefore, it was the responsibility of the contractors to review the architects' design, assess them against EnerPHit requirements, and complete or alter them to meet the EnerPHit standard. The drawings produced by the architects contained dashed green lines separating the elements which were to be the CDP. The contractors were responsible for completing the detailed design of these elements. According to the contract, the contractor-designed details were to be reviewed by the contract administrators prior to fabrication. Figure 6.5 is an example of the architects' drawing specifying the CDP elements, shown on the right side of the green line.

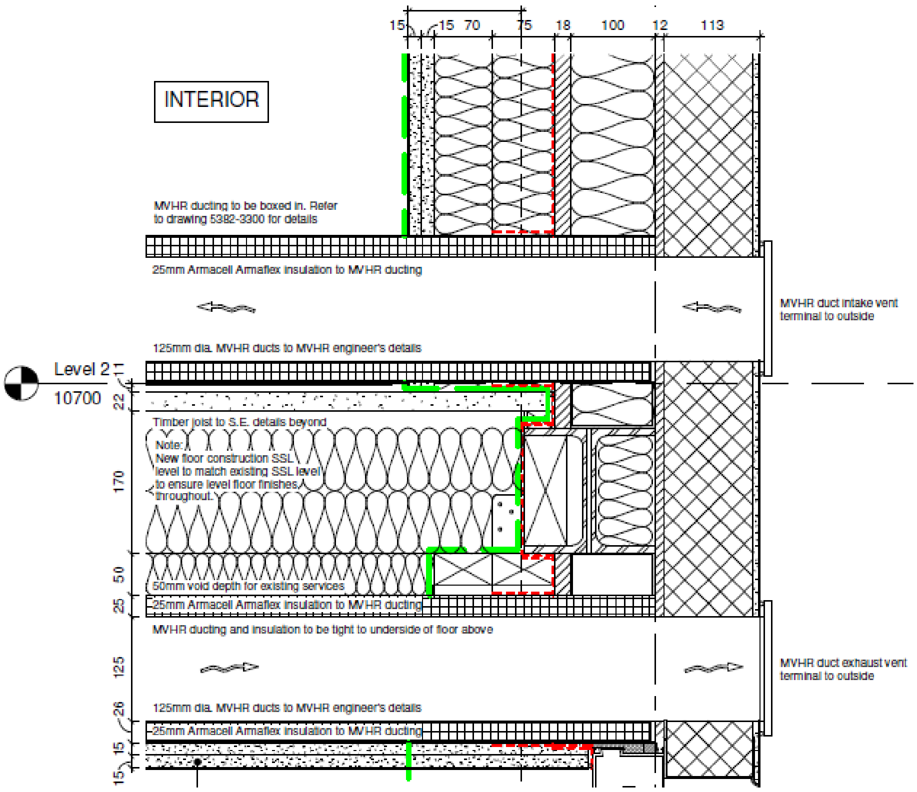

Figure 6.6. Typical MVHR vent detail, construction elements to the right of the green line are contractor's design portion (ECD Architects, 2013).

As will be discussed in chapter 8, the CDP element of the contract later became a controversial issue among the teams working on site. Interviews with the architects shed light on the reasons behind their decision to specify the CDP elements. The architects pointed out that Wilmcote

House was more than forty years old and had not undergone significant repairs during its lifetime, meaning that the quality of its structure and construction were inefficient from the beginning. Consequently, it was expected that the building was not in a good physical condition. They believed that the building investigations they undertook at the beginning of the project could not possibly provide them with sufficient information about all the building elements and any potential defects. According to architect A (2015), this type of information could only be attained while working on site. During an interview, architect A (2015) explained that tower block refurbishment projects involve encountering unexpected conditions on site. Their previous tower block refurbishment project, the Edward Woods Estate tower blocks, was delayed due to some unanticipated circumstances. For instance, some faults and gaps between slabs made the structural concrete frame repairs more extensive than initially expected (Bates, et al., 2012). Thus, they did not want to finalise their design for Wilmcote House. Furthermore, they did not want to be too prescriptive, giving freedom to the contractor (Architect A, 2017). It should be noted that the architects emphasised during the interviews and on other occasions that they had designed most of the elements to assist the contractor with the CDP elements.

6.5 Conclusions

Unlike the fabric over-cladding and heating system upgrade, the development of an airtightness strategy and MVHR system were specific requirements for EnerPHit, with the former playing a critical part in the refurbishment scheme. The architects carried out extensive planning and design to define the airtight zone, identify the location of the airtightness layer, specify the airtightness materials and installation details, prepare the airtightness instructions with regard to the construction process, and specify the air tests that were detailed in the tender documents. The specific layout and construction of the building affected the architects' airtightness strategy. For instance, they found it challenging to create a single airtight zone due to complications with the building design. Thus, they divided the building into volumes with separate airtight layers. This solution would reduce the challenges of compliance with the airtightness requirement, specifically in terms of detailing and undertaking the air tests.

The architects faced certain challenges with specifying the MVHR system. They had to utilise the existing risers for the distribution of ducts, and could only situate the MVHR unit within a cupboard at the entrance of each flat. These requirements created limits with the specifications of unit size and type of ducting arrangement. This type of problem is related to the integration of MVHR to existing buildings where there is no provision for its installation. Nevertheless, the fabric specifications of the EnerPHit scheme created further challenges. The enclosure of walkways due to the EnerPHit requirements meant that the intake and exhaust ducts had to be extended from inside the maisonettes along the width of walkways to reach the ambient air. This would increase the heat loss and reduce the efficiency of the system, resulting in a potential lack of compliance with EnerPHit requirements.

This chapter detailed how the building fabric, airtightness, and MVHR system were specified as part of the Contractor's Design Portion. Thus, it was the contractor's responsibility to ensure the achievement of EnerPHit targets. Even though the architects designed most of the refurbishment elements, they did not finalise the design. The architects used PHPP as a tool to develop the EnerPHit fabric specifications and to examine compliance with some of the main EnerPHit requirements such as the annual heating demand. However, being committed to achieving EnerPHit on site, the contractor had to use PHPP to assess the design against all EnerPHit criteria such as primary energy demand that was not previously examined by the architects.

Chapter 7: Contractors' preparations to achieve EnerPHit before the commencement of construction

7.1 Introduction

The previous chapters examined the process leading to the client's decision to upgrade Wilmcote House according to the EnerPHit standard, and how the architects designed the EnerPHit refurbishment scheme. As discussed in chapter 6, the architects utilised a Standard Building Contract with a Contractor's Design Portion. Accordingly, the contractor was responsible for finalising the architects' design and achieving EnerPHit. This chapter examines the appointment of the contractor and the period of transition between design and construction. Over this period the contractor and their consultants took necessary actions in preparation for the construction stage. This chapter reveals that to develop a quality assurance strategy to ensure EnerPhit compliance, prior to the commencement of construction, the contractor closely cooperated with Passivhaus consultants, the site architect, and structural engineers. As part of this process, they reviewed the architects' design specifications and planned the construction sequences. Similarly, they made provisions for developing an airtightness test strategy and training the tenants about the components of EnerPHit. This chapter indicates that this transition period was a significant stage of the project where it became clear that Wilmcote House would not meet the primary energy required by EnerPHit, and the crucial future steps that would be needed to ensure its full compliance.

7.2 Appointing the contractor

As explained in the previous chapter, the client and the architects decided to separate the design from the construction. According to an interview with ECD Architects, they were responsible for preparing the tender documents and assisting Portsmouth City Council with appointing the contractor. In Passivhaus projects, producing the tender documents is a demanding process. Hopfe and McLeod (2015) point out that tender documents should be highly comprehensive as to the levels of expected performance. They explain: "The key here is that the building standards and specifications are clearly identified and adhered to". The level of detail included in the tender documents impacts the contractor's capability to achieve Passivhaus targets on site. ECD Architects explained that although it was the responsibility of the contractor as per the Contractor's Design Portion to complete the design and carry out the construction stage, they made every effort to design as much as possible of the refurbishment elements to facilitate the contractor's works (Architect B, 2016).

Investigating the tender documents reveals that the architects produced highly detailed design drawings, including specifications and instructions which would be superfluous in a conventional project. The additional information provided for the Wilmcote House tender mostly related to achieving the airtightness requirement. Unlike a typical refurbishment, a critical aspect of an EnerPHit project is the provision of an elevated level of airtightness. As pointed out by Bere Architects (2012), architects should take responsibility for airtightness at the design stage, producing sufficient details to assure the buildability of the scheme. ECD Architects prepared detailed drawings to a scale of 1:5, showing the location of the airtightness layer in the different parts of the building fabric, such as the roof and the external walls. It should be noted that these details were produced with the purpose of guiding the contractor and did not necessarily display the right dimensions. As specified in all Contractor's Design Portion drawings produced by the architects, the contractor had to check the drawing dimensions prior to the launching of construction. In addition to the airtightness details, the architects had included the specifications of all the airtightness materials to be utilised in the project and instructions for the necessary air tests. Thus, the architects had significantly higher input in preparing the tender documents in comparison to a similar project not aiming for EnerPHit.

With regard to appointing the contractor, the architects explained that only six contractors responded to the client's tender request; nonetheless, four of them withdrew their bids due to potential project risks (Architect A, 2015). This suggests that they considered the project to be too challenging and were unsure they could meet with EnerPHit requirements. The interview with the client revealed that there was uncertainty at this stage because there were only two bids under consideration, leaving them unsure as to whether the received bids contained the desired qualities (Maintenance manager A, 2016). Out of the two remaining contractors, Keepmoat was selected as the winner. Considering that it was the first tower block refurbishment designed to achieve EnerPHit, the questions arise: What were the criteria the bids were assessed against? How would the contractor demonstrate they were capable of complying with EnerPHit criteria?

Reviewing the invitation for tender showed that the main requirements specified by the client addressed compliance with EnerPHit, the scale of the project, and communication and liaison with the residents (Buckwell, 2013). In terms of achieving EnerPHit, the contractors needed to demonstrate their knowledge of Passivhaus principles and their adaptability to existing high-rise buildings. They were required to propose a method for ensuring compliance with EnerPHit airtightness standards, weighing its stringency alongside conventional specifications. Another requirement related to the training aspect of EnerPHit: the contractors needed to identify their plans to train the residents about the control and function of the MVHR system, and other mechanical and electrical installations. Another evaluation area concerned the contractors' method for carrying out construction while the tenants occupied the building. The contractors had to identify strategies to communicate with the residents to keep them updated on the progress of the works, and to liaise with them regarding access to their properties during the refurbishment. Lastly, the contractors were required to provide the details of a similar project that they had been previously involved in to demonstrate their proposed methods were pre-tested and the management team and site staff had the relevant qualifications and experience needed for this type of project (ECD Architects, 2013).

The bid from Keepmoat was selected due to its compliance with the tender criteria; however, architect A at ECD Architects explained that what particularly distinguished it from the other bid was that it indicated a better understanding of EnerPHit targets, principally the airtightness requirement. Architect A (2015) pointed out that Keepmoat's bid benefitted from the input of Passivhaus consultants (Encraft) and site architects (Sustainable by Design) employed for the development of their bid. The interview with the contractor indicates that they did not have previous experience of EnerPHit (Contractor's design manager A, 2016), but they had made considerable effort to become familiar with the standard throughout the engagement of specialist consultants. According to Helen Brown, a Passivhaus consultant at Encraft, they assisted Keepmoat with understanding EnerPHit requirements and developing a strategy for achieving the airtightness target (Brown, 2015). Architect A (2015) argued that the methodology and rigorous documents provided satisfied the architects that Keepmoat had an acceptable amount knowledge of EnerPHit airtightness requirement. The interview with architect A (2015) revealed that despite producing strategies, Keepmoat had doubts over the achievability of the EnerPHit airtightness requirement on site; thus, one of the major challenges the architects encountered was convincing the contractor that they were capable of meeting this objective.

7.3 The alterations during the tender stage

The interviews with the architects, the comparisons between the tender documents and the final contract, and the documents produced by Encraft such as their PHPP calculation results revealed that after the involvement of the contractor and the investigations of their consultants, some alterations were made to the project scope and design specifications identified in the tender documents. The most significant change was the target of the project decreasing from achieving full certification to merely meeting with the airtightness requirement of EnerPHit. This section aims to examine the alterations at this stage of the project and explore how the involvement of the contractor affected it.

7.3.1 Changes to contract requirements

As explained in the previous chapter, the architects developed the refurbishment scheme according to EnerPHit criteria, specifying that the contractor was responsible for achieving EnerPHit by referring to their design specifications. According to the interview with architect B, the contractor and their consultants such as the Passivhaus consultants, structural engineers, and site architects reviewed the tender documents prior to contract finalisation. The specific responsibilities of the Passivhaus consultants were utilising PHPP to calculate the project outcomes based on the architects' design specifications, enable the EnerPHit certification process, and assist the contractor with developing ventilation and air-tightness strategies (Brown, 2014). Architect B (2016) pointed out that Encraft carried out comprehensive calculations utilising all the available data, such as the fabric specifications, the heating system, and the MVHR specifications, producing the final results for annual space heating and cooling, airtightness, and primary energy demand. At this stage, it was revealed that the building would not comply with the primary energy requirements if electric heaters were utilised. According to Encraft, upgrading to more efficient electric heaters would enhance the controllability and comfort of the tenants, but would not reduce the primary energy demand to the level required by EnerPHit (Brown, 2014).

As discussed in chapter 5, the utilisation of individual gas heating systems proved unworkable due to the structural weakness of the building, resulting in the client rejecting the proposal for a communal heating system; nevertheless, both options would lead to attaining the primary energy demand. Despite the unlikeliness of full compliance with EnerPHit, the client did not change their views regarding the choice of heating system. They even concluded that they wanted to maintain the existing heaters to avoid additional costs, recognising the familiarity of the tenants with the existing heaters; additionally, replacing the existing heaters with new electric ones would not result in compliance with the primary energy demand (Architect B, 2016). During an interview, maintenance manager A at the Council explained that full compliance with EnerPHit and achieving an EnerPHit certification, were not their priority. From the beginning, their main priorities were tackling fuel poverty and the provision of comfort. They found the fabric upgrade sufficient to achieve these targets, finding full EnerPHit certification unwarranted. Under the circumstances, the contractor called upon changing the contract requirement for achieving the EnerPHit standard. As explained by architect A (2015) at ECD Architects, the client and the architects concurred, and consequently, revised the contract condition to instead comply with the EnerPHit airtightness requirement.

It should be pointed out that despite this contractual alteration, the stakeholders continued to contemplate the possibilities of EnerPHit compliance and potential certification. The meeting minutes kept during the construction stage indicated that this issue was discussed repeatedly during meetings between 2014 and 2016. According to these minutes and the interviews with ECD Architects, Encraft attempted to negotiate with the Passivhaus Institute over the restriction of piped gas, due to the difficulty of meeting with the primary energy demand of EnerPHit in a Large Panel System block. Encraft requested flexibility with regard to the primary energy requirement, and the granting of EnerPHit certification on the condition that Wilmcote House met all other EnerPHit criteria, but this was refused by the Passivhaus Institute (Architect B, 2015). Nevertheless, as discussed in chapter 5, they introduced new routes to compliance with the primary energy demand through the utilisation of renewable energy. For Large Panel System blocks such as Wilmcote House, this provides a new opportunity to meet EnerPHit.

Portsmouth City Council confirmed their interest in installing Photovoltaic Panels in Wilmcote House. However, according to a 2016 site meeting, the costs of the panels were unaffordable at the time of project completion, so this alternative remains under consideration for future application. Consequently, completing the upgrade of Wilmcote House and achieving EnerPHit in one step proved unfeasible, making future measures essential. This is the approach promoted by "EuroPHit", a project aiming to provide solutions to deep and step-by-step refurbishments (Anon., 2014). As part of the EuroPHit project, some residential and non-residential buildings across Europe have been retrofitted according to Passivhaus principles. This project is a response to EU energy saving targets such as 20% improvement in energy efficiency and 20% cut in carbon emissions by 2020[36]. According to the European Commission (2013), deep retrofits can generate significant savings in future energy consumption and costs;

[36] "The 2020 package is a set of binding legislation to ensure the EU meets its climate and energy targets for the year 2020. The package sets three key targets:

- 20% cut in greenhouse gas emissions (from 1990 levels)
- 20% of EU energy from renewables
- 20% improvement in energy efficiency

The targets were set by EU leaders in 2007 and enacted in legislation in 2009." (European Commission, 2013) whereas partial retrofits without overall future planning may result in a clash with any refurbishment works required at a later date. As in the case of the Wilmcote House refurbishment, one-off deep retrofits may prove challenging due to factors such as financing, motivation, and disturbance to residents. Through a step-by-step retrofit, current works can be future-oriented. For instance, if a façade requires renewal, simultaneous additional works can be implemented to maximise the thermal protection of the exterior walls (Brown, 2016). After becoming aware of the plans to achieve EnerPHit in Wilmcote House, the UK partner of the EuroPHit programme, BRE selected the Wilmcote House refurbishment as the UK case study for EuroPHit. It is notable that EuroPHit has partners in a considerable number of European countries, typically research associations promoting the Passivhaus standard. Each partner monitors a EuroPHit case study in the country they are based. Across a number of countries, EuroPHit provided Passivhaus and step-by-step retrofit trainings for architects, engineers, and contractors involved in these specific projects (EuroPHit, n.d.). In the UK, BRE funded the Passivhaus training for a number of architect and contractor's team members involved in the Wilmcote House project.

