
RESPONSIVE RETROFIT MEASURES FOR TRADITIONAL LISTED DWELLINGS: AN INVESTIGATION INTO A MIXED METHODS APPROACH

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Abstract: *The body of scientific research corroborates that reducing energy consumption alongside other environmental impacts can help reduce climate change effects. Existing buildings are major contributors to energy consumption and carbon/GHG emissions. Even more so is the housing stock, and more specifically, the dwellings of some cultural value or heritage merit. In the case of historic dwellings, because of constraints imposed by their heritage value, improvements are not as easy as for the rest of the existing building stock. The UK must address retrofit measures in this sector as it inherits one of the oldest, most culturally-rich yet most poorly-performing housing stocks in Europe.*

This paper sets out to elaborate on the methodology developed for a research project aimed at devising a framework for interventions in traditional listed dwellings to improve the environmental impact at reasonable cost, in order to shape a more future-proof heritage by providing decision support structures for stakeholders groups. The paper concentrates on the proposed mixed methodology, which is centred on a selection of C.19th case study dwellings in Brighton, South East of England. Following a critical literature review, secondary data collection and analysis, interviews/questionnaires, measured surveys, data logging, thermal imaging and energy simulations are proposed in order to investigate the current energy performance and the possible improvements to suggest responsive and cost-effective energy retrofits of the selected dwellings.

Keywords: *Energy retrofit, Sustainable refurbishment, Cultural Heritage, Housing, Listed buildings*

1. Introduction

This paper describes the methodology and methods developed for an ongoing study aimed at devising a framework for intervention in traditional listed dwellings (TLDs) to improve their environmental impact. The research seeks a solution based on an overall sustainable approach; one that takes into account socio-cultural aspects, environmental aspects and economic aspects. For the purpose of this study, a pragmatic philosophical position has been adopted that will opt for the use of more than one research strategy in order to gather data in a variety of ways to investigate the problem in-depth and guarantee reliability of the results generated triangulating data sources. Such approach is what this paper aims to address.

The novelty of this study lies in the comprehensive account and unique combination of a mixed method approach on multiple case studies for the analysis of the current performance and the possible energy improvements of TLDs. The combination of a carefully selected set of appropriate methods should allow for gathering a whole set of qualitative and quantitative data to be collated, analysed and inputted in an environmental simulation software in order to achieve models as close to reality as possible. Such comprehensive, multifaceted and multi-criteria approach to environmentally concerned interventions can particularly be recommended for heritage buildings to mediate between environmental and conservation issues with a sensible account of cost and financial aspects. Academics, practitioners, legislative bodies and policy makers in local and central governments have repeatedly called for the need for such methodology to justify a systematic decision making for performance improvement in this sector.

2. Rationale for research

The Intergovernmental Panel on Climate Change (IPCC 2014) stated that anthropogenic activities are the main cause of global warming today, being responsible for increasing concentrations of greenhouse gases (GHG). To face this threat, the UK has committed to lowering emissions by at least 80% by 2050 as compared to 1990 levels (Climate Change Act 2008).

The built environment is responsible for about half of these emissions in UK (UK-GBC 2014) and the housing sector produces about one quarter of the total GHG emissions (HM Government 2009) mainly due to space heating (HM Government 2012). Furthermore, most of the 25 million homes existing today in the UK are expected to still be in use by 2050 (Wright 2008). The built environment therefore, and in particular the housing stock, can surely play a major role in mitigating climate change. The UK, however, is facing a major challenge to address retrofit measures in this sector as it inherits one of the oldest, most culturally rich yet most poorly performing housing stocks in Europe. Approximately one quarter of the total number of dwellings in UK, are so-called traditional buildings (STBA 2012a). This definition applies to dwellings built before 1919 - which is widely known as the date for the introduction of DPC and cavity wall construction in the UK (English Heritage 2008) - with solid permeable walls (Historic England 2011). Most of these buildings are generally poorly performing (Boardman 2007).