Passivhaus consultants employed by the contractor planned the steps of the Wilmcote House refurbishment so that any works found unachievable at the present time, had the potential for future completion. As explained by Brown (2016), the EuroPHit project utilises a method called the modernisation route planner. Believing it necessary to plan a route due to the interdependency of different energy efficiency measures a comprehensive retrofit plan is developed before the first renewal step for the cost-effective achievement of retrofit targets. A Passivhaus designer or energy consultant is responsible for preparing the overall retrofit concept with the modernisation route planner. The planner identifies all the future steps, removing the need for planning at every stage, and clarifying the energy demand and time points needed for future measures. Consequently, this facilitates the financial planning for a project, utilising a Passivhaus certifier to evaluate the efficiency of the modernisation route planner. The first step can be implemented if the evaluation shows that EnerPHit will be achieved after the completion of the planned measures (Brown, 2016). Encraft produced a modernisation route planner for the Wilmcote House refurbishment, identifying three types of future works: replacement of the heaters, insulation of ground floors[37], and installation of PVs.

[37] According to the interview with site architect John Pratley, the existing concrete ground floor could not be broken due to structural issues related to the prefabricated concrete panel system; thus, it was unfeasible to install insulation beneath the slab. Furthermore, it was not feasible to apply insulation over the slab because of the

Accordingly, the refurbishment of Wilmcote House required the stipulation of three main steps to be carried out by 2016, 2020, and 2025. The first step was to upgrade both the fabric and the ventilation system, identifying measures such as the insulation of the external walls and the installation of MVHR systems[38]. The second step included the installation of new electric heaters and the final step was to install PVs and insulate the ground floor (Anon., 2014). Thus, Wilmcote House was expected to comply with all EnerPHit requirements except for the primary energy demand by the completion of step one, and to meet all EnerPHit requirements by the end of step three. The summary of the modernisation route planner prepared by Encraft can be found in the following figure.

Retrofit step No.	1-Existing Pre-Refurbishment	2-Step 1 - fabric plus new ventilation	3-Step 2 - new heating system	4-Step 3 - Ground floor insulation + PVs
Year	Until 2014	2016	2020	2025
Measures				
Occasion ("anyway measure")		Window replacement	New heating systems	New ground floor
Energy-saving measure		Passivhaus windows	Energy efficient heating system	Insulated ground floor
Occasion ("anyway measure")		New façade		New roof covering
Energy-saving measure		External wall insulation		PV
Occasion ("anyway measure")		New ventilation system		
Energy-saving measure		Heat recovery ventilation system		

Figure 7.1 Modernisation route planner (Encraft, 2015).

It should be noted that the aim of the modernisation route planner is to inform the client about potential future improvements and the path for meeting EnerPHit, but neither the architects nor the contractor had any commitments regarding possible future works. The route planner contributed to organising the refurbishment works in a way that maintained the opportunity to achieve EnerPHit, without the requirement to make alterations to the works carried out in step one. Put another way, compliance with EnerPHit would be accomplished through additions, rather than alterations.

7.3.2 Changes to the MVHR specification:

Another important alteration during the tender stage related to the MVHR specification. As discussed in chapter 6, the MVHR system specified for Wilmcote House was the Paul Focus 200 with rigid metal ducts arranged in a branch system. Nevertheless, this proved an inefficient option due to the long metal ducts that would need to extend from the maisonettes to the

insufficient floor to ceiling height, but this could hypothetically occur in the future after a potential price reduction of very thin but high-performance insulation (Pratley, 2017).

[38] This step reflects the current refurbishment project, scheduled for completion by 2016. Nevertheless, this date has since been postponed several times.

external surface of the walkways, increasing the heat transfer, and requiring such a high level of fan power that it would risk compliance with its associated EnerPHit requirement. Additionally, the meeting minutes reveal that the client found this to be an uneconomic option. Thus, an alternative system called Zehnder ComfoAir was adopted after the contractor’s appointment. From a different standpoint, this system would be more suitable for utilisation in Wilmcote House. It included a compact ventilation unit, meaning it would fit well inside the cupboards in the entrance of maisonettes where the units needed to be installed, but more importantly the ducts were made of plastic with highly insulated intake and exhaust ducts; thus, the system minimised the heat transfer through the relatively long distance between the unit and the outside air (Architect B, 2016). Consequently, the calculations showed that when installed in Wilmcote House maisonettes, the system would meet EnerPHit requirements. In addition to its efficiency, the initial quotation for the Zehnder system indicated that it would be more cost-effective than the Paul system; thus, the client approved the alteration to its MVHR specification. Generally, it can be expected that the advances in future MVHR system technology will provide more efficient systems at lower costs.

7.4 Refurbishment program

According to the site architect’s report on the refurbishment of Wilmcote House, the contractor and their consultants developed a program to identify the works required to be undertaken to ensure compliance with EnerPHit on site and to meet the contract requirements (Pratley, 2016). The most important tasks planned were the review of design details, the development of a quality assurance system, an air test strategy, construction sequencing, and a training program. Some of these tasks, such as the air test strategy, were related to achieving EnerPHit, while others such as the construction sequencing would be required regardless of the project benchmark; nevertheless, they would be affected by EnerPHit requirements. The review of the contractor’s refurbishment program reveals that the task was planned with an elevated level of detail and cross-team cooperation.

7.4.1 Quality assurance framework

According to the site architect’s report on the on-site refurbishment program, the site architect and the contractors utilised a quality assurance system to carry out the Wilmcote House refurbishment, finding this essential for EnerPHit compliance in such a large-scale project. According to P.C.Chan (1996), “the concept of Quality Assurance has arisen to ensure that customer demands, and a level of quality and conformance are achieved”. Chan (1996) argues that this is realised through fundamental management strategies controlling the activities undertaken by each party involved in the construction. It should be noted that adhering to a quality assurance framework is not mandatory in the UK. The question is: Why the contractor found it necessary to utilise a quality assurance system to achieve EnerPHit in Wilmcote House? Generally, using a quality assurance system in UK construction projects would be advantageous because there is often a performance gap between the predicted and in situ thermal performance of the fabric (Johnston, et al., 2015). Passivhaus projects are more rigorous than conventional construction practices in terms of the required on site performance, the knowledge for meeting the airtightness requirement, the installation of the MVHR system, and the building insulation (Visscher, et al., 2009). In fact, a Passivhaus building is very sensitive to the quality of construction (Visscher, et al., 2009) due to its strict requirements, such as an airtightness target over five times that of UK building regulations. Consequently, a quality management system is an imperative, more so than it would be in comparative conventional construction projects.

As discussed by Siddal (2015), Passivhaus building projects, particularly large and complex ones, require very efficient quality assurance systems to maintain the necessary design and construction standards. Without recourse to quality assurance, problems may be encountered such as delays in project completion, a significant level of additional costs, and failure to achieve the contract requirements. According to the site architect, the quality assurance method developed for the Wilmcote House project was based on guidelines provided by the Passivhaus Trust in a report prepared by Mark Siddall called “Passivhaus Quality Assurance: Large and Complex Buildings” (Pratley, 2016). This is currently the only comprehensive guide provided for this specific purpose available in the UK. As explained in this guide, Passivhaus validates the performance of materials and products and the quality of works through PHPP and the applicable BS EN standards. However, it does not dictate a specific method for quality assurance during the works. The following box explains the methods proposed by the guide.

Box 7.1: Quality assurance system for large and complex buildings (Siddall, 2015)
Project management checklist: The major components of a Passivhaus project and their integral sub-components should be matched with their relevant BS EN standards. One of these components is the installation of insulation on the walls, roof, floor, windows, junctions, and services. Another key component is airtightness. To examine its efficiency, the air barrier system, the window installation, and service penetrations required checking. Other services to be assesses include the MVHR installation, the MVHR ductwork and silencers, the Domestic Hot Water (DHW), pipes and plumbing, heat sources, and controls. Builders work should be examined, including the joinery, such as door undercuts. The design and construction team should gather photographic evidence at key construction stages. The Passivhaus consultant is expected to assist with the method of evidence compiling.
Desktop buildability reviews: This includes a complete examination of construction drawings, specifications, and sequencing, resulting in the identification of the risks which may affect project delivery. Buildability reviews enable the project team to develop strategies to collaboratively deal with potential risks (Siddal, 2015).
Buildability workshops: The design team, contractors, and site managers can participate in focus groups to assess and analyse the results of the desktop buildability reviews.
Tool box talks: These are formulated to train and up-skill site trades people by involving them in the planning of the construction sequences, all the while allowing for the incorporation of further data into the buildability analysis. All sectors such as roofs, walls, and foundations impact the success of a project; therefore, participation of all the on-site teams is necessary. The tool box talks may include the review of each detail, its construction sequence, the technologies required for construction, and the trades which will affects its completion. Collaboration between the participants can increase the session productivity. Each participant can raise their concerns so others can attempt to address them.

Intermittent site inspections and site inspection reports: Site inspections by the design team are necessary for identifying any risks. Following the inspection, a site inspection report should be prepared in order to record and resolve risks before commencing the following stage.

Generally, inspections include the installation of insulation, the application of insulation at junctions, the airtightness of service penetrations, site storage, the MVHR installation, MVHR commissioning, and below-ground and above-ground fabric. In addition to handing over the reports, the design team should discuss the contents with site managers. It would be beneficial to include lessons learned from the site visit in the inspection report to review them in future stages and future projects.

On-site quality assurance champion: An on-site quality assurance champion should be appointed and trained to make sure that the building achieves the airtightness target. The responsibilities of this role are to ensure the proper installation of the insulation system, to arrange airtightness tests, to organise tool box talks for all trades, to review the sequencing of construction process (buildability of air barrier, wind barrier, insulation systems), carry out daily site inspections, and to ensure that the materials specified by the designer are used. Change management: It is likely to consider cost cutting options during the construction of projects. Management tools including change order requests should be utilised in case of any changes. Certain changes orders in Passivhaus projects should be checked by the Certified Passivhaus Designers. These changes include designs such as position of windows within the walls, products (MVHR,…), materials (insulation,…), sequencing and staff changes.

The box above suggests that the quality assurance guide focused primarily on quality control, risk detection and prevention, staff training, and cost-effectiveness. Similarly, it is evident that the process specified by the guide required a significant level of cooperation and team work. According to the site architect (2017), all the quality assurance methods explained in the box were utilised in the Wilmcote House project. Desktop buildability reviews and buildability workshops were arranged to review the construction sequencing. All the teams who were working on site received EnerPHit training via toolbox talks and workshops. In terms of the airtightness requirement, contractor's design manager A was appointed and trained as an on site quality assurance champion (Contractor's design manager A, 2016). According to contractor's design manager A (2016), all the stages of the refurbishment works, particularly those relating to airtightness, were photographed and filed for use as evidence in case of any problems being detected (Contractor's design manager A, 2016).

Regarding site inspections, the author observed regular visits to the site were by the project architects, the site architect, and the Passivhaus consultants. Furthermore, the stakeholders held monthly meetings to raise potential issues and develop solutions, with problems discussed pursued in later meetings. The meeting minutes were recorded and archived by the teams. Consequently, all the stakeholders, including the client and the project architects, were actively engaged in the quality assurance process; nevertheless, the site teams had higher input due to their responsibilities at the construction stage. Explained below, the application of quality assurance methods is reflected in the contractor's different pre-construction activities.

7.4.2 Design review

As explained earlier in the chapter, the design of elements specified as part of the Contractor's Design Portion were not finalised by the architects. According to the site architect (2017), the design drawings included in the tender documents were reviewed by the site teams to examine the feasibility of achieving them on site, detect potential problems, and make necessary amendments. This was part of the quality assurance process. Following the review process, the site architect replaced some fabric and airtightness materials specified in the tender documents with more appropriate or cost-effective alternatives. This conformed with the "change management" strategy included in the quality assurance guidelines. For instance, instead of the parge coat proposed by the project architects, the site architect decided to specify the existing concrete walls of the building as the airtight barrier. According to the site architect (2017), this alternative was more cost-effective and less technically challenging. Another major outcome of the design review prior to the commencement of construction was the alteration to some of the structural specifications.

As explained in chapter 5, structural engineers appointed by the project architects, had proposed the installation of steel frames to carry the high level of insulation required to achieve EnerPHit. To ensure that the weight of the insulation and frame did not overload the structurally unsteady arrangement of balcony, deck and fins on the courtyard façade, the steel frame on this façade was to be self-supporting with new independent foundation piles (Ijeh, 2015); however, the frame on the street façade would be fixed to the existing foundation. According to the interview with the project architects, the contractor's in-depth analysis[39] revealed that the structural detail of the street façade was unrealistic, requiring the contractor to specify larger

[39] The in-depth analysis included vacating and then digging into the ground floor, and testing the foundation slab (Architect B, 2015).

beams and design their attachment to the existing foundation to prepare the structure to carry the insulation on its street façade. The process of amending details and specifications was time-consuming, leading to a delay in the commencement of the project (Architect B, 2015). Following the design review, the contractor's alterations indicate this stage's significance when assessing the feasibility of EnerPHit compliance and the possibility of more fit-for-purpose solutions. It is worth noting that the design review and revisions did not end at the commencement of construction. According to the contractor's design manager A (2016), they encountered challenging situations during construction, requiring the site architect to provide design solutions.

7.4.3 Construction sequencing

As discussed by Hopfe and McLeod (2015), in the main stages of the construction process of a Passivhaus project, planning and coordination is essential to avoid a gap between the predicted and actual performance of the building. In other words, construction sequencing is an important stage of quality assurance in Passivhaus projects, particularly in terms of meeting with airtightness requirements. The project architects' design specifications and instructions included within the tender documents specified the main works required to achieve EnerPHit. According to these documents, efficiency of the building fabric had to be maximised by creating an even and superinsulated façade, installing Passivhaus windows, and replacing the existing roof with an efficient one. These works would result in minimising heating demand and preventing thermal bridges. To create an even and seamless façade, it was necessary to extend the living rooms on upper floors of the maisonettes and to enclose the balconies and the open access walkways. Prior to installation of external insulation, an external steel grillage had to be installed to each façade. To achieve the airtightness target, specific products had to be applied to each thermal zone specified by the architects. Air tests were required to be carried out to detect any air leaks and to seal them before the progression of the works. Furthermore, it was essential to install an MVHR unit and its required ductwork within each maisonette.

The sequencing required structuring for the purpose of achieving EnerPHit requirements. Box 7.2 explains the construction sequencing planned by the contractor. As can be seen, the first steps of the works were to be the structural measures, as prior to stabilising the building commencing other works would prove unfeasible. As a result, the installation of MVHR was one of the last measures to be undertaken after the completion of the fabric upgrade. One possible challenge was the tenants' occupation of the building during construction, needing the contractor to sequence the works in a way that disturbance would be minimised to the tenants' lives. As explained in chapter 5, it was necessary to extend the living rooms on the courtyard façade to create an even façade. Nevertheless, this was impossible without the removal of the existing living room walls. Due to the tenants' presence, the contractor had to provide temporary walls and remove them at the right time.

Box 7.2: Sequence of works (Pratley, 2016)

- Structural works: completion of the ground beams, piling on the courtyard façade, erection of the scaffold, crashing the decks of the courtyard façade, undertaking concrete repair surveys, carrying out the concrete repairs.
- Erection of the steelwork specified for carrying the insulation.
- Installation of insulation.
- Installation of the Passivhaus windows, then completing the airtightness layer around the windows.
- Carrying out interim airtightness tests.
- Installation of the ductwork associated with MVHR and the MVHR unit.
- Replacement of the kitchen windows and the entrance doors on the lower levels of the maisonettes (the new kitchen windows are inoperable for fire safety reasons).
- All the remaining internal works, such as drylining.

The street façade would be complete following the superinsulation of the external walls. Nevertheless, on the courtyard side, additional works were required to extend the living rooms, enclose walkways and balconies, and create an even façade. The existing living room doors, windows, and balcony balustrades would be removed, with temporary screens erected in living rooms during the extension works. Utilising temporary screens was necessary because during the refurbishment, the tenants would continue residing within the maisonettes. Following the completion of this stage, temporary screens would be removed and new balcony screens and doors would be installed. While extending the living rooms at upper floor, external wall insulation and rainscreen cladding would be installed at the lower floors.

7.4.4 Training programs

All project staff and tenants received some level of EnerPHit training, as it is one of the more critical parts of Passivhaus projects. Without a sufficient understanding of Passivhaus, the architects will not be capable of developing an effective design, and the residents will not efficiently utilise the building and recent technologies such as MVHR. More importantly, the site teams will not meet EnerPHit requirements on site. In constructing a Passivhaus project, it is essential to develop a deep understanding of the importance of airtightness and how to deliver an airtight construction without thermal bridges. This understanding can be mostly achieved through training and practical experience (Hopfe & McLeod, 2015). Thus, training becomes an unavoidable and ongoing process in Passivhaus projects, because each new staff member will require educating. In the case of the Wilmcote House project, the architects had not received training at the design stage as they were previously familiar with the standard. According to the interview with architect B (2015), BRE provided full Passivhaus training to the architect and the contractor teams prior to the construction stage. This was part of the EuroPHit training courses planned for summer 2014 in all of their partner countries, and coincidentally, precisely before the commencement of the Wilmcote House construction stage (EuroPHit, n.d.). It is worth noting that in the UK, designers and contractors can attend the available certified Passivhaus trainings courses to become prepared to undertake Passivhaus and EnerPHit projects. A Passivhaus certified designer course in the UK cost around £2800 in 2017 (Passivhaus Trust, 2017). Normally, the Passivhaus training expenses increase the total costs of the project. Nevertheless, this was very much not the case for the Wilmcote House project.

While BRE had trained the architects and contractors, it was the responsibility of the contractor to train the building residents and workers on site. Training the workers was of utmost importance. As discussed by Mark Siddal (2015) in his report of Passivhaus quality assurance methods, the key to handling project risks and financial risks after the beginning of works on site is ensuring that site teams have been provided with sufficient training, preparing them to achieve the project targets. Generally, it is necessary to ensure that any UK workforce receives Passivhaus training as they are not believed to have enough knowledge and skill to carry out construction projects with low energy targets (Gambin, et al., 2012).

It is argued that in comparison with countries such as Germany and Austria, the UK has a less well-trained construction industry (Lynch, 2013). In their, ‘Passive House Solutions’ report, the Passivhaus Institute recognised some of the main barriers to achieving Passivhaus in the UK to be workforce skill levels, on site build quality, and adoption of additional details for large house builders (Strom, et al., 2006). Additionally, Kym Mead, the head of Passivhaus at the BRE, suggested that the level of attention to detail required to achieve Passivhaus, particularly relating to airtightness, has been missing in the UK construction sector (Buxton, 2012). As explained earlier, the key members of the contractor team attended Passivhaus courses before they started works on site. During the construction stage, each sub-contractor and worker joining the project received relevant training through workshops organised by BRE or the contractor (Contractor's design manager A, 2016). As observed by the author, the main focus of these workshops was to provide knowledge of the airtightness requirement and its significance in the EnerPHit standard, to introduce airtightness products, and the details of their installation. As discussed in the next chapter, the contractor encountered difficulties with providing training to all the site staff mainly due to their considerable number.

To train the tenants, the contractor organised events to inform them about the targets and key features of the project (Contractor's design manager A, 2016). According to the contract, the MVHR system was one of the main aspects of the project requiring the residents' comprehension. A large number of studies revealed that MVHR performed negatively when coupled with residents' insufficient understanding and inappropriate interaction with the system. McGill et al. (2015) recall some of these wrong interferences by tenants in social housing. For instance, in some cases, the tenants tried to turn off the system despite being instructed against it. One of the main reasons for this was an intention to save on electrical usage. In another case, some tenants turned on the by-pass[40] mode of the MVHR system in the winter months, and then complained about the system not working efficiently. According to the site architect (2017), to minimise the potential of problems resulting from tenant interference, the council decided to limit the residents' control over the system. The residents cannot access the system settings; in fact, they are limited to a boost switch, designed to accelerate ventilation in wet rooms. Limiting the control of the system simplified the training to only covering general information about the system, and guidance on when to use the boost switch.

[40]"The summer bypass function provides fresh air and extraction in the warm season without heat recovery." (Paul Heat Recovery, 2014)

7.4.5 Air test strategy

As discussed before, it was the responsibility of the contractors to carry out airtightness tests. Some requirements of the tests explained in chapter 6 were specified by the architects; nevertheless, the contractor was required to develop an overall air testing strategy. The interviews with the contractor, site architect, and Passivhaus consultant revealed that the contractor encountered serious difficulties with devising an air test strategy (Site architect, 2017) (Passivhaus consultant A, 2017) (Contractor's design manager A, 2016). The major challenge for the contractor was that they did not know the most efficient method for defining a test area. In a conventional building, a single test is carried out to calculate the level of airtightness throughout the building, but it would be problematic to achieve this in a tower block due to its scale. There are no specific methods proposed by the Passivhaus Institute in regard to the air testing of tower blocks; however, the Air Tightness Testing & Measurement Association (ATTMA) in the UK has identified requirements for measuring air permeability of building envelopes, including high-rise and multi-storey buildings. According to ATTMA (2016), to carry out air permeability tests in a high-rise building, it might be necessary to employ several fans at various locations to achieve equal pressure across the building. Floors with an area of lower than $4000m^2$ do not require compartmentalisation. Pressure loss through the stairwells can be significant above twenty floors due to the demand for all internal pressures to be within the range of ±10%. Thus, for tall buildings with more than twenty storeys, it may not be suitable to test all the floors in one attempt. Alternatively, a number of air tests can be carried out on a floor-by-floor level.

Based on the ATTMA requirements, the floors in Wilmcote House would not need to be compartmentalised because the area of each floor is less than $4000m^2$. Furthermore, it would be possible to assess the entire block through a single test because the number of storeys is less than twenty. However, the site teams found it challenging to utilise this method, because it was essential that the residents left the building during the test and they argued that it would be unfeasible to evacuate the entire block and keep them outside for a number of hours (Passivhaus consultant A, 2017) (Site architect, 2017). Therefore, they looked for alternative methods. It should be noted that it would be inadequate to test the maisonettes because the enclosed walkways would be included within the building thermal zone; thus, they were also required to achieve the airtightness requirement. The contractor considered testing each maisonette and walkway separately, but this would take an excessive amount of time and be unworkable (Contractor's design manager A, 2016). Subsequently, they devised a strategy to carry out an individual air test for every two floors. Contractor's design manager A (2016) explained the logic behind this strategy was that the maisonettes were spread over two floors and likewise, there was one corridor every two floors. Their plan was to employ fans at the fire exit doors at the two sides of the corridors. During the test, all the entrance doors of the maisonettes opening on to the corridor and the internal doors of the properties would be kept open to connect all the internal spaces within every two floors and all the windows on the street façade would remain closed to separate the internal spaces from the outside space. Each test would be undertaken following the completion of works at every pair of floors. Through this strategy, it would not be necessary to evacuate the entire block and it was less time-consuming than testing the maisonettes and walkways separately. However, it should be mentioned that this alternative remained unused due to the perforations that circulated the air between all the floors. This problem is explored more extensively in the next chapter.

7.5 Conclusion

The investigation of the transition from design to construction reveal this period to be very important in terms of assessing the feasibility of achieving EnerPHit requirements. The contractors saw the Wilmcote House refurbishment as risky, partly reflecting their lack of preparation for undertaking a large-scale EnerPHit project. Thus, the appointment of the contractor was a challenging stage. It is understood that the involvement of Passivhaus consultants played a critical role in the contractor's capability to undertake the Wilmcote House project. In fact, the evaluation of the architects' design specifications and some of the subsequent changes were the outcome of the input of the Passivhaus consultants, particularly their calculations with the PHPP program. Therefore, if Passivhaus consultants are employed at the design stage, there will be fewer design alterations, and the period of transition from design to construction will be less onerous.

One of the contractor's major tasks prior to commencing construction was the development of a quality assurance system to ensure compliance with EnerPHit requirements. The quality assurance process included a high level of quality control through the careful investigation of the design and construction details, the training of the workforce, the regular observation of the project progress, and the constant evaluation of solutions utilised in the project. These tasks would only be accomplished through extensive collaboration between stakeholders. To put it another way, to assure the achievement of EnerPHit requirements, the stakeholders had to cooperate with each other.

The main obstacle to fully achieving EnerPHit in Wilmcote House was the lack of compliance with the primary energy demand; nevertheless, taking a step-by-step refurbishment approach could produce a future opportunity for achieving EnerPHit. According to this method, compliance with EnerPHit could be accomplished through a staged approach when dependant on various factors, such as the financial capability of the client.

Chapter 8: Project Challenges at the Construction Stage

8.1 Introduction

As explained in chapter 7, the selection of the contractor for the Wilmcote House project followed the completion of the design. The contractor team commenced their involvement in the project by preparing and planning for the construction process. They received EnerPHit training, reviewed the project architect's design and made necessary revisions, developed a quality assurance system necessary to achieve EnerPHit, planned the sequence of construction works needed to meet EnerPHit requirements, and arranged an EnerPHit training program for the teams participating in the construction process. The purpose of this was to make provisions for the construction stage and to produce effective solutions to deliver the project successfully. Nonetheless, significant challenges were encountered at the construction phase. One consequence was that the project did not proceed according to plan and fell behind schedule. According to site meeting minutes, piling started on site in September 2014. The project was expected to finish in November 2016, around two years from the start date (Maintenance manager A, 2016). However, the completion date was initially postponed to January 2017 (Rockwool, n.d.); then further delayed to summer 2017 (Architect B, 2017); and after falling further behind schedule, arranged for completion by January 2018.

The delays resulting from the construction challenges led to negative consequences such as cost overrun and disturbance to the residents. Wilmcote House had attracted £700,000 ECO funding; however, this amount was later reduced to £300,000 due to the changes made to the scheme. Delays in work completion in the flats resulted in a loss in the total amount of ECO funding (Architect B, 2016). Furthermore, the residents were permitted to receive compensation for the disruption to their lives caused by the project delays.

The question is: how far did the challenge of complying with the EnerPHit standard contribute to the delays? To find the answer, all the key factors contributing to the delays have been investigated. Interviews with different project teams, site meetings, and direct site observations reveal that some factors such as communication between teams, conformance with design details, and quality control were not specific to the use of EnerPHit; however, meeting the standard meant that these factors became crucial and had more profound consequences than in conventional projects. Nevertheless, problems resulting from issues, such as the sourcing of specific products, were explicitly caused by attempting to meet EnerPHit. Ultimately, there were general challenges specific to the project unrelated to the use of EnerPHit, such as the residents' presence inside the building during the construction. This chapter analyses all three factors and their contribution to the challenges and difficulties encountered during the construction process.

8.2 Form of Contract

Interviews with maintenance manager A at Portsmouth City Council, Contractor's design manager A, and the site architect, suggest that the form of contract and the procurement method adopted were a major source of difficulty. Naoum & Egbu (2015) define procurement method as "a mechanism for linking and coordinating members of the building team throughout the building process in a unique systematic structure, both functionally and contractually. Functionally via roles, authority and power, contractually via responsibilities and risks". Generally, the form of contract or the procurement method plays a critical role in the 'success of the project', measured by its prompt completion, within its budget, and meeting certain quality standards, while simultaneously satisfying the client's expectations (Naoum & Egbu, 2015).

ECD Architects concluded that the traditional procurement method was the most appropriate method to be applied to the Wilmcote House refurbishment project. The form of contract they utilised was the Standard Building Contract with the Contractor's Design Portion procured via traditional method. In this form of procurement, the design process is separate from construction (The Joint Contracts Tribunal, 2011). Before appointing a contractor, the employer has the scheme developed to an advanced stage; therefore, the responsibilities of the contractor are limited to the construction of the project (Hopfe & McLeod, 2015). Generally, a contractor is appointed via a competitive tender process. In the majority of traditional contracts, the client must appoint a consultant to act as a contract administrator. Through their appointed consultant the client controls the design, expected quality, and standards. Normally, the client has certainty on project costs since the cost amount is specified at the outset; however, this amount can be adjusted later. The project programme is relatively long because design and construction are two separate sequential processes (The Joint Contracts Tribunal Limited, 2016).

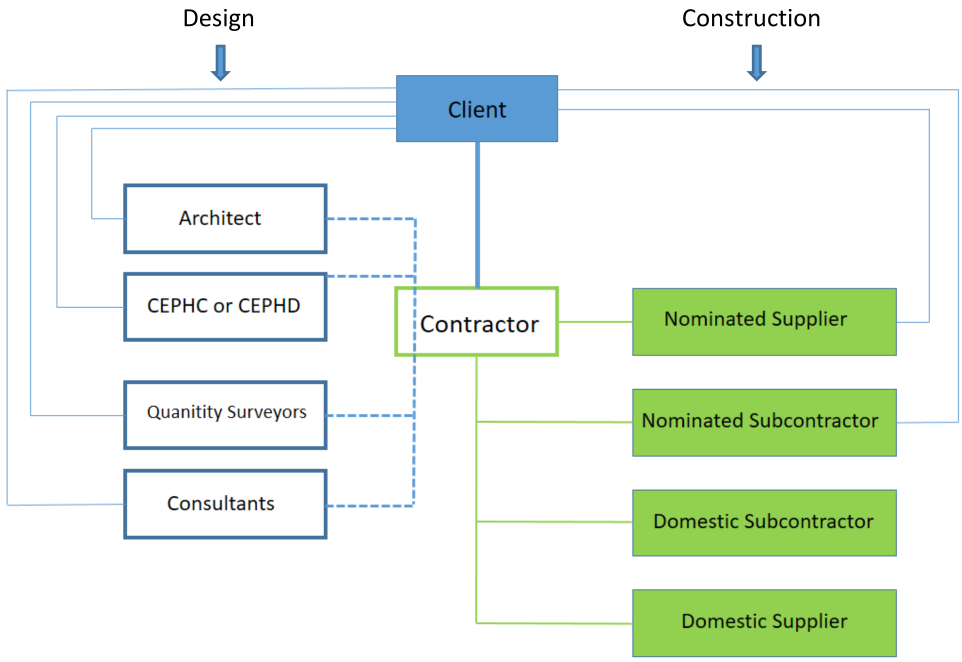

Figure 8.1. Structure of traditional procurement (Hopfe & McLeod, 2015).

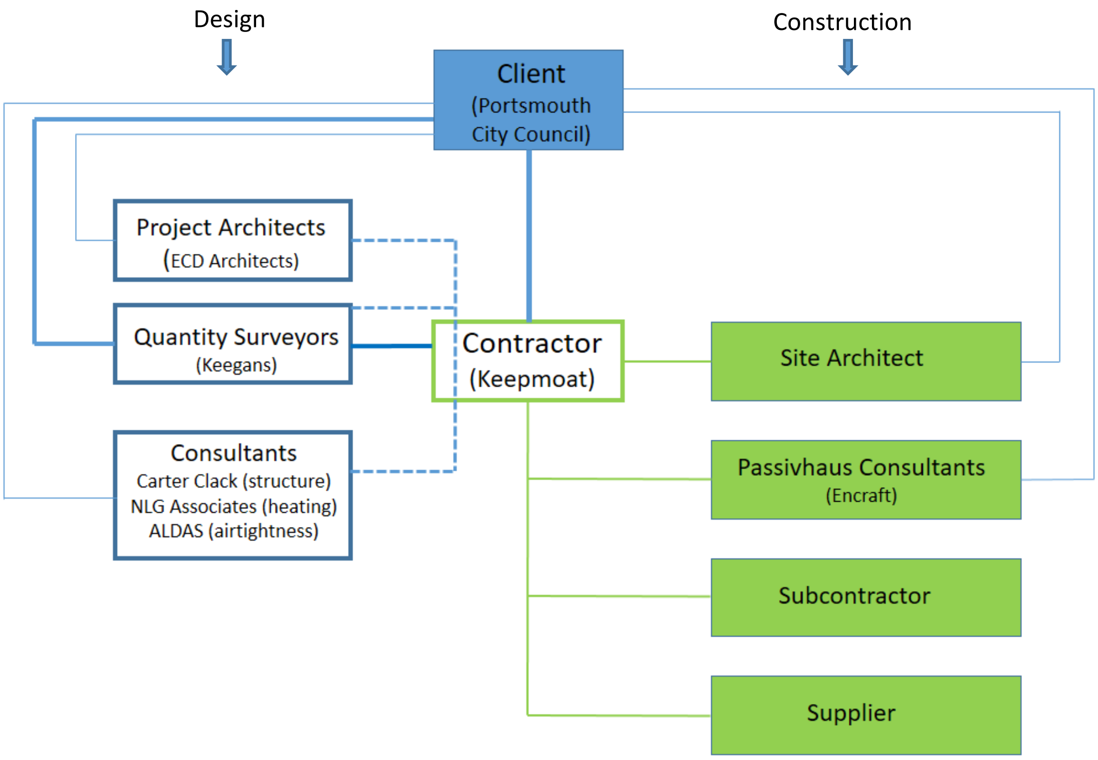

Figure 8.2. Structure of Wilmcote House project contract.