The problem becomes even more complex considering that about one quarter of the traditional housing stock in the UK is listed or within conservation areas (Bottrill 2005). These are buildings of special architectural merit and/or historic interest therefore protected to guarantee their conservation. However, the listing makes their energy upgrade particularly challenging as any retrofit measure has to be weighed against the

damage it may pose to their heritage value. A report by the Sustainable Traditional Buildings Alliance (STBA 2012a) has also evidenced how it is still uncertain what can be achieved with typical retrofit measures without damaging the heritage. This is mainly due, according to the report, to a lack of proper understanding of how traditional buildings operate as well as of the effects of an energy efficient refurbishment on them.

To be able to properly evaluate how they actually operate, more research is needed firstly to thoroughly investigate their fabric and understand how it behaves, then to translate this knowledge into models and simulation software to assess their current energy performance. Finally, responsible solutions for them will be devised carefully balancing energy upgrade measures and conservation issues. This needs to be carried out weighting the trade-offs between interventions, improvements as a result of such interventions and cost implications while considering the impacts on the historic and architectural values perceived to be inherent characteristic of this section of the heritage.

3. Aim and Objectives

This paper attempts to present the methodology and methods developed for a research aimed to provide a framework to intervene, within the set boundaries of the relevant legislation and regulation, in TLDs to improve their environmental impact within a reasonable cost bracket in order to shape a more future-proof heritage.

To successfully achieve the aim of this research, the following objectives need to be fulfilled successively during the different stages designed for this study:

- 1) To identify the actual energy use, CO₂ emissions and other related environmental impact categories of TLDs.
- 2) To investigate the range and extent of possible retrofit interventions within the context of legislation, regulation and guidance applicable to listed buildings.
- 3) To investigate the impact of the selected possible interventions on TLDs with reference to their historic fabric, CO₂ emissions, energy consumption and other environmental impact categories.
- 4) To define a methodology to propose appropriate combinations of retrofit solutions to apply to TLDs with reference to performance, legislation, regulations, heritage values and cost implications of such solutions, so that an overall sustainable approach to such measures can be taken.

4. Critical literature review

A critical review of literature has been conducted in order to aid in the definition of the research design, methodology and methods to be adopted for this study.

Examining the documents related to energy performance of existing buildings in their unimproved condition and after retrofit, it is immediately evident that the majority of the research is concerned with retrofitted buildings, while very limited work has been done to investigate their performance in the original condition (STBA 2012a). This is however fundamental knowledge to take into account when setting out effective interventions and is the starting point for any calculation of the benefits of the measures to be adopted (Moran 2013; Panayiotou 2014).

The initial critical review has been done of the state of the art literature on the energy performance of existing dwellings in their unimproved condition. Looking at residential buildings, the research conducted by Panayiotou (2014) attempted to define a model representative of the whole range of dwellings in Cyprus. The study adopted questionnaires to gather data about a statistical sample of 500 properties; from the analysis of the data collected, a model house was designed that summarised the characteristics of the majority of the dwellings in Cyprus. On such a model, different energy conservation measures were tested using software simulation. The study, however, concluded asserting that, in order to properly evaluate the thermal insulation combinations suggested and to validate the theoretical results obtained on the modelled typical house, it would be useful to check the simulation results with outdoor experiments under real conditions. A similar approach for the definition of a baseline of performance was adopted by Akande et al. (2015) investigating six grade I listed churches as case studies using a questionnaire survey. However, no simulation has been done of the buildings performance before and after retrofit interventions and the study could only conclude suggesting the adoption, coupled with behavioural changes, of careful measures that respect the heritage value.