As can be seen from the diagram, under a typical Standard Building contract there are separate design and construction stages. The left side of the diagram shows the teams in charge of the design process, who communicate mainly with each other and the client, but maintain minimal communication with the contractors. Being responsible for the construction stage the contractors work and communicate with the site teams shown on the right side of the diagram, including the suppliers and the subcontractors. The Wilmcote House contract had a similar structure. Nevertheless, due to the CDP elements the contractors were also required to design; therefore, the site architect and the Passivhaus consultants were also among the construction teams. ECD Architects and their consultants prepared the design; thereafter, the contractors reviewed and completed the design with the Passivhaus consultants and the site architect. Keegans, the quantity surveyors, were also appointed to provide project management, and therefore, were present on site during the construction stage. In fact, Keegans was the main communication bridge between the contractors on one side and the client and architects on the other.

This form of contract corresponded to ECD Architects' decision to prepare the design before the involvement of the contractor, specifying the works related to the external layer of the building and the MVHR system as the Contractor's Design Portion. According to architect A (2017) the CDP package: "provided a fully detailed design whilst allowing the contractor to select alternative methods or products to achieve the same performance criteria". The contract between ECD and the client covered RIBA stages 1 to 4[41]. Based on the contract, the architects were only responsible for internal works. Nevertheless, they developed a level 1 BIM[42] model of the project. This level of BIM typically includes a 3D model for concept work and 2D drawings for the "drafting of statutory approval documentation and Production Information" (McPartland, 2014). ECD Architects provided all the technical and detailed drawings for the construction of the project, also preparing a Revit model. However, the Revit model did not coordinate with other disciplines, or to put it another way, the project parties did not share a single project model (Architect B, 2017).

[41] Find more information on RIBA stages at: www.ribaplanofwork.com/PlanOfWork.aspx

[42] "BIM or Building Information Modelling is a process for creating and managing information on a construction project across the project lifecycle. One of the key outputs of this process is the Building Information Model, the digital description of every aspect of the built asset. This model draws on information assembled collaboratively and updated at key stages of a project. Creating a digital Building Information Model enables those who interact with the building to optimize their actions, resulting in a greater whole life value for the asset" (NBS, 2016). BIM levels 0 to 3 are defined to specify recognisable milestones within the collaborative working progress.

The other project teams understood the rationale for the architects' decision about the form of contract; however, they believed that it practically decreased the speed of works and led to delays. The architects disagreed with this point of view and associated the delays with the mediocre performance of the contractor. "This [lengthy delays and disputes] can happen when using any type of contract if the contractor does not adequately resource the job" (Architect A, 2017). To investigate the role of the contract form in project problems, the opinions of different project teams are examined.

According to the contractor's design manager A (2016), "the architects have designed 95% of the refurbishment, but the 5% they did not design was the part that they found too difficult, so they decided to leave it to the contractor to sort it out". He argued that the architects were not responsible for the accuracy of the details they had designed; "the architects think whilst we believe we got everything right, if we haven't got it right it is up to the contractor to pick up on the things that we haven't got right and to detail it" (Contractor's design manager A, 2016). In other words, contractor's design manager A believed that implementing the architects' design to the building was a challenging process for the contractor team precisely because they needed to make certain adjustments to fit the design to the building. This implies that the contractors were not completely familiar with the CDP portion when bidding for the project. The contractor's design manager A believes that one reason that they had difficulty with designing the details was that their team had not become involved at the design stage. Based on his point of view, the architects produced the design solutions without having an adequate understanding of all the building details and how their design would fit to the building. When problems occurred with implementing the design, the project architects who had designed the scheme were not responsible for dealing with them; it was instead the responsibility of the contractor and their appointed site architect to produce the right solutions. The Contractor's design manager A (2016) presumed it would be more appropriate if the architects had prepared all the design details so the contractor would only be responsible for the construction (Standard Building Contract without CDP elements), or if the client had initially given all of the design work to the contractor so they could carry out both design and construction (a Design and Build Contract). He believed that the CDP elements led to a significant waste of time; on the one hand, the architects had already spent two years on design, on the other hand, the contractor's architect needed to spend additional months on reviewing, understanding, revising, and completing the design. However, the architects did not find it appropriate to involve the contractor at the design stage.

He explained that they decided to specify most of the design as Contractor's Design Portion because they suspected that the building had unpredictable irregularities. When the project started, Wilmcote House had existed for more than forty years; in addition, it was built in a period when inefficient construction methods were used. As a result, it could be expected that there would be defects or unpredictable detailing, and therefore, the architects understood that it was not possible to finalise these details before the works on site started, choosing to specify it as Contractor's Design Portion.

Similarly, the site architect (2017) pointed out the difficulties of designing details on site. He explained that he had had to change some of the project architects' design specifications based on the physical condition of the building. Nevertheless, the architects do not believe that the site architect made significant changes to their design. Architect A (2017) emphasizes that their details were "used by the contractor's architect with minor adjustments to suit site tolerances". One of the changes that the site architect made to the project architects' original design was related to the airtightness aspect of the scheme. The site architect found the parge coat specified by the project architect inappropriate to be applied to the building, deciding to utilise its existing concrete walls as the airtightness layer. Generally, the site architect (2017) also believed that it would have been beneficial if the ECD project architects had increased their level of cooperation and presence on site. In addition to the contractor and the site architect, several members of Portsmouth City Council had been involved in the Wilmcote House refurbishment and had been dealing with the project problems and the tenants' demands. Maintenance manager A (2016) at the city council admitted that the client had been unhappy with the extensive amount of time that had to be spent on Wilmcote House, describing their engagement with the project as "almost like a full-time job". He believed that "the client has to deal with a lot of problems because the contractor team faces difficulties and needs extra support. It would be helpful if the project architects were on site more often to help with the problems".

The arguments above show that the architects believed the traditional procurement method to be the most suitable method for the Wilmcote House refurbishment project; nevertheless, the contractors see this form of contract as a contributor to its problems and a reason behind the project's delays. The contractors believe that using a Design and Build Contract would have reduced the challenges of the project and its interruptions. The conflicting views of the architects and the contractors raise several questions: was the choice of contract a determining factor? Was traditional procurement inherently unsuitable for the Wilmcote House project? And, are there alternative forms of contract that would have been more appropriate?

To address these questions, it is critical to examine some of the common forms of contract used in a construction project, including Design and Build. It is not within the scope of this research to carry out a thorough study of contract types; however, the following section briefly reviews the primary features of a few forms of contract to make general comparisons between them in terms of suitability to the Wilmcote House project. As explained previously, one of the key features of the traditional procurement method is the separation of design and construction, to be carried out by different teams. This feature makes it possible for the client and their consultant to control the project cost and design, limiting the contractors' control over quality targets and standards. However, the separation of design and construction increases the length of the project. It is also likely to negatively affect the constructability of the project (Alencastro, et al., 2017). Many contractors argue that most often the designers do not have sufficient practical experience of construction to assess the constructability of their designs (Ndekugri & Turner, 1994). Furthermore, due to the contractor's lack of responsibility at the design stage, the traditional method can result in disputes over contract changes or extra claims (Alencastro, et al., 2017). It is important to investigate how these features corresponded with the Wilmcote House project to assess whether the traditional procurement method was best suited.

Firstly, Portsmouth City Council was concerned with the project costs; this meant that the certainty over costs provided by traditional procurement was a positive aspect. Secondly, because the project was aiming for EnerPHit it was beneficial that the client and the architects controlled the design allowing them to meet its specific EnerPHit targets. This was one of the main considerations of ECD Architects in choosing traditional procurement. However, the potential problems with constructability associated with this form of procurement can have more serious impacts on a Passivhaus project. It should be considered that in addition to the design process, the construction stage of a Passivhaus project, particularly achieving the adequate level of airtightness and thermal bridge control (Hopfe & McLeod, 2015), also needs to be carried out with extra care and caution. Therefore, any issues with the constructability of the design can overcomplicate the construction process and lead to problems. This was the main argument made by the Wilmcote House project contractors against this form of contract. Being the only party responsible for making the design work, they claimed to have spent considerable time and effort assessing the viability of the architects' construction details and making the essential revisions. Thus, the separation of design and construction dictated by the traditional procurement form of contract created problems at the construction stage.

According to the contractors, an alternative form of procurement which would have been more effective was Design and Build. The main feature of this method is that the contractor is responsible for both design and construction of the project. Firstly, the client commissions design consultants to develop concepts and prepare the requirements which are necessary to call in proposals in the tendering process. Then, the appointed contractors take over the project. Generally, two-stage tendering is applied in this method so that the early appointment of a contractor occurs before collating all of the information needed to allow the contractor to offer a fixed price. In this route, the client has control over the initial design; however, they cannot directly control the contractor's detail design development after the contract is let (The Joint Contracts Tribunal, 2011).

There is controversy over the effectiveness of the Design and Build Contract. It is generally thought to be advantageous in terms of speed of delivery, having a single point of responsibility, constructability, a reduction of disputes, a lower potential for claims, and cost certainty (Hopfe & McLeod, 2015). According to Burrell (2016), Design and Build is popular for large-scale Passivhaus projects in the UK because clients, particularly, public clients, want to have the benefits of Passivhaus, but they do not want to take responsibility for the delivery of these projects because Passivhaus market in the UK is relatively immature and thus there are project delivery risks. If any serious problems occur, the costs and delivery time of the project will increase and the Passivhaus targets may not be achieved. With a Design and Build Contract, the clients can pass most of these risk on to the contractor. One example of a large-scale Passivhaus project in the UK which was carried out using a Design and Build Contract was the construction of the University of Leicester's Centre for Medicine, completed in 2016 within less than 2 years of its original starting date. However, it was a new-build project which did not have to deal with the complications of retrofitting an existing structure. It was the client's appointed design team including engineers and architects who proposed to design a Passivhaus building. The project was tendered as a two-stage Design and Build Contract, with the appointed contractors working with low-energy building specialists and Passivhaus certifiers. They followed the design team's proposal; however, they made changes to certain aspects of the scheme such as the cladding in some parts of the building. The contractors faced complications due to the changes they had made, resulting in the development of new solutions to comply with Passivhaus requirements. The teams believe that involving the contractors at the early stage of the design was fundamental to producing constructible design solutions. Thus, a key factor in the success of the project was the effective teamwork between the design team and the contractors. (Pearson, 2016)

However, it is also argued that the Design and Build Contract creates a risk that the expected quality will not be achieved if adequate attention is not paid to client demands or architect proposals (Alencastro, et al., 2017). Furthermore, the contractor exerts too much control over the project both in terms of quality and the selection of suppliers and components (Hopfe & McLeod, 2015). For instance, a Design and Build Contract was used for the refurbishment of Grenfell Tower, which burnt down only one year after project completion (Booth, 2017), largely due to cost-saving measures that compromised its fire safety. According to Ben Derbyshire, the president of the Royal Institute of British Architects (RIBA), Design and Build Contracts are associated with "value engineering" in which budget cuts and the replacement of materials do not involve consultation with the original architects (Booth, 2017). In fact, value engineering is the process of saving costs by finding cheaper building elements providing similar quality and functionality; however, it is often misused by focusing solely on substituting elements for cheaper ones – at the expense of it functionality – in the later stages of design (McCarthy, 2017). As explained in chapter 5, one of the outcomes of the value engineering in the case of Grenfell Tower was the substitution of fire-retardant cladding specified by the original architect for flammable panels. £293,368 was reduced from the cladding cost (Booth, 2017), at the expense of a fatally devastating fire spreading across the surface of the building.

One of the main reasons ECD Architects were against utilising a Design and Build Contract was the risk of the contractor not achieving EnerPHit targets. Architect A (2017) argued that the "contractors commonly seek to use D&B (Design and Build) Contracts wherever possible as this enables them to produce the detailed design documents and thereby vary the products used and quality achieved". Achieving Passivhaus in a large-scale new building is expected to be less complicated than reaching EnerPHit in an existing large-scale construction. As argued in the study by Egbu (1997), refurbishment projects are complex in nature; without the control of the client and their consultant, the contractor may not achieve acceptable quality levels. Having no previous experience with EnerPHit, the contractors needed to meet the standard for the first time in a complex project. Therefore, there was a chance that the contractors would face more challenges had a Design and Build Contract been utilised.

A Management Contract is another common form of contract. In the Management Contract method, the client appoints the consultants to prepare the overall design (The Joint Contracts Tribunal, 2011), and the contractor defines specific packages of work and hires different contractors to undertake these construction activities. The main contractor is normally appointed by the client in the initial design stage so that their experience can be applied with the purpose of improving the cost and buildability of the project. Additionally, it can allow some work contracts to be tendered earlier, even before completion of the design. Thus, the project completion time can become shorter; however, the price will not be known before the completion of the design (Alencastro, et al., 2017). The main contractor does not directly carry out construction works; in fact, the works are broken down into packages and undertaken by work contractors. The main contractor manages the works, with the work contractors accountable to them (The Joint Contracts Tribunal, 2011). Based on the features of the Management Contract, it can be concluded that it would better suit a new Passivhaus project rather than a refurbishment. Firstly, due to the complexity of works and the possibility of unexpected situations, the input required from the contractor is greater than defining work packages and managing work contractors. Secondly, it should be considered that in a Management Contract the resultant cost amount will not be clear, so that final costs will only be known after the last package of work is let (The Joint Contracts Tribunal, 2011). This is not suitable when a client wants to allocate a specific amount of budget to a project, but does not wish to spend beyond this amount, as was the case with the Wilmcote House project.

The final form of contract that could potentially be utilised is a Partnering Contract. In fact, Partnering is not considered to be a procurement method but a concept that can be incorporated into a contractual arrangement (The Joint Contracts Tribunal, 2011). Partnering can be used in a project situation known as ‘project partnering’ or applied to a long-term relationship as ‘strategic partnering’; however, the key to a Partnering Contract is negotiation instead of competitive tendering. One of the main benefits of a Partnering Contract is that it results in the integration of the design and the construction process, increasing the possibility of incorporating innovative and practical alternatives into the building (Hopfe & McLeod, 2015). One of the advantages of the Partnering method is that it integrates the design and construction process, reducing the number of potential disputes between parties (Hopfe & McLeod, 2015). According to Hopfe & McLeod (2015), Partnering is specifically useful in Passivhaus projects which demand innovative solutions; however, they also argue that this type of contract can be exploited by one of the parties involved. In general, it should be practised over a number of projects before it becomes effective, as with the partnering approach excellent levels of project management and communication are required between all parties. In other words, this method can only work based on the willingness and effort of the relevant parties to communicate with each other efficiently. Taking into consideration that the Wilmcote House project teams had no previous experience working together, using a Partnering Contract might not have resulted in the outcomes desired.

Out of the examined forms of contract, the Management Contract is the one which least corresponds to the requirements of a large-scale EnerPHit project; when executed efficiently, a Partnering Contract would be most suitable because it is based on the maximum collaboration between parties. However, due to the parties' lack of previous collaborations with each other, it may not have been effective had it been utilised in the Wilmcote House project. The Standard Building Contract procured via the traditional method, and the Design and Build Contract suit the project in certain ways; nevertheless, both of these forms of contract can create further challenges. Considering the stringent requirements of EnerPHit and the parties' lack of experience with the standard, the separation of design and construction dictated by the traditional procurement method negatively impacts the constructability of the design. On the other hand, utilising Design and Build could risk compliance with EnerPHit targets due to potential alterations which would be made by the contractors.

Nevertheless, there is not sufficient evidence to suggest that any of these contracts are unsuitable to be used in large-scale EnerPHit projects, and they can both result in successful progress and completion of the project if implemented efficiently. Because of the separation of design and construction and the decisions as to the teams' responsibilities, the length of a project carried out via traditional procurement is relatively longer than using a Design and Build Contract. Yet, the form of contract cannot explain the significant delays to the Wilmcote House project. Utilising the same contract, the project would be less challenging if the project teams had proper communication. The difficulties of achieving EnerPHit can be overcome if the teams communicate and collaborate with each other to understand the challenges, developing effective solutions. The investigation of the Wilmcote House project reveals that there was a lack of such communication and collaboration between its teams. Discussed in the next section, their contradicting opinions about the project challenges are a clear sign of insufficient communication.