The literature review conducted indicates that only a few studies have involved listed or historic dwellings in their entirety. The research carried out in Scotland by Ingram (2013), made use of steady state (SAP and RdSAP) and dynamic simulation (IES-Ve) tools in five case study traditional dwellings to assess their energy performance and compare the quality of the results given by the different methods. The simulated energy demand was compared against measured data only in one case, hence the study concluded suggesting the importance of extending such methodology to a much wider range and number of cases. The approach taken by Moran (2013) in Bath with historical dwellings proved to be also workable elsewhere. His methods involved the use of a questionnaire survey about domestic energy consumption on a selected representative sample of the population of historic dwellings to define a baseline for interventions. The results were then matched with national statistics about energy use. Finally, three case studies were used to model their energy consumption using three steady state assessment systems and one dynamic modelling tool and validating the predicted energy use results against actual energy use data. Such an in depth analysis, however, has been carried out in this study with the main purpose of confronting the results obtained from a dynamic software with those given by steady assessment tools and determine the loss of detail as a result of adopting steady state models.

Conspicuous is the body of research produced by Historic Scotland and Historic England on the analysis of traditional buildings performance; however it mainly looks in detail at one or more elements of the external envelope like windows (Baker 2008; Wood et al. 2009) or walls (Baker & Rhee-Duverne 2012), or specifically at their U values (Baker 2008, 2011) or investigates the potentialities of energy simulation software for accuracy in the evaluation of the building energy performance (Barnham et al. 2008; Heat et al. 2010; Ingram & Jenkins 2013; Jenkins 2008). A more holistic approach has been adopted by Ascione et al. (2011) investigating in-depth a single case study in order to define possible improving interventions. The object of the research was a public historic building in South Italy. The study proposed a methodology for the performance analysis, coupling several experimental studies and simulations; the careful combination of them generated a model as close as possible to the real building. It was also validated comparing the results of the energy simulation with the meter reading of gas and electricity. Subsequently, the dynamic energy simulations were used to test the effectiveness, singularly and coupled, of several solutions for the building energy

upgrade. This approach guarantees an in-depth understanding of the building's materials and techniques and the generation of a realistic model but does not prove to be easily applicable on the whole body of historic dwellings due to the invasiveness of the experimental studies involved.

From the literature review conducted it seems that a holistic approach (Boardman 2007) is widely agreed as the most suitable one for traditional buildings, to improve the energy performance with low impact interventions that respect the character of the building in order to allow our heritage to withstand future challenges; such approach has rarely been adopted with this purpose and only limited to few case studies while the need for a major number of cases has been repeatedly called for.

A literature review has also been used to investigate the potentialities of simulation methods for the analysis of the building energy performance. Such a method is a validated strategy used to assist in the design process of energy efficient buildings (Garber 2009; Nguyen et al. 2014; Wang et al. 2005; Fesanghary et al. 2012) as well as in the choice of suitable retrofit interventions on the existing stock (Ascione et al. 2011; Ascione et al. 2015; Kolaitis et al. 2013; Pernigotto et al. 2012; Stazi et al. 2013). Nevertheless, when it comes to traditional buildings, there are still some important concerns with regards to the proper application of models and performance simulation software to investigate the energy consumption of this part of the stock (STBA 2012a, 2012b). Previous research on the subject of performance and energy efficiency of traditional buildings has frequently highlighted a gap between current monitored research evidence and most modelling of traditional building performance (Barnham et al. 2008; Heat et al. 2010; Ingram & Jenkins 2013; Jenkins 2008; Moran 2013, STBA 2012). Comparing Leeds Metropolitan's study (Wingfield et al. 2011) and Good Home Alliance one (Thompson & Bootland 2011; Taylor & Morgan 2011) on the performance gap for new build, with works by Rye (2010), Baker (2011) and Hubbard (2011) on traditional buildings, it emerges how the performance gap between the model of a traditional building and as-built reality may be considerable. However, while new buildings' performance is frequently overestimated by the simulation, research has demonstrated how traditional buildings often perform much better than expected because of processes and synergies that are not well seized by models. Although it is not the main focus of this research, this finding was considered to be relevant to take into account in this study because, if the secondary strategy of data collection was not workable and this research was only to rely on simulation, it will be assured that the results obtained by the energy modelling per-se will be sitting on the safe side providing a worst-case baseline scenario for the interventions to apply.

5. Methodology and Methods

For the specific nature of this research, its aim, objectives, data types and analysis required, a pragmatic philosophical approach has to be taken, hence a mixed method strategy (Creswell 2014) which starts with critical literature review and secondary data analysis to build up the underlying frame for collection and analysis of primary data through a multiplication of different methods. The literature review conducted on similar studies and summarised above has evinced how an holistic approach as such is unprecedented if not for single case studies and proves to be the most suitable to take into account all the complex synergies that characterise historic buildings.

5.1. The setting

Before moving to the data collection and analysis phase of this study, it is important to set the research within the location chosen and explain the rationale for the selection of this context. The City of Brighton and Hove has been chosen as the geographical setting due to the full combination of different influential factors that it provides, which make of it an extreme case within the English housing context.

Brighton is centrally located within the South East of England, which has the highest predicted temperature rise for the future time period of 2080s (Jenkins et al. 2009).

Most of the historic buildings in the city belong to the early 19th century. At that time Brighton turned into a spa town and seaside resort and flourished with notable examples of regency architecture (Antram & Morrice 2008). The Council recognises these buildings as possessing a great heritage value, hence the significance of the special care owed to the preservation of their character (Brighton and Hove City Council 2009). This places constraints on retrofit measures for such buildings when the interventions may affect their fabric and aesthetics.

The city of Brighton and Hove has a remarkably large number of pre 1919 dwellings (The definition of dwelling is given by the Government's Guidance in line with the 2011 Census definition - DCLG 2012). Of the total number of dwellings – both listed and not listed - (104,100), almost 40% were built before 1919, (Brighton and East Sussex 2008). This proportion far outweighs the considerable percentage of traditional dwellings in Britain, where approximately 25% of dwellings are traditional ones (BPIE 2011).

A substantial number of the traditional dwellings in the town are listed; 1218 in total are the listed entries. The Council is however unaware of the existence of any kind of statistic breakdown for the data concerning listed entries. From a first analysis of the list, it is evinced that more than 95% of the entries date before 1919 and approximately 750 are residential; generally though, one single residential entry refers to a cluster of individual buildings, frequently a listed terrace of houses. Therefore, the number of entries that are houses is estimated to be more than 3000. Furthermore, many of the listed residential units are magnificent regency terraced houses that have been split into four or five individual dwellings, one at each floor level. Hence, the number of listed traditional dwellings is surely higher than the total estimated number of listed residential buildings. By simply considering some of the main 19th century terraces and supposing that each house is divided into flats at each level, the total number of listed dwellings is estimated to be more than 5000. Further and deeper investigation is necessary to extract precise numbers. However, from this initial study, it can be concluded that certainly more than 12% of the traditional dwellings in town are listed.

Most of these residential estates perform poorly (Brighton and East Sussex 2008) because they were built at a time when very low energy standards were applied and because of a lack of investment in this sector. This evidence could be a consequence of the general trend in Brighton that shows a tendency to split houses into flats and rent them out leading to a high rate of deterioration. The House Condition Report (Brighton and East Sussex 2008) shows how the building type profile in Brighton & Hove differs from the national pattern with a much higher level of converted flats; over seven times found nationally. The council website (Brighton and Hove City Council 2016) states that the amount of private rented properties in Brighton & Hove is 21%, twice as much as the national average and the sixth largest private rented sector in the country.

The typical construction material in Brighton during the 19th century was “bungaroush”, a compound with uncertain thermal performance, which will possibly contribute to describe a worst-case scenario to provide findings that will be sitting on the safe side.

The combination of these factors identifies Brighton as a worst-case scenario to analyse; such setting for this research should give results that will likely prove to be easy to tailor or amend in order to propose validated solutions for similar listed properties elsewhere in the South East of England.