8.3 Communication between the parties

The concerns brought up by key members of the Wilmcote House project teams during the interviews and discussions reflect a lack of adequate communication between the teams, particularly the architects and the contractor. During an interview, maintenance manager A at Portsmouth City Council expressed his doubts over some of the design specifications provided by ECD Architects. For instance, he suspected that the large windows in enclosed walkways would result in overheating. When interviewed about this client concern, architect A (2016) explained that they had specified low-e glass in walkway windows to prevent this occurrence, and were surprised that the client had not discussed their concerns with them. As mentioned earlier, the client also felt that it would have been helpful if the architects had spent more time on site. In his interview, Maintenance manager A (2016) argues "it would be easier to work with local architects because they could get to site fast and effortlessly". Nevertheless, the architects claim that they would always travel to the site if the client asked them (Architect B, 2016). It can be realised that the client team did not communicate some of their concerns or requirements with the architects. Therefore, the architects were unaware of the client's apprehensions, and so had no opportunity to provide them with solutions.

Figure 8.3. Windows in the walkways (Photo by author, 2017)

A lack of adequate communication between the contractor team and the project architects also had negative impacts on the project. The site architect maintained that the project architects should have been on site more frequently. He also argued that that the difficulties and delays at the construction stage could have been reduced if they had designed the details together with the architects. However, the contractor team is aware that based on the contract, the project architect was not in charge of detail design at the construction stage. As stated by architect A (2017) at ECD, “the contractor was fully aware at tender stage that this was a CDP project and that they would need to include input from their own design team and they priced and programmed the job accordingly based upon the detailed information provided in the tender documents”. Therefore, the architects did not expect the contractor team to require their support on site. According to the architects, the contractors did not seek their assistance with detail design; thus, they did not provide them with any advice. Architect A (2016) explained that ECD did not want the client to feel that they were interfering with their design.

Thus, lack of efficient communication resulted in the teams’ misunderstanding what their expectations were of each other. The client expected the architects to spend more time on site and the contractors expected the architects’ collaboration at reviewing and designing the details. However, these expectations were not communicated to the architects; thus, they expected the contractors to complete the design without significant challenges. Evidently, the teams’ expectations of each other were not met because they had no awareness of them. This situation led to conflicts at later stages. During site meetings, the teams often became defensive while discussing the progress of the project. This was possibly one of the factors which increased frustration amongst the staff. Taking into consideration that the teams were delivering a large-scale EnerPHit project for the first time, developing a collaborative relationship could have built confidence about the scheme and provided them with the support they needed from each other. As discussed by Egbu (1997), cooperation between contractors and architects is vital in refurbishment projects in which unexpected changes and crisis are likely occurrences, with new decisions taken promptly to minimise delays. This is specifically important in a Passivhaus project in which the teams did not have a considerable level of knowledge or experience. In fact, providing the staff with knowledge of Passivhaus was another challenge which the contractors faced at the construction stage.

8.4 Passivhaus Training

As discussed in the previous chapter, the architects and the key members of the contractor team received Passivhaus training. To achieve Passivhaus, it is necessary to understand the standard and its targets and to learn new skills; therefore, new members who joined the project required the provision of Passivhaus training. Generally, it is very important that everyone working on a Passivhaus project site realises that they need to implement each detail rigorously and accurately. Without this understanding, they are likely to make mistakes which might have minor consequences in conventional projects, but may result in serious problems in a Passivhaus project. For instance, Contractor's design manager A pointed out in his interview that the workers needed to understand that if they punctured the airtight barrier, they would need to seal it before proceeding to the next stage. Otherwise, it would not be possible to rectify this mistake in the later stages, resulting in the failure to achieve the airtightness requirement.

However, it is difficult to arrange training and to explain project targets to everyone working on a site. To make sure that mistakes are minimised, a significant level of control and supervision must be provided on site. Typically, a refurbishment project requires a higher level of supervision compared to a new build project, taking its project managers additional time and effort to run (Koehn & Tower, 1982). Considering the additional supervision required to achieve EnerPHit, the Wilmcote House contractors had to employ a considerably larger number of staff to control the project. Contractor's design manager A (2017) mentioned that they had to watch all the site works very closely and carefully to avoid mistakes. He also explained, "If we did not aim for EnerPhit, we would need two site managers, but now we need at least five site managers, operations manager, contracts manager, etc." Therefore, the level of knowledge, skills, and understanding needed in a Passivhaus project poses certain complications to its management and supervision.

Furthermore, key members of the project in different teams reported that the training aspect became even more complicated for the Wilmcote House project because a considerable number of site staff quit the project and a subcontractor went bankrupt. In fact, when a project employee or a team of subcontractors who had already received Passivhaus training left, the same training with equal time and cost implications needed to be provided to their replacements. Therefore, the works on site were often delayed until training was organised and the inexperienced staff were prepared. Apart from Passivhaus training, staff gained practical knowledge by complying with the EnerPHit requirements on site. As discussed in the earlier chapter, different members of the project participated in events and programs, such as desktop buildability reviews, buildability workshops, and toolbox talks. The more the site staff engaged in the project, the better they could understand and learn the effective methods of working on it. The withdrawal of staff from the project resulted in a loss of the knowledge and experience they had gained. It was a time-consuming process for the new staff to reach the same level of familiarity with the project; therefore, the capability of the contractor to meet deadlines and the overall quality of the works declined.

Although any project can be affected adversely if its members quit, Passivhaus projects face a serious loss of knowledge which is critical to its delivery. The contractors could have possibly prevented some of the staff from leaving if they had built effective relationships with them and provided them with sufficient support; in addition, they could have taken greater care when choosing the right subcontractors. In fact, checking the financial status of a subcontractor should be treated as a necessity, to ensure they will not go bankrupt or underperform due to lack of finances (Olawale & Sun, 2010). It is worth noting that the contractor team believed that they may not have the opportunity to use their EnerPHit knowledge in the future because they may not be appointed to work on similar projects at a later date. “New people will work on the next EnerPHit project and they will make the same mistakes as we did” (Contractor’s design manager A, 2016). Therefore, it is possible that future projects will also be negatively affected by the learning and training process required to achieve EnerPHit.

8.5 Project management

As explained in the prior section, training the site staff was a major EnerPHit-related issue posing difficulties to the project management. The contractors believed that in general, EnerPHit requirements complicated the project management. Essentially, managing a large-scale refurbishment project is challenging regardless of its performance benchmark. Egbu (1997) described a refurbishment project as an environment of uncertainty with variations to the works and increased costs. Based on his research, the managers should have high skills in forecasting, planning, and project risk analysis to handle such an uncertain environment (Egbu, 1997). According to the research by Olawale & Sun (2010), some of the factors that complicate the control and management of the project are design changes, risk and uncertainty, non-performance of sub-contractors, the complexity of works, and conflict between project parties, etc. The lack of availability of resources and the quality of workmanship are two further management challenges identified by Egbu (1997).

It can be argued that the Wilmcote House project management faced higher levels of the aforementioned challenges than a conventional project would. The contractor’s design manager A (2016) explained that aiming for EnerPHit made the Wilmcote House project very different from previous projects that he had participated in. One of the major differences that he pointed out was about the level of insulation. “In other projects, you stick some external insulation to the walls, or all the insulation is within the wall cavity; here we had to use massive insulation in different layers of walls and roof[43]”. Two other crucial differences that he identified were creating an airtight barrier and installing the extra skeleton. A lack of earlier experience with meeting the specific requirements of the project made the whole construction process challenging. He also believed that a lack of Passivhaus expertise at the design stage similarly contributed to the contractors’ delay. As mentioned earlier, he insisted that the contractors had to spend too much time on understanding and adjusting the architects’ details. He believed that the details would have required fewer revisions if the architects had employed Passivhaus consultants at the design stage.

Figure 8.4. Insulation of roof and walls (Photos by author, 2016).

[43] The details of walls and roof can be found in chapter 5.

Figure 8.5. Skeleton installed to the courtyard façade (Photos by author, 2016).

During an interview, the contractor's design manager A (2017) also reported some difficulties with Passivhaus products. For instance, the contractors struggled with supplying the specific fire-resistant Passivhaus doors which were to be installed at the two ends of the enclosed walkways. Passivhaus windows were required on the street façade and enclosed walkways, while the Passivhaus doors were to be utilised on each enclosed walkway. This situation is specific to the layout of Wilmcote House. Typically, the external doors of Passivhaus buildings should be Passivhaus doors. However, in the Wilmcote House case the entrance doors of flats open on to enclosed balconies, and thus, are not required to be Passivhaus doors. The reasoning behind this is that the enclosed balconies are within the thermal zone of the project. Nevertheless, there are two staircases at the two sides of each enclosed walkway excluded from the thermal zone. The doors at the ends of walkways separate the thermal zone from the non-thermal zone, and thus, they had to be replaced with Passivhaus doors. This was a challenging issue because these doors did not have a common size; furthermore, they were required to be fire-resistant to prevent spread of fire from the enclosed walkways to the staircases.

Figure 8.6. The enclosed walkways are within the Passivhaus thermal zone. The walkway windows are on the exterior facade of the building, and thus, are Passivhaus windows. However, the entrance doors and kitchen windows face the walkways; therefore, they are not required to be Passivhaus. The doors at the end of the walkways are Passivhaus because they separate the walkways from the lift area which is outside the Passivhaus zone (Photo by author, 2017).

In general, the contractor's supplier of Passivhaus doors and windows was Ecohaus Internom[44], a UK distributor of doors and windows including Passivhaus products; however, the contractor struggled to find the type of Passivhaus door that was to be installed on every floor (except for the ground floor) of each block (Contractor's design manager A, 2017). Evidently, this problem resulted from the limited availability of uncommon Passivhaus products. The failure to supply the products within the scheduled time resulted in further disorganisation and delay.

In addition to the doors, some challenges arose around supplying a suitable MVHR system. In fact, it should not be difficult to find the required product because there are many MVHR suppliers within the UK as MVHR systems are also utilised in some non-Passivhaus projects. Nevertheless, the problem that the contractor faced was that the final cost of the MVHR system was higher than the supplier's initial quotation. The suppliers increased the cost after their appointment, because of the first quotation including the cost of the product, but excluding the additional items required to install the system on site (Site architect, 2017). Consequently, the contractor had to surpass the estimated initial costs. One of the reasons the contractor did not

[44] Find more information at: http://www.ecohausinternorm.com/

expect this cost rise was a lack of sufficient knowledge about the installation of the MVHR system or its cost implications.

However, the project management was not only weakened by factors related to EnerPHit, but adversely affected by the contractor's poor performance. The contractor's delay in stripping the roof was one of the core components that created serious problems and major project delay. As explained in earlier chapters, replacing the roof was included in the refurbishment plans for the project. Stripping the existing roof had been scheduled for the summer, but the contractor postponed it to October. The weather at this later date was rainy. This could be anticipated because although it may rain in the summer, it is more likely in October. As the architects explained, the rain penetrated the building because the existing roof was being stripped, and subsequently, water leaks occurred in the top floor flats. As the leaks became more severe, the top floor flats had to be decanted, with the residents relocated to some vacant flats within Wilmcote House (Architect B, 2015). Therefore, the contractor's delay caused disturbance to both the residents who had to move into other flats, and the members of the client team who had to provide alternative accommodation to the residents and assist them with relocation. Moreover, the contractor team themselves were required to carry out the extra works of building a temporary roof. This procedure led to delays and expenditure of additional funds. According to the contractor, the reason for postponement was that there were seagull nests on top of the roof (Project manager A, 2016); however, the architects did not find this a valid excuse for delaying the work (Architect B, 2015).

Another task which the contractor completed behind schedule was setting up the temporary partitions in flats. As explained in the previous chapter, the partitions were required to be installed in each flat while the living rooms were being extended. Based on the site meeting minutes archived by ECD Architects, this process took longer than initially planned. Thus, the contractor had to pay compensation to the residents for the disturbance caused to them. The delays with different tasks resulted in some significant changes to the plans. As well as the more evident problems discussed here, different issues were detected on site visits which signified the overall poor management of the project. Some of these issues include the cracks observed in the newly installed window frames, defects in an MVHR system which was randomly tested, and the site staff ending their work before the close of official working hours.

Subsequently, the construction stage was more difficult than within a conventional refurbishment project as a result of the requirements of EnerPHit, such as the additional insulation, the stringent level of airtightness, and the utilisation of specific products. However, the problems related to the contractors' performance suggest that to a greater extent this resulted in the unusual delay in the completion of the Wilmcote House project. Therefore, it should be expected that any future tower block refurbishments based on the EnerPHit standard would be completed in a considerably shorter time if the site teams plan and manage the construction stage more efficiently.

Figure 8.7. The extended living room (Photo by author, 2017).
**The red line indicates where the living room ended before the extension.*

8.6 Project-specific factors

In addition to the detailed requirements of EnerPHit and the contractors' measures to follow them, the construction stage of Wilmcote House was affected by project-specific factors and their compatibility with EnerPHit. One of the more significant factors was the requirement to carry out the project while the residents continued to occupy the building. This was a decision made by the client at the early stage of the project, however, the evidence shows that the presence of the residents increased difficulties in achieving EnerPHit. Similarly, another factor is that the specific building conditions added to the challenges of using EnerPHit. The following section takes a closer look at some effects of these reasons at the construction phase.

8.6.1 Presence of the residents

There were various aspects to the negative impact of the residents' presence on site. Firstly, compliance with EnerPHit requirements increased the extent of works which had to be completed inside the flats[45]. To access the flats arrangements needed to be made with the occupiers; however, the contractors explained that they were not always available to provide access at the times previously agreed (Contractor's design manager A, 2016). As a result, the works took longer than planned. Furthermore, carrying out certain design related aspects to achieve EnerPHit became more complicated due to the presence of the residents. For example, in order to meet with the EnerPHit requirements, the living rooms were extended to create an even façade and to minimise thermal bridges. To extend the living rooms, their existing walls had to be removed. However, precautions were needed prior to the removal of the walls because the flats remained occupied. The contractors' solution was to install temporary partitions in the living rooms and to maintain them until the new walls would be completed.

In general, the presence of the residents resulted in extra pressure on the client and contractors. Due to the project delays resulting from the reasons previously explained, such as complexity of meeting EnerPHit targets, the residents' lives were seriously disturbed. According to a local news website which interviewed the residents, they were angry at the project setbacks. One of the residents said, "it's supposed to be our home, but it's like living on a building site", while another resident showed their anger, saying, "it's not fair that people have to live like this. People's lives have been totally disrupted" (Cotterill, 2016). To control the situation, it was necessary that the client supported the residents and developed solutions to minimise the disruptions. Correspondingly, the contractor was required to pay a penalty to the residents for the late completion of works. Generally, the Wilmcote House project teams including the client and the contractor found it very difficult to carry out the refurbishment while the residents were living inside the building. This can apply to any refurbishment projects, but it became a particularly serious challenge for Wilmcote House refurbishment because extensive structural works were necessary to be carried out and alterations had to be made to the interiors of the maisonettes. In the interviews with different members of the site teams, they all maintained that if the building had been decanted it would have been less challenging to meet the EnerPHit requirement at a tower block scale (Maintenance manager A, 2016) (Contractor's design manager A, 2016) (Project manager A, 2016).

Conversely, as was discussed in chapter 3, one of the reasons that Portsmouth City Council decided to refurbish Wilmcote House was because it was possible to undertake the

[45] Installation of MVHR and extending the living rooms are two examples of the works required to achieve EnerPHit.

refurbishment without decanting the building, reducing the project costs and protecting the residents' community. Thus, the decanting of the building was a paradoxical factor for the Wilmcote House refurbishment: whilst keeping the residents in the building had a positive effect at the start of the project, it became an obstacle during the construction stage. Consequently, although keeping the building occupied can increase difficulties during a refurbishment project, the Wilmcote House refurbishment reveals that it becomes significantly more challenging when EnerPHit is used as the project benchmark.

8.6.2 Building conditions

As explained in previous chapters, the design solutions for some refurbishment elements were restricted by the specific conditions of the building. For instance, gas heating was not used due to the structure of the building, and a communal MVHR system was not specified due to the lack of required space for pipes, etc. However, the specific conditions of the building continued to create different challenges on site, with some of these challenges related to the EnerPHit requirements specifically. The airtightness test was one of the project requirements which became complicated due to the building details. As discussed in chapter 6, the contractors were planning to carry out an airtightness test on every two floors (lower level and upper level of maisonettes). However, more than two years after the commencement of works on site, the site architect discovered perforations in the risers which had been used to accommodate long removed gas pipes that had connected to each flat. The site architect (2017) explained that despite starting from the first floor, the risers had not been shown in any survey documents; therefore, they were not taken into consideration at the design and planning stages. The perforations in the risers were partly sealed after the gas pipes were removed; however, air still passed through the space. According to the site architect, it was not possible to completely seal the perforations, and consequently, the contractors' previous plan to separately test every two floors could not occur due to air within the risers circulating between all the floors through the same riser. Thus, the testing of every two floors was no longer suitable, leading the teams on site to investigate other options.

The discussions between different members of the site teams revealed that it was challenging to develop any other straightforward alternatives. For instance, all the floors above the ground floor which are connected to the riser could be tested at the same time, but the site teams had serious doubts over the possibility of evacuating the whole block and keeping the residents outside of the building for hours (Site architect, 2017)(Passivhaus consultant A, 2017). It should be noted that based on the tender documents, carrying out the airtightness tests was one of the responsibilities of the contractors. During the interviews conducted in June 2017 with the site architect and the Passivhaus consultant A, they expressed their doubts over the feasibility of undertaking the tests.

Another complication was about the ventilation of the flats. As analysed in the second chapter, the open walkways of the buildings were enclosed to meet with EnerPHit requirements. The kitchens in all the flats face the access walkways, and residents had previously ventilated their kitchens by opening the operable kitchen windows. However, it was not possible to open the windows after the enclosure of the walkways because due to fire safety reasons they had been replaced by fixed windows (shown in figure 6). Based on the initial plans, the ventilation of the kitchens was going to be provided by the MVHR system. In the interview with Architect B (2015), she pointed out that the client had performed a test in one of the flats following the installation of the MVHR system to ensure the provision of an adequate level of ventilation. After the completion of the test, the client decided that the MVHR system did not ventilate the kitchen immediately and took some time - around an hour - before it gave sufficient ventilation[46]. As the residents were used to opening windows and the benefits of instant natural ventilation, the client was worried that they would not feel comfortable relying on MVHR. Therefore, they decided to add a kitchen hood to each maisonette. Evidently, adding a new feature to the design takes extra time, raises costs, and possibly creates further complications. The further costs, time overrun, and other challenges resulting from the state of the building are common in refurbishment projects. The refurbishment of the Edward Woods Estate tower blocks were similarly delayed by a year, partly due to structural issues in the building (Bates, et al., 2012). However, the Wilmcote House case study suggests that building conditions can lead to more serious complications specifically because the project is aiming for EnerPHit standards.

8.7 Conclusion

The investigation of the construction stage of the Wilmcote House refurbishment reveals the reality of serious challenges throughout. The study suggests that aiming for EnerPHit differentiates the project from conventional tower block refurbishments, adding certain complications to the construction process. Part of the challenges faced by the Wilmcote House

[46] According to architect B (2015), the test result may not be reliable because during its implementation several people were present in the kitchen and a large pot of water was boiled; consequently, the kitchen became quite warm with a lot of vapour and the test conditions did not meet the standard.

project were directly related to achieving EnerPHit targets, such as developing the EnerPHit design details, providing Passivhaus training for the staff, and sourcing the required Passivhaus products. Meanwhile, the withdrawal of staff, the presence of residents on site, and the unexpected physical conditions of the building, were issues that could be expected in a typical refurbishment project, complicated here by the use of EnerPHit. Furthermore, the project teams' lack of prior EnerPHit experience exacerbated the situation. One of the main difficulties faced by the contractors was developing buildable details. It is typically challenging to create buildable design solutions in large-scale Passivhaus projects due to the stringent requirements of the standard. Therefore, it takes a significantly higher level of mutual communication to develop these solutions and to accurately implement them on site.

The Wilmcote House project suffered different problems due to a lack of communication and collaboration between the project teams. The traditional procurement method which was utilised in the project generally suits large-scale refurbishment, but it is less effective when using EnerPhit if the teams do not build a sufficient level of mutual communication. The Wilmcote House project teams should have examined the design details, resolved possible misunderstandings, identified potential problems, and found effective solutions before the beginning of the construction process. Furthermore, the construction stage would have been less problematic if communication between the teams had continued and the contractors received the support of the architects. However, without adequate communication, the teams did not understand each other's expectations.

Providing the staff with understanding and training of Passivhaus is a critical aspect in all Passivhaus projects. It became one of the more challenging aspects of the Wilmcote House refurbishment due to the scale of the project and the considerable number of staff who worked on site. To avoid mistakes resulting from a worker's lack of EnerPHit knowledge, the contractors increased the level of site supervision by employing a higher number of site supervisors and managers. The training of staff is likely to remain a challenge in future EnerPHit-based UK tower block refurbishments because the UK construction industry does not have sufficient Passivhaus experience. Therefore, it would be helpful if contractors developed training plans for staff in advance. The Wilmcote House project also suggests that the presence of residents on site can pose difficulties to using the EnerPHit standard. Due to the extent and sensitivity of the works required to achieve EnerPHit, it would be less difficult and time-consuming to carry out the project when the building is unoccupied. In addition to the aforementioned problems and difficulties, the contractors' inefficient performance in managing the project aggravated the situation and led to an increase in the length of the project. Overall, the problems discussed in this chapter suggest that achieving EnerPHit in tower blocks is a challenging process; however, it can become more manageable through substantial planning and collaboration.

Chapter 9: Discussion

9.1 Introduction

This chapter reviews the most critical findings of the research derived from the case study of the Wilmcote House refurbishment process and the investigation of [REDACTED] and [REDACTED], and Edward Woods Estate tower blocks refurbishment projects. These findings identify the challenges encountered at each stage of the Wilmcote House refurbishment process including decision making, design, and construction. Based on this research, the main factors affecting the pre-construction process of the project are: the client's and the architect's approaches to the selection of EnerPHit as the potential project benchmark; the financial capability of the client; and the compatibility of the tower block with EnerPHit requirements in terms of structure, envelope, and the heating system and its impact on the client's decision. This study reveals that the construction process is impacted by various factors, including the controversies between the architects and the contractor team over the source of problems during the construction stage, such as form of contract; project management weaknesses; the requirement for EnerPHit training and experience; the optimism and pessimism of different project members; and a lack of efficient communication between the groups involved in the project.

9.2 The approach of the client

The decision to apply EnerPHit to Wilmcote House was significantly affected by the approach of the client, Portsmouth City Council, towards the management of their building stock. It should be noted that refurbishment projects in the UK are required to comply with UK building regulations, while it is not mandatory to achieve EnerPHit standard. EnerPHit is a benchmark for low energy retrofits. It is the retrofit version of Passivhaus, a standard that has been gaining recognition in the UK due to its advantages, such as minimising energy consumption. The adoption of EnerPHit in the UK relies on the commitments of the client. Nevertheless, some building owners or builders are discouraged by the challenges associated with achieving EnerPHit. Undoubtedly, tower block refurbishment is a relatively complicated type of project and aiming for EnerPHit can further increase its complications. Compounding this, the government has not necessarily been supportive of EnerPHit-based tower block refurbishments. Therefore, councils are not encouraged to refurbish rented social housing. Additionally, the government has not offered any specific financial support for achieving EnerPHit. Funding programmes for existing buildings such as the Green Deal have gone through changes and revisions. As a consequence, landlords are unable to rely on such schemes. Without any obligation to achieve EnerPHit or financial assistance and support from the government, tower block owners would need both financial liquidity and strong motivations to go beyond building regulations to comply with EnerPHit.

As the Wilmcote House project suggests, a commitment to improving the lives of residents and carbon reduction targets are two significant motives that can encourage landlords and architects to upgrade a tower block to EnerPHit level. Portsmouth City Council has been deeply concerned with the quality of their tenants' lives. Even though in many cases, councils have demolished tower blocks and relocated its residents to homes that are not necessarily an improvement, Portsmouth City Council was not willing to destroy resident community or to relocate them to inadequate accommodation. Additionally, the council intended to improve the building to provide maximum comfort for the residents while minimising their energy bills. Their dedication to a sustainability plan focusing on dealing with climate change and carbon management affected their decision making and planning for the future of all of their building stock, including Wilmcote House. Based on their commitments, they opted to achieve EnerPHit resulting in higher initial costs. Nevertheless, extra expenses were only one of the consequences that they had to face. To stay committed to the scheme, it was necessary to spend a considerable amount of time and energy supporting and handling the project throughout every stage. In fact, Portsmouth City Council placed the long-term benefits above the short-term in choosing EnerPHit, and went to considerable lengths to achieve it. In general, if the approach of a tower block owner is to prioritise immediate benefits, or in other words to spend minimum initial costs, EnerPHit will not be the best option for them. The greater the commitment of the owner to the people and the environment, the less likely they are to take a short-term approach.

However, there were other factors that affected the approach of the owner, such as the location of the building. In locations with a high housing market value, such as central London, there is considerable profit-making potential from selling or renting houses in the private sector, and subsequently, there is greater likelihood that the owner will prioritise the financial benefits. Similarly, there is less chance that they would opt for spending their budget on refurbishing the block to a high standard. Another factor to be considered is whether the building requires to be decanted during the refurbishment. If it is necessary to decant, the residents will need relocation. Some of the tenants will not return to reoccupy the building, wherefore the owner will have the opportunity to sell some of the units to the private sector. In this case, a refurbishment of the flats based on EnerPHit would further add to their market value. On the contrary, if the building were not decanted, the same tenants would keep occupying the building post-refurbishment. Therefore, although achieving EnerPHit would add value to the flats, the owner would not be able to make any immediate profit out of it because the flats would not be sold. The Edward Woods Estate tower blocks refurbishment was a non-EnerPHit tower block refurbishment project in London, where residents stayed inside the building during the refurbishment. To make financial profit, the owner built new flats above the existing floors. However, in a location with a relatively low housing market value such as Portsmouth, selling the flats was not a credible option. In fact, Portsmouth City Council preferred to keep the tenants inside the building during the refurbishment because they wanted to avoid the extra costs related to decanting and relocating residents.

It should be considered that the decision of an owner would depend on their financial situation, regardless of what approach they take; they would either need an adequate budget to achieve EnerPHit or be eligible for a financial loan. Poor financial conditions would curtail the owner's potential to carry out a deep retrofit of their tower block stock, particularly to the level required by EnerPHit. ECD Architects estimated that the refurbishment of Wilmcote house would cost around £12m to reach UK building regulations, and £13m to meet with EnerPHit. It is worth noting that the initial budget that the council had allocated to the improvement of Wilmcote House was £3m; thus, the deep retrofit of the building required a significant budget rise. The cost estimations show that compliance with EnerPHit would increase the cost of deep retrofit, although not at a significant rate. Portsmouth City Council was financially capable of increasing their budget from the initial £3m to around £13m.

However, some of the potential factors leading the council to decide to expand their budget and apply EnerPHit to Wilmcote House were unique to this case. Firstly, the residents of Wilmcote House were extremely dissatisfied with the existing condition of the building, such as the inefficient heating system, to the point of making complaints to local politicians. Therefore, it was necessary to go the extra mile to appease the residents by selecting a long-term solution to maximise their comfort. Secondly, by applying EnerPHit to Wilmcote House, the council would become involved in a pioneering project that could bring them prestige, setting an example for any future tower block refurbishment projects. Another project-specific factor was that the cost of a standard deep refurbishment for Wilmcote House based on UK building regulations was less than half of the cost of demolition and rebuilding. Achieving EnerPHit would cost only around 9% more than the building regulations level. Consequently, EnerPHit refurbishment was significantly more cost-effective than demolition and rebuilding.

In fact, cost was a central concern because the project would not receive any specific financial aid for being a pioneer in targeting EnerPHit, apart from funding later received to provide Passivhaus training to some members of the architects' and the contractors' teams. BRE covered the training costs because they had selected Wilmcote House as their case study for the European EuroPHit project which promotes step-by-step refurbishment based on EnerPHit. Thus, it was necessary that the council could financially justify their decision to comply with EnerPHit standard.

9.3 The approach of the architects

The Wilmcote House case study revealed that the decision to achieve EnerPHit in a tower block can be highly dependent on the approach of the project architects and their knowledge of energy efficiency standards. ECD Architects, the project architects of the Wilmcote House refurbishment, is a practice with significant involvement in sustainable projects, including tower block refurbishment. Unlike most practices, the team is experienced with BREEAM, the Code for Sustainable Homes and Passivhaus; similarly, it would be unrealistic to assume that most practices are familiar with the Passivhaus standard, or have the same amount of experience and insight into energy efficiency standards. Therefore, there is an even lower possibility that a client would be aware of Passivhaus and its advantages. In the case of Wilmcote House, the architects convinced the client to change their initial targets and to widen the scope of the project, familiarising the client with the EnerPHit standard and its potential benefits. Nevertheless, if the client had taken a different approach or was not financially capable of achieving EnerPHit, the architects might not have been able to affect their decision. In general, it was the architects who recognised the potential of achieving EnerPHit, believed that it would be an appropriate option for the Wilmcote House refurbishment, and managed to communicate this to the client.

Thus, the decision to use EnerPHit was the outcome of both the client's and the architects' perspectives. ECD Architects' design proposal based on EnerPHit reflected the commitment to sustainable and energy efficient design demonstrated throughout all of their projects. Since becoming familiar with the Passivhaus standard, they have attempted to implement it in all their projects where there is the opportunity. Additionally, they have made excessive efforts to carry out cost analyses and studies comparing the application of Passivhaus/EnerPHit with UK building regulations, so that they will have adequate evidence to present to potential future clients. Their dedication to Passivhaus/EnerPHit despite the additional cost, work, and practical challenges, indicate that they consider this standard to be an effective way of implementing their energy efficiency principles. This level of dedication is a significant factor in motivating clients and increasing the possibility of the use of EnerPHit.

Therefore, based on the Wilmcote House refurbishment project, it can be concluded that the first challenging step to achieving EnerPHit in UK tower blocks is finding adequate evidence to convince the client that complying with this standard is both feasible and advantageous. As previously explained, the approach of the client and the project architects are critical in making this decision. However, the case study of this research also revealed that the specific conditions of a building, including its structure and heating system, can make it extremely difficult to comply with EnerPHit, to the point that a client may reassess meeting this standard or complying with all its requirements.

9.4 Compatibility of the tower block with EnerPHit requirements

The study of Wilmcote House, [REDACTED] and [REDACTED], shows that the physical properties of UK tower blocks can make it difficult to comply with certain requirements of EnerPHit. In terms of achieving the airtightness requirement, one advantage of tower blocks over low-rise buildings is that, generally, they are more compact and airtight because other flats surround each flat. The initial airtightness tests on Wilmcote House showed that the existing airtightness level of maisonettes was around 3 ACH^{-1} @ 50 Pa. Considering that the airtightness requirement of EnerPHit is 1 ACH^{-1} @ 50 Pa, it can be realised that there were minor differences between the existing level and the EnerPHit level. Consequently, even though it was a practical challenge to reach the airtightness target on site, it was not considered to be a serious obstruction for Wilmcote House to achieve EnerPHit. The development of a strategy to measure the airtightness level of the blocks after the refurbishment challenged the contractor. Generally, air testing a conventional low-rise building is a straightforward process, but it can become complicated as far as a tower block is concerned. A typical tower block consists of corridors and flats spread over different floors and some communal areas. In a conventional tower block refurbishment, it would be enough to test the airtightness of the flats; however, all the communal areas within the thermal zone of the building would need testing if the project were aiming for EnerPHit. As it would be quite challenging to test the whole thermal zone of the block at the same time, an effective strategy must be devised to divide the building into separate test areas. The initial strategy of the Wilmcote House project contractor was to separately test every two floors of each block. However, the site architect discovered perforations in the risers of Wilmcote House which were the remnants of gas pipes previously removed from the building. The perforations would circulate the air in all the floors above the ground floor; thus, it would become impossible to fully separate the floors. Consequently, the contractor was required to devise an alternative test strategy. Additionally, it would be difficult to keep the residents outside of the building during the test process, taking into consideration the number of residents and that the duration of the test would last a minimum of a few hours.