5.2. Case study research

5.2.1. Rational

The primary data collection and analysis phase of this research uses case studies as main approach where a multitude of different methods can be utilised to provide and support multiple units of analysis. This is because “the researcher can study information systems in a natural setting, learn about the state of the art, and generate theories from practice” (Benbasat et al. 1987: 370). Multiple-case design allows for cross-case analysis and the extension of theories. Furthermore, the use of multiple units of analysis consents triangulation and guarantees better reliability of the research conclusions (Benbasat et al. 1987). Hence, the approach of this research, where a multitude of cases have been involved and analysed with multiple methods to generate reliable, comprehensive answers to the research questions and allow comparison between the findings.

Concerning the practicability of any generalization out of case studies, Tsang (2014) affirmed that cases are not to be considered as sampling units and should be treated instead as experiments. They can therefore be generalized to theoretical propositions (Yin 2013). It is of paramount importance to note that the knowledge claims, which can be made with a case study approach, are not of the same nature and application of those made using pure quantitative methods. While samples research calculates frequencies in order to provide a statistical generalization, the purpose of case study research is to expand and generalize theories. The outcome of case study approach can be what Yin calls “analytical generalization” (Yin 2014).

5.2.2. Target population and representative case studies

In order to select representative case studies for the purpose of this research, it has first been necessary to define the target population, for which the study aims to generalise its findings. This is made of all TLDs in the South East of England. At present no statistic is available to define the actual number of this population with a good degree of certainty. The only data available today refers to the whole listed entries in England: that is 376,099 according to Historic England (2015), which have been clustered based on their period in Figure 1.

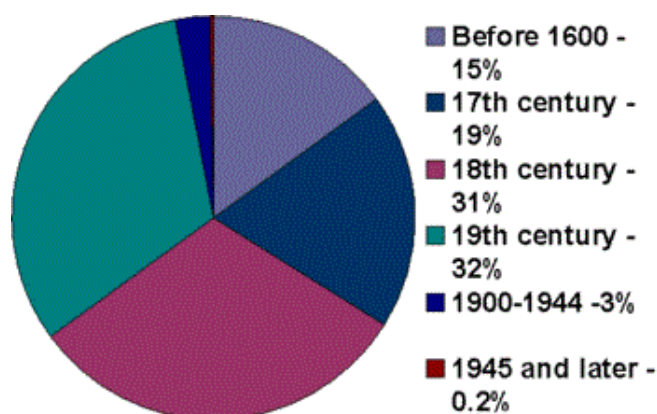


Figure1: Historic England, 2016. Graph detailing the age range of listed buildings in the UK (2016)[online] Available from: <https://www.historicengland.org.uk/listing/what-is-designation/listed-buildings/>, [Accessed: February 2016].

The graph illustrates that a total of 63% of the overall listing belongs to the 18th and 19th century. Looking specifically at dwellings though, a quick scan of the period of listed residential entries in Brighton, shows that the great majority of them belong to the 19th century, most of which being big regency terraces of houses (also divided into flats) listed as just one single entry. This is specific to the regency Brighton but can also be considered valid, with some decades of difference sometimes, for the whole south east of England, where the big boom of houses happened with the development of the terraced house typology before, during and after the industrial revolution (Muthesius 1982). Therefore it is realistic to assume that the majority of pre 1919 listed dwellings in the South East of England belong to the 19th century; hence this could be, with a better approximation, the target population.

This research is using approximately 10 - 15 case studies reflecting the local 19th century listed housing stock. This sample size will be enough to allow comparative studies on the chosen dwellings (Gay & Airasian 2000). In order to decide how to choose representative cases out of this population, the proportion of grade I, II* and II dwellings has been taken into account. The list of Brighton entries reflects the trend found in England, with more than 90% of the whole population listed as grade II, the remaining as grade II* and grade I. Therefore, it has been first considered whether to use a stratified sampling in order to allow a proportional representation for each grade. However, it has finally been deemed a good approximation, to consider the total listed 19th century dwellings in Brighton, independently from the grade, as available population (at the risk of not finding any available participant from any grade II* and grade I because of their rarity). The results obtained for the grade II samples will be validated also for dwellings of the same period listed as grade I and II* because the grading does not imply any difference in the statutory regime. It is not feasible to apply any random statistic sampling either to this available population due to the uncertainties about the exact number of it as well as the actual accessibility of the properties. Therefore, case studies are being selected using a carefully balanced mixture of convenience and purposive sampling technique. A first selection has been done to find out potential participants who might be interested in this study, in order to be able to procure a number of accessible dwellings. An email was circulated within the University of Brighton mail system calling for all residents or owners of listed 19th century dwellings interested to take part in the study. This initial convenient sampling technique provided a set of accessible dwellings from which representative samples could then be selected. Purposive sampling will help then to limit the number of case studies or to decide which other ones to add, basing the choice on the knowledge