Minimising the thermal bridges, another requirement of EnerPHit, would not be achievable in Wilmcote House without the enclosure of the existing access walkways. This was because it was impractical to insulate the surface of the walkways due to the change in level and drainage issues. Alternatively, insulation could be applied to the ceiling of the areas below, leaving thermal bridges at slabs and the exposed precast structure. Therefore, it was essential to enclose the walkways entirely to minimise both heat transfer and thermal bridges. Furthermore, enclosing the open spaces would result in a more compact form with lower surface area exposed to the external environment. From the technical point of view, it was feasible to enclose the walkways and balconies and to create an even façade, but it required a considerable amount of additional design and construction work due to the unstable structure of the building. Similarly, the enclosure of walkways would impact the daily lives of the residents, who would not be able to open the walkway-facing windows of their kitchens. They could no longer stop in the walkways to smoke or to get fresh air without opening the walkway windows which were operated by the client. In fact, the walkways would become passages which would lead the residents to their homes rather than a place where they could stop and interact with each other. Therefore, this was one of the project aspects which some of the residents were initially not in favour of. However, the client and the architects had meetings with the residents and convinced them as to the benefits of the scheme. In addition to its energy saving aspects, one of the advantages of enclosing the walkways was that it could result in greater privacy and safety for residents. Thus, it can be concluded that complying with EnerPHit imposed changes on to the relationship between the residents and the building. Consultations and meetings with residents was a good opportunity to explain the reasons behind the changes so that they could acquire a greater tolerance and even appreciation for them.

The installation of superinsulation, another EnerPHit requirement, was a serious challenge to the [REDACTED] and [REDACTED] refurbishment design due to the inadequate quality and low strength of their structures. Generally, the post-war UK tower blocks suffer from structural problems due to utilisation of poor materials and construction methods such as LPS (large panel system). From a structural analysis of the aforementioned blocks [REDACTED], it can be understood that the structure of post-war tower blocks might not be sufficient to carry the superinsulation layers. Applying a method avoiding the loading of the insulation weight on to the building structure could be a solution to deal with this problem. For instance, new elements including steel frames and foundation piles, were added to Wilmcote House so that they would carry the insulation load. However, in the case of [REDACTED] and [REDACTED], the major problem was that the structural elements were in an extremely poor condition and kept deteriorating; consequently, adding insulation to the existing layers of the building (overcladding) was not a practical possibility. It would be better to remove the existing cladding and to replace it with new cladding, however this was estimated to be an expensive choice; additionally, it required the decanting of the building which would further increase the costs. [REDACTED] found it economically unfeasible to cover the costs of decanting the blocks and fitting a new cladding system. Consequently, they decided not to continue with the [REDACTED] and [REDACTED] refurbishment projects.

However, the review of the Wilmcote House project shows that complying with the primary energy demand was the most serious obstacle to achieving EnerPHit and it is highly probable that it would be similar for other UK tower blocks with an LPS (large panel system) structure. The risk of disproportionate collapse resulting from the poor building structure inhibits the use of gas pipes in blocks with an LPS structure; thus, electricity was used as a substitute form of energy. The electric heating systems installed in post-war tower blocks are mostly inefficient and in need of replacement. Nevertheless, with reference to the Wilmcote House project, a tower block is unlikely to meet EnerPHit standard if the building relies on electric heaters supported by the electricity grid, even if the heaters utilised are modern and efficient. One solution would be to use alternative sources of energy, such as gas, supplied to a communal heating system or any other type of renewable energy.

Version 9 of PHPP (Passivhaus Planning Package) has made it viable to calculate the primary renewable energy demand. With the publication of PHPP 9, the Passivhaus Institute launched new categories of Passive House. Unlike the traditional Passivhaus version which did not assess renewable energy, the new categories are based on the primary renewable energy demand and the building’s own renewable primary energy production (Passipedia, 2015). Therefore, the new method provides an opportunity which did not exist before for tower blocks to comply with the primary energy demand of EnerPHit. However, the energy source and the heating system utilised in Wilmcote House would not be upgraded by the completion of the project, and subsequently, the building will not achieve EnerPHit by the completion date. The possibility of using gas or biomass through communal heating was also investigated, but was rejected by the client because they did not want responsibility for operating the system. They were particularly concerned with the payment of bills, in that if any of the tenants did not pay the council would need to cover their share in order to keep the communal system running, preferring an individual system where every tenant would be responsible for their own payments. Similarly, the council did not approve of incorporating any renewable energy technologies to the building because they did not find it financially workable at the refurbishment stage; nevertheless, they were open to considering the installation of photovoltaic panels at a future date. Consequently, the opportunity to fully achieve EnerPHit still remains for the Wilmcote House project.

Although the general traits of the high-rise building typology are suitable for achieving Passivhaus standard in that they have some advantages over low-rise buildings by way of form and compactness, the Portsmouth case studies suggest that the low quality of existing UK tower blocks, especially those with LPS structure, may create challenges in terms of complying with certain requirements of EnerPHit, such as superinsulation and the primary energy demand. The case studies show that it is theoretically possible to arrive at solutions to overcome these problems; however, these are often too costly or difficult to achieve in practice. Taking into consideration that tower block owners in the UK are mostly councils, they may not be able to justify the allocation of budgets to utilising expensive solutions.

Based on both the Wilmcote House and the [REDACTED] and [REDACTED] projects, it can be concluded that the first step to refurbishing a tower block to EnerPHit standard is convincing the owner that it is the most appropriate decision for the future of the building. The approach of the client and the architects are both crucial factors affecting this decision. Nevertheless, the project-specific conditions may impose serious barriers to reaching EnerPHit, making it an unfeasible choice to pursue. Portsmouth City Council was encouraged by ECD Architects to aim for EnerPHit, believing that they made the right decision and feeling positive towards using the standard in their future projects. However, [REDACTED] decided against a refurbishment of [REDACTED] and [REDACTED] based on EnerPHit because the structure and the overall quality of these buildings are poorer than Wilmcote House, requiring a higher budget to meet the standard. As a conclusion, the potential to achieve EnerPHit is not equal for all tower blocks and can significantly depend on project-specific factors.

9.5 Design Concept

The analysis of design proposals for the Wilmcote House and [REDACTED] and [REDACTED] projects reveals that compliance with EnerPHit criteria was prioritised over architectural and aesthetic aspects. In addition to meeting EnerPHit requirements, factors such as the physical condition of the building and budget restrictions limited the architectural design creativity. In general, tower block refurbishment projects in the UK have aimed at enhancing buildings both in terms of physical condition and energy efficiency. Consequently, refurbishment plans typically include the upgrade of the fabric and heating systems, providing fire safety, and either the replacement or repair of older elements. The EnerPHit refurbishment design for the blocks in Portsmouth had similar targets; however, the major differences were that a higher level of insulation was specified to be installed to the fabric, Passivhaus windows and doors were to be used, and a stricter airtightness strategy was devised to achieve the EnerPHit airtightness requirement. Regarding the Wilmcote House project, the proposed alterations to the layout of the flats and the enclosure of balconies and walkways were dictated by airtightness and the minimisation of thermal bridges. Aesthetic aspects were partly reflected in the building façade through the selection of finishing materials. For instance, ECD Architects used colours and patterns in the façade of Wilmcote House to add to the liveliness of the building, giving it a modern look.

9.6 Form of the contract

The analysis of interviews with some of the Wilmcote House project staff on site indicated that there was controversy over the appropriateness of the contract form. The Standard Building Contract used for the project was devised by the client and the project architects, due to a lack of precedent in applying EnerPHit to UK tower blocks resulting in no specific contract form appropriate for this type of project. To determine the best way, the general requirements of the project and the specific demands of the client were taken into consideration. Some of the main differences between the common forms of contract, such as the Standard Building Contract, the Design and Build Contract, and the Management Contract relate to: the level up to which the scheme is developed by the client's consultants; the stage at which the contractor gets involved in the project; the client's versus the contractor's control over design; and the certainty over costs. Due to the sensitivity of refurbishment works needed to achieve EnerPHit on a tower block scale, the client and their consultants decided that it was more reasonable that they, rather than the contractor, developed and controlled the design of the Wilmcote House refurbishment. Thus, the project architects produced all the design drawings and specifications before the selection of a contractor. Furthermore, as a local authority, Portsmouth City Council had a limited budget to allocate to a single refurbishment project; therefore, it was appropriate to include a fixed price in the contract. ECD Architects believed that the Standard Building Contract suited the criteria to a greater extent than other forms of contract. They specified most of the design elements as CPD so as to give the contractor the freedom to select from various alternatives to achieve EnerPHit targets, believing that EnerPHit was not too prescriptive in the way it could be achieved. On the other hand, the contractor claimed that the separation of design and construction, one of the main aspects of the Standard Building Contract with CPD, resulted in serious complications during the construction stage. They found it challenging to adjust the architects' design to the building. The contractors argued that reviewing the architects' design, making revisions, and designing additional details, delayed the completion of the project on site. Therefore, they believed that it would have been more appropriate to utilise a D&B (Design and Build) Contract allowing the contractor to design and construct; or to use a Standard Building Contract without the CPD elements so the architects designed all the details.

However, the project architects refused to recognise the contract form as an acceptable reason for project delays. They believed that the interruptions were the result of the contractor's mediocre performance, particularly its management weaknesses. None of the two conflicting points of view are completely right or wrong. This study concludes that when used appropriately, both the Standard Building Contract and the Design and Build Contract may fit this type of project. Design and Build Contracts can reduce the length of a project because they do not separate the design and construction, but they can risk a project's compliance with EnerPHit, as contractors may not be capable of developing the complicated design scheme that conforms to EnerPhit requirements. To overcome this problem, the contractors should have effective communication with the project architects to ensure they understand all of the project requirements, consulting with them about producing solutions to challenging aspects of the project. Alternatively, a Standard Building Contract obtained via traditional procurement can increase project duration, due to having two separate design and construction stages carried out by different teams. In addition, a contractor may find it difficult to understand and implement the design prepared by the architects. To reduce these challenges and to minimise potential delays, the architects and the contractors should maintain an adequate level of communication to increase efficiency at the construction stage. This will be particularly effective if they collaborate at reviewing and potentially revising the design details. According to the Wilmcote House project contractors, it is beneficial for the architects to employ Passivhaus consultants at the design stage to minimise design errors, so that the contractors can spend less time on amending details.

9.7 Project Management

The construction stage of the Wilmcote House project suffered serious problems resulting from project management issues. Some of these problems delayed the project completion, frustrating both the client and the building residents. On one hand, the contractors suffered from poor management performance, and on the other hand, they were challenged by complications related to achieving EnerPHit standard. The contractors' management weaknesses reflected in their inability to meet their work schedule. It took them significantly longer to finish certain works, such as replacing the roof, and they did not take precautions to minimise the negative consequences of the delays; thus, their deviations from the schedule complicated the situation leading to serious issues, such as water leakage in some flats.

Furthermore, the contractors demonstrated a serious inability to retain staff. A considerable number of site staff, including some key members of the contractor's team, quit the project impeding the prompt progress of works on site. Additionally, the contractors made minor mistakes that increased the length of works; for instance, the installation of cracked windows in some parts of the building which had to eventually be replaced. This situation had a negative impact on the construction stage. Overall, the evidence suggests that the contractors did not have enough control over the project; however, the contractors associated the project management challenges with EnerPHit requirements. Examining the problems encountered at the construction stage, the study concludes that EnerPHit requirements undoubtedly did make it harder for the contractors to manage the project. Firstly, the contractors had to carry out a considerable level of additional design and practical work; secondly, the project required a significant level of control and supervision because even minor mistakes could lead to grave consequences. In addition, the workers did not have previous knowledge and experience of EnerPHit, and thus more likely to make mistakes. To provide the necessary supervision, the contractors had to employ a higher number of staff and provide them with Passivhaus training, while generally facing difficulties with training all the project staff.

9.8 Passivhaus training and experience

Educating the staff was an EnerPHit specific challenge: it was necessary that the staff gained new knowledge and skills to be capable of carrying out an EnerPHit project. However, the contractors found it difficult to train the considerable number of regularly increasing project staff. Following the training program, the learning process continued on site. As the staff worked on the project, they gained greater knowledge and experience of EnerPHit. Therefore, the contractors faced profound consequences when any of the teams or members quit the project as their knowledge and experience were lost, alongside the considerable time and effort it took to train and prepare the unfamiliar staff who replaced them. This situation led to project disorganisations and delays. It is likely that potential future projects could be negatively affected by the project staff's lack of EnerPHit experience. The members of the teams that participated in the Wilmcote House project may not be appointed to another EnerPHit project; thus, they will not have the chance to apply any acquired knowledge. The inexperienced teams working on the next project may make similar mistakes and need the same amount of time to understand EnerPHit and learn accordingly from their experiences.

9.9 Communication between project teams

The examination of different project team assessments of the Wilmcote House refurbishment indicated that they had contradictory perceptions of the project and its subsequent difficulties. To some extent, this situation was the outcome of the unexpected complications of a project in which the teams had no prior experience, with difficulties related to the scale of the project and EnerPHit targets. For instance, it can be understood from the architects' approach that they found it appropriate to follow a procedure which was similar to their previous tower block refurbishment projects, such as the Edward Woods Estate. However, they believed it was essential to prepare the Wilmcote House refurbishment design with a higher level of detail in order to facilitate the contractor's work in terms of achieving EnerPHit. During the construction stage, they periodically visited the site to inspect the progress of the project, and to have meetings and discussions with the contractor team and the client. They trusted that they had a sufficient level of input, and thus, they did not expect the contractor to encounter serious challenges. Consequently, when problems did occur on site, the architects associated them primarily with the mediocre performance of the contractor. On the contrary, the contractor argued that because of its scale and targets, the project was too challenging to continue without the further involvement of the architects.

However, the teams did not communicate their viewpoints effectively; therefore, they did not have an adequate understanding of the other's expectations. Gradually, dissatisfaction grew between the teams as their expectations went unmet. Subsequently, they became more critical than supportive of each other. This lack of effective communication between the project architects and the contractor became a barrier to developing a collaborative relationship. One consequence was that the contractor never contacted the architect to seek their advice on a specific detail design challenge that they encountered, arguably because it was not a contractual requirement for the architects to get involved at the construction stage. Conversely, the architects did not find it appropriate to offer their assistance with designing the details so long as the contractor did not express a desire for it. In fact, the architects did not want the contractor to assume that they were intervening in their work. As a result, the contractor did not receive the support they believed they required to resolve their challenges on site. Had there been a more collaborative relationship between the teams, it would have been less complicated for them to achieve a higher level of cooperation on site, regardless of their contractual responsibilities.

Another consequence was that this inadequate communication became a contributor to the feelings of uncertainty and frustration among the client team and staff. Considering that the Wilmcote House project teams had no experience of tower block refurbishment based on EnerPHit, and similarly, being the first of its kind in the UK, it was natural that some of them would hesitate over the feasibility of the targets, and the effectiveness of the design and construction methods utilised in the project. However, some of their hesitations could have been overcome if they had shared and discussed them with the other teams. For instance, a key member of the client team was not confident that the actual performance of the Mechanical Ventilation and Heat Recovery system would match the performance predicted by the PHPP (Passivhaus Planning Package). One reason was that they had tested the system in one of the flats and it had failed to achieve the predicted performance. However, the test was carried out prior to the installation of insulation to the external walls; therefore, it was not a reliable indicator of the future performance of the system. If the client raised this issue with the architects, they could have provided them with more knowledge about how the productivity of the MVHR system would rise after insulating the building. The client was also concerned that the vast area of glazing which had been installed in the communal walkways would result in overheating; however, they were not aware that the architects had specified low-e coated glass to minimise this possibility. The resultant confusion and uncertainty created by a lack of effective communication frustrated the staff and created negative feelings towards the project. It is highly probable that experiencing these feelings was one of the reasons why some staff resigned.

9.10 Optimism vs. pessimism

The decision of the client to upgrade Wilmcote House to EnerPHit was affected by the optimism of the project architects towards the feasibility and benefits of reaching it. The architects convinced the client that it was necessary to improve the building fabric so as to resolve the problems that plagued the residents of Wilmcote house; therefore, EnerPHit was the appropriate standard to use because it prioritised the fabric. They analysed the physical conditions of the building and developed design solutions for achieving EnerPHit level. Furthermore, the architects prepared a comprehensive feasibility study comparing the possibilities of achieving UK building regulations and EnerPHit. The outcomes of the study revealed that achieving EnerPHit would lead to a 90% reduction in the annual heating and hot water demand, and a £750 saving in energy bills per flat. Comparatively, reaching UK building regulations level would reduce heating and hot water demands by 22% and energy bills by £745 per flat per annum; however, the savings could only be achieved if Wilmcote House heating system was switched to gas supplied to a communal heating to which the client was opposed. As a consequence, the client was convinced that complying with EnerPHit was the most suitable option.