of this population achieved by the researcher and validated through interviews and meetings with experts in this sector.

To date 11 potential case studies are to be investigated; Figure 2 evidences their locations and Table 1 summarises their characteristics.



Figure 2: Map showing the location of the case studies selected at this stage

Table 1: Characteristics of the case studies selected

Case study No.	Approximate Location	Typology and ownership info	Date of construction	Grade
CS1	First Avenue	Tenanted flat in converted house	2 nd half of the 19 th C.	II
CS2	Brunswick Place	Tenanted flat in converted house	1 st half of the 19 th C.	II
CS3	To be confirmed	Owned flat in converted house	2 nd half of the 19 th C.	II
CS4	Hanover Crescent	Owned terraced house	1 st half of the 19 th C.	II
CS5	Brunswick Place	Owned flat in converted house	1 st half of the 19 th C.	II
CS6	Russel Square	Owned flat in converted house	1820	II
CS7	Arundel Terrace	Owned flat in converted house	1 st half of the 19 th C.	I
CS8	Norfolk Terrace	Owned flat in converted house	1860	II
CS9	Grand Parade	Owned flat in converted house	1 st half of the 19 th C.	II
CS10	Roundhill Crescent	Owned flat in converted house	2 nd half of the 19 th C.	II
CS11	Sussex Square	Owned flat in converted house	1 st half of the 19 th C.	I

The case studies selected so far are, therefore, well distributed geographically throughout the city as well as historically within the 19th century and furthermore they contain a good mixture of owned and tenanted flats as well as grade II and grade I dwellings. Needless to say that owner-occupiers will have different incentives compared to tenants when it comes to any refurbishment interventions; this will be accounted for and factored accordingly at later stages of this study.

For each of the selected case studies a desktop research is first conducted to collect and analyse data about the heritage value of the building and its specific fundamental features needing protection (Historic England 2011; Herman and Rodwell 2015).

5.3. Simulation

5.3.1. The simulation software

At this stage, the research methodology involves the use of energy dynamic simulations in order to identify the current energy consumption and carbon emissions for each case study. Simulation has been chosen as it has several advantages compared to a field test (Yang et al. 2014): it is less time consuming and less expensive compared to a field experiment; importantly, in case of buildings in-use, it is non-intrusive; factors like outside weather data can be controlled and changed in order to isolate the effects of occupancy alone as well as those of one retrofit measure or of a combination of them.

In order to make a decision concerning the simulation software to use, a literature search has been conducted together with a desk survey of the available data and conversations with experts in the sector. The research conducted so far gives good reasons to believe that either Energy Plus (Ascione et al. 2011; Olsen & Chen 2003; Pernigotto et al. 2012; Stazi et al. 2013; US Department of Energy 2015; Yang et al. 2014; Wei et al. 2014) or IES-VE (IES 2016; Ingram 2013; McNally 2014; Memon 2014; Moran 2013; Pomponi 2015; Yang et al. 2015) is a suitable software to be used in this study for modelling the energy efficiency of TLDs. IES-VE has been chosen because it is already validated by a number of studies, it allows the simulation of multiple case scenarios to be applied on the same model, hence the comparative analysis of the interventions. Furthermore, it is an application developed in the UK and its use is widespread in the country as well as around the world. It offers a more user-friendly interface and requires less coding skills than Energy Plus. However, unlike Energy Plus, it is not an open source (which can potentially introduce some limitations on more advanced coding in complex simulations) but this was not considered to be the case in this research.