Unlike the architects, the contractor was pessimistic about the achievability of all the project targets on site; however, the architects convinced them. When certain challenges were faced on site, some members of the contractor team argued that the optimism of the architects misled them. They believed that the architects had been too encouraging and had underestimated the difficulties of meeting some EnerPHit requirements, such as airtightness. To investigate this, the architects' initial expectations were compared to the actual project outcomes. It was revealed that the most significant incompatibility surrounded compliance with the primary energy requirement. The architects had used PHPP to develop their design specifications based on EnerPHit; however, they had not calculated the primary energy demand. After the contractor was involved in the project, their Passivhaus consultant carried out PHPP calculations and discovered that the building would not comply with the primary energy demand of EnerPHit while electric heaters were in use. The exclusion of primary energy from their initial assessments could have been the result of the architects' lack of training and sufficient knowledge in using PHPP. In addition, due to a lack of experience with applying EnerPHit to a tower block, the architects did not anticipate that the electric heaters would result in exceeding the primary energy target. Nevertheless, their failure to predict this complication did not have a serious effect on the project's process, as it was not the client's main priority to fully achieve EnerPHit or to get EnerPHit certification. They also did not challenge the contractor because their responsibility became restricted to complying with the airtightness requirement of EnerPHit. To avoid this type of miscalculation, the architects should have either discussed their design proposal with a Passivhaus consultant or received full Passivhaus and PHPP training at the initial design stages.

In addition to a lack of compliance with the primary energy demand, the architects did not predict the problems that occurred at the construction stage. Firstly, they did not have a thorough knowledge of all the existing building details, their understanding based on general investigations and a number of tests restricted to a few elements and areas of the building. Secondly, their perception of the difficulties of detail design and application were based upon previous tower block refurbishments that did not target EnerPHit. In addition, some of the project complications were the outcomes of the contractor's poor management performance. On the other hand, the contractor team had carried out their own investigations and had also sought advice from both Passivhaus and design consultants. Even though they had reservations over the viability of the project, they had ultimately committed to achieving the airtightness target, implying they did not find any significant barriers to reaching it. Therefore, the optimism of the architects misleading the contractor is a weak argument overall.

In fact, without the optimism of the architects, it would not have been possible to pioneer the application of EnerPHit to a tower block in the UK, a consequence of the pessimism of some architects and contractors about the application of EnerPHit or Passivhaus to any type of building. However, the optimism of the architects or other project teams should not overshadow the facts and lead to unrealistic expectations. To avoid any future disappointments or conflicts between project teams, it is necessary to fully investigate the feasibility of targets before finalising the contract. An increase in a number of tower block refurbishments based on EnerPHit would expand the experience of the construction industry and would provide them with new knowledge in this area; furthermore, it would lead to a more accurate assessment of the potential problems and the feasibility of the project targets.

Chapter 10: Conclusion

10.1 Introduction

This research has explored the possibility of applying the EnerPhit standard to a UK tower block, based upon a case study of the Wilmcote House refurbishment project. The aims of the research were to detect the challenges of this process, to explore the solutions to overcoming these challenges and thus to assess the feasibility of using EnerPhit in tower blocks in the UK. To achieve this, the study focused on the case study of the Wilmcote House refurbishment and recorded the progression of this project from its initial stage to final delivery. The outcomes of this study clarify the most challenging factors related to each point of the project, explaining possible methods to solve them, and the feasibility of utilising these methods. Some of these findings are supported by the design and decision-making stages of the [REDACTED] and [REDACTED] projects. However, due to the association of these outcomes with project-specific circumstances, their generalisability to other projects is limited. Thus, the answers to the main questions of this research concerning the challenges and feasibility of using EnerPHit in UK tower blocks partially lies within the unique circumstances of each project. This chapter presents the major conclusions of the research and recommendations for future research.

10.2 Major challenges of applying EnerPHit to UK tower blocks

Out of the challenges identified in the literature review, structural problems, financial affordability, and the construction industry's insufficient skills conforms with the findings of this study. Overall, the research concludes that the most challenging aspects of adopting EnerPHit standard in social housing tower blocks in the UK are the client's decision to select EnerPHit as the refurbishment benchmark, superinsulation of the fabric, compliance with primary energy demand of EnerPHit, minimising thermal bridges, and implementation of the design solutions on site.

- The client's decision to select EnerPHit is affected by their approach to upgrading their building stock, their financial capability, project specific factors, and the appointed architects' familiarity with EnerPHit. Project specific factors such as low market value of the flats and high housing demands in the area can encourage the client to choose refurbishment of the block over its demolition. However, there is a low probability that the social landlords are familiar with EnerPHit refurbishment. Therefore, their decision to use EnerPHit can be the result of their appointed architects' knowledge of the standard and its advantages. Generally, the clients who are optimistic towards the viability of meeting with EnerPHit requirements, prioritise long-term financial benefits over short-term ones, and feel highly committed to improving the living conditions of the building occupiers are more likely to adopt EnerPHit. Another significant reason behind the client's decision to use EnerPHit is their approach towards refurbishment. The clients prioritising fabric optimisation over heating system upgrade are more likely to use EnerPHit because of its fabric first approach. This approach aims to maximise the fabric efficiency to minimise heating demand leading to a minimum reliance on heating system. The financial capability of the client is also a determining factor because the UK government does not provide considerable financial support for the deep refurbishment of hard to treat social housing stock, making it necessary for the social landlords to rely on their own finances to meet additional costs of achieving EnerPHit. The project costs will significantly rise if the structural conditions of the block necessitates decanting. Overall, although decanting can mitigate the complexity of achieving EnerPHit in a tower block, it will reduce the affordability of the project. One of the most significant reasons the client decided to refurbish Wilmcote House using EnerPHit was that the residents could occupy the building during the refurbishment; thus, the project was financially feasible.

- Superinsulation is considered to be a challenging issue because the majority of post-war tower blocks have substandard structure and deficient fabric. Consequently, it might be unsafe to overload the building with additional weight of insulation; thus, the use of conventional methods of insulation installation will be unfeasible. Furthermore, if the fabric is highly corrupted, it will be ineffective to cover it with insulation. In this case, the fabric needs to be removed and replaced, requiring the evacuation of the building and relocating the residents, increasing the costs of the project.

- Compliance with primary energy demand of EnerPHit can be complicated due to the structural instability of tower blocks constructed with Large Panel System. The use of piped gas, one of the most common primary energy sources, is not permitted in Large Panel System blocks; thus, they are connected to electrical grid, a secondary energy source. To meet with primary energy requirement of EnerPHit, these blocks must be provided with alternative primary energy sources such as biofuels and solar energy. The technology to utilise these sources can become financially unfeasible or technically challenging depending on the project specific factors. Thus, it can be concluded that it is more feasible to achieve EnerPHit in blocks with no restriction on use of piped gas.

- Minimising thermal bridges: may require important alterations to the façade and function of spaces. The existence of communal and private open spaces such as balconies and open walkways create junctions on the façade where thermal bridges occur. To minimise thermal bridges, it is necessary to cover the open spaces and to create an even façade. Restricting open spaces alters the way the building occupiers use them. These alterations may dissatisfy the residents.

- Implementation of the design solutions on site: can become challenging in different ways. One of the complications associated with this stage of the project is concerned with the EnerPHit training. It is necessary that all the staff working on site receive sufficient EnerPHit training. This is difficult to achieve considering the higher number of site staff required to work on a tower block refurbishment compared to a conventional low-rise building. This situation can become more onerous if site staff quit the project. In this case, the contractor is required to provide the same training for the replacing staff, leading to waste of time and frustration. The second factor is the more complicated and unconventional details required to meet with EnerPHit requirements, particularly airtightness. To achieve EnerPHit, it is essential that the site teams fully understand the details designed by the architects and implement them accurately because even a slight mistake can lead to lack of compliance with EnerPHit targets. As suggested by the literature review, due to lack of sufficient skills, the contractors in the UK might encounter problems with achieving EnerPHit. This issue becomes more serious in the case of tower block refurbishments as they are less efficient than conventional buildings; furthermore, the UK contractors have no previous experience of complying with EnerPHit in tower blocks. Thus, there should be a high level of communication and collaboration between the architects and the contractors so the contractors can understand the details, raise any issues regarding their accuracy, and consult with the architects when they encounter unexpected complications during construction.

  Utilising Standard Building Contract procured via the traditional method can minimise the collaboration between the architects and the contractors because this type of contract separates design from construction. On the other hand, using this method has significant advantages such as increasing the client's control over the design and expected quality. To achieve better results with this type of contract, the architects and the contractors should attempt to maintain their collaboration at the construction stage. It is advantageous if they cooperatively design and review the details prior to the commencement of the construction. Otherwise, the construction stage may be prolonged, leading to dissatisfaction of the client and the residents. Another time-effective solution is that the architects seek the advice of Passivhaus consultants with regard to the accuracy of details at the design stage; consequently, the contractors will require less time on review and amendment of details.

Thus, there is a range of problems complicating the success of achieving EnerPHit in UK tower blocks. It might not be possible to resolve all project-specific problems; nevertheless, this research provides solutions for the most serious difficulties encountered at the Wilmcote House refurbishment project including lack of compliance with the primary energy demand and the contractors' difficulties with implementing the details on site resulted by insufficient communication between the stakeholders and the site staff quitting the project.

10.3 Solutions

- Meeting with the EnerPHit primary energy demand can be unfeasible in Large Panel System tower blocks where the use of gas pipes is restricted. One solution is to switch from electricity to renewable energy sources, or to supply the block with hot water heated by an external source of gas. The client might not have sufficient budget to provide renewable energy technologies. However, it is worth mentioning that in order to tackle climate change, there is a global effort to switch from fossil fuels to renewable energy sources. The existing research in this area shows that the cost of renewable energy has fallen in recent years, so that the application of different renewable energy sources is gradually becoming a cost-effective option (Griffin, 2017) (Z. Amin, 2015) (Carrington, 2017). If the costs continue to descend in the future, there will be a better opportunity for councils to provide renewable energy in their building stock. Additionally, there is a possibility that they will have obligations in the future to utilise renewable energy in order to reduce carbon emissions. The rise in the use of renewable energy in tower blocks will increase their potential to comply with the primary energy demand of EnerPHit.

  Another alternative is to connect to a district heating system which can provide tower blocks with the opportunity to switch from electricity. Currently, hundreds of thousands of domestic customers, including some tower block residents, use heat networks in the UK and the government plans to expand the district heating system (The Association for Decentralised Energy, 2018). If a large-scale district heating system is not accessible to a tower block, the owner could install and run their own district heating system. In most cases, where there is more than one single tower block in one area, the owner could utilise the system to supply all their stock.

- The case study of Wilmcote House revealed that despite the architects' solutions and full design specifications prior to the commencement of the project on site, serious problems were encountered at the construction phase of the project. These problems had roots in numerous factors and their interactions; however, they were exacerbated by a lack of sufficient cooperation and a collaborative relationship between the teams. Therefore, it is concluded that the construction stage could have been optimised by employing methods to improve cross-team communication. One solution could be to utilise a Partnering Contract, based upon the collaboration of the teams in managing the project so the teams can have an elevated level of cooperation. A Partnering Contract can be applied for one specific project; however, it is more appropriate to use it over different projects because the project teams will have had the opportunity to develop a better understanding and mutual trust. For instance, if the Wilmcote House project teams extend their cooperation to future projects, it would be feasible for them to form a Partnering Contract. In fact, Portsmouth City Council was planning to reappoint ECD Architects for their future tower block refurbishment project based on EnerPHit. Had the project been financially viable, they would have collaborated for the second time on a similar project.

  Another factor contributing to complications at the construction stage of the Wilmcote House refurbishment was the loss of staff who had received EnerPHit training and had spent a considerable time increasing their knowledge throughout the duration of the project. Furthermore, interviews with contractors suggest that despite the fact that they had gained valuable experience from the Wilmcote House project, they may not have the opportunity to use this at a future time. This is because the company might appoint different staff to similar projects in the future, resulting in inexperienced staff having to go through the same learning process. To minimise the waste of time and training funds, construction teams undertaking Passivhaus/EnerPHit projects can specify a team of staff, providing them with Passivhaus training so they can specifically work on these projects. Consequently, the members of the Passivhaus team can gain greater knowledge and experience through their involvement in different Passivhaus projects and thus the experience-based knowledge of the staff will not be lost.

Overall, it seems that the feasibility of upgrading UK tower blocks to EnerPHit level will increase over time. The teams undertaking the first UK tower block refurbishment according to EnerPHit feel positive about the future of this type of project. Portsmouth City Council are investigating the possibility of reaching EnerPHit in their tower block stock. ECD Architects will continue to introduce EnerPHit to future clients and will explore the possibility of achieving it in upcoming tower block refurbishment projects. Keepmoat has already been involved in the second EnerPHit tower block refurbishment project in Glasgow.

10.4 Future research

This research has revealed the challenges of applying EnerPHit to UK tower blocks. However, single case study, the method used to carry out the research, has limitations. The main limitation is low generalisability. As some of the challenging factors are related to project specific factors, further research on tower blocks with different conditions will provide more evidence on generalisability of the outcomes of this research. Based on the research findings, three areas are recommended for future investigation:

- In chapter 3, it is explained that Portsmouth City Council is the sole owner of Wilmcote House and all the building occupiers are tenants. Therefore, the Council was the only party making the decision for future of the building. Nevertheless, this is not a common situation because the majority of UK tower blocks are occupied by a mix of tenants and leaseholders. Unlike the tenants, the leaseholders are required to pay for refurbishment costs. Considering the uplifted costs of achieving EnerPHit requirements, the leaseholders may find it too costly to adopt the standard. As the number of Passivhaus and EnerPHit projects in the UK is rising, it is worth investigating whether the leaseholders would take the long-term approach and agree to paying additional costs of EnerPHit if they become aware of the growing popularity of the standard in the UK and its advantages such as minimum energy consumption and health benefits, and whether the social landlords would be willing to provide them with any financial schemes to pay the costs over a longer period of time.

- In chapter 4, the structural problems of Large Panel System blocks leading to restriction of using piped gas is discussed. Chapter 5 explains that this issue resulted in lack of compliance with primary energy demand in Wilmcote House; nevertheless, the new versions of Passivhaus allow the alternative route of meeting with primary energy demand by utilising renewable energy. Consequently, the Council plans to install photovoltaic panels on Wilmcote House in the future to fully comply with EnerPHit standard. However, the financial and technical feasibility of meeting with primary energy demand in a tower block relying on renewable energy requires further investigation. From the interviews with a number of Wilmcote House project staff and the review of PHPP calculations carried out for Cedar Court tower blocks project, the author suspects that the possibility of including renewable energy in primary energy demand calculation has been misunderstood. It has been assumed that the additional primary energy consumption of the building can be offset by using renewable energy, meaning that it is possible to meet primary energy demand by calculating both primary energy (PE) and primary renewable energy (PER). Nevertheless, this is a wrong assumption because Passivhaus Institute validates either PE or PER calculation (Passive House Institute, 2015). Thus, the author believes that if renewable energy is used as a route to comply with primary energy target, no non-renewable source of energy including the electricity from the electrical grid can be utilised in the building[47]. Under the new version of Passivhaus Classic, the primary renewable energy target is 60 kWh/m².yr (Passipedia, 2015). It is possible to use traditional route and meet with: PE ≤ 120 kWh/m².yr + ((Specific Heating Demand - 15 kWh/ m².yr) x 1.2), or to use the new route: PER ≤ 60 kWh/m².yr. The question is: Is it financially and technically feasible to disconnect Wilmcote House from electrical grid, and meet all its energy demand via photovoltaic panels?

- The literature review suggests that sufficient evidence is not available to identify the more suitable procurement methods to be used in Passivhaus buildings. This gap is confirmed by the findings of this research. The discussions in chapter 8 indicate that the stakeholders of Wilmcote House project have conflicting opinions on the suitability of different contract types. The architects believe that Standard Building Contract procured via traditional method is the most appropriate type of contract; whereas, the contractors maintain that Design and Build Contract could be a suitable option. Partnering Contract seems to be the most effective option, maximising the cooperation between the project teams and minimising conflicts. Nevertheless, the feasibility of utilising Partnering Contract requires to be examined more extensively. For instance, would this type of contract increase the

[47] Unless electrical grid is 100% generated from renewable energy sources.

project costs? If yes, would the client be willing to increase the budget to achieve better results?

- The author recommends a post-occupancy evaluation of Wilmcote House to measure the energy consumption in the maisonettes, investigate the internal environmental conditions, and understand the occupants' perspective on the refurbishment process and its outcomes. This will provide an opportunity to compare predicted and actual performance of the building.

The author believes that the research on application of EnerPHit to UK social housing tower blocks is at starting point. This research has addressed some of the gaps in this field and has left room for future improvements.

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