5.3.2. Simulation stage 1: primary data collection and new data generation

The body of scientific research agrees in suggesting the importance of using empirical data in order to achieve a good similarity between the modelled and the monitored fuel consumption pertaining to space heating (Hong et al. 2006; Stazi et al. 2013). It is therefore fundamental to describe the building in-depth in its geographical location, shape, materials and construction, pattern of use (Ingram 2013; Panayiotou 2014) as a part of an in depth multi-units of analysis multi-case study approach chosen for this study. Hence, a measured survey is being conducted for each case study and data concerning building typology, orientation, size and type of the openings, domestic appliances, materials of the envelope, are being collected. Secondly, as soon as the environmental conditions are suitable, a thermal-imaging survey of the envelope will be carried on. Data about the building services, the actual pattern of use, life style and temperature set points, retrofit interventions already executed in the dwelling, eventual

hurdles faced to install them, are being gathered for each case study using a questionnaire to be filled by the participants and a follow-up interview conducted with them. The actual data relating to the real use of the building obtained from the questionnaires and interview, will replace the default values in datasets built in the energy performance simulation package to make sure that the results will be as close to the actual performance of the building as possible. Two data loggers (one in the living area and one in the bedroom area) will be placed in each case study, possibly for two consecutive winter months, to record the internal temperature and relative humidity in the dwellings. These data will be used as a checkpoint to quality control the information produced by the users.

The whole set of data collected will be inputted in the dynamic simulation software in order to predict, with a good degree of certainty, the current energy performance and carbon emission of each case study.

The use of case studies in this research presents an ideal opportunity to check the simulated energy consumption results against actual energy use data and therefore guarantees a higher reliability of the results generated through simulation of the intervention scenarios. For this purpose, the main household electricity and gas supply meter readings will be collected in each dwelling on a monthly basis for a period of one calendar year. Also, with permission of the residents, historic data could be collected from the relevant energy companies. The historic data, combined with an analytical review of seasonal meter reading, will help work out the share of energy use for space heating, hot water, cooking and appliances (Lloyd et al. 2008; Moran 2013). The results in terms of energy consumption achieved with the modelling will finally be checked against the data collected through meter readings (Ascione et al. 2011; Lomas et al. 1997; Moran 2013).

To allow comparison between the different samples, a second modelling phase of the buildings in their status-quo condition will be conducted within this stage, using a typical household with identical or similar pattern of use, temperature set-points and lifestyle for each of the case studies. The results achieved from this second round of simulations will constitute the benchmark to refer to when assessing realistic energy savings and carbon reduction potential improvements.

5.3.3. Simulation stage 2: evaluation, comparative analysis and assessment

To evaluate the approaches and common practices adopted in the refurbishment of this type of properties, part of the literature review that has been done, will be further developed and secondary data collection (concerning similar listed buildings' consents already guaranteed in the area) will be carried out. The analysis of the data (concerning retrofit interventions already done within the dwelling and the hurdles eventually found) previously gathered from the questionnaires and interviews with the users, will aid in shaping the list of feasible interventions. Finally, semi-structured questionnaires will be sent to local conservation officers and possibly a few interviews with them will take place. The combination of such methods will generate possible scenarios supported by the outcomes of this systematic analysis with an expert overview of the practicality of such measures to come up with the potential retrofit interventions on the selected listed buildings within the context of regulations and guidance.

This second stage of simulations will be again divided in 2 phases. The first one will aim to find out the impact of each possible intervention with reference to the historic fabric, energy consumption and carbon emissions for each of the dwellings. This will be done using the standard pattern of use, lifestyle and temperature set points used for the second phase of modelling within stage 1 in order to compare the results with those of the benchmark.

Finally, the economic aspect of any retrofit measure will be analysed and used to carefully weigh the interventions scenarios. Combinations of interventions will be selected and simulated within a final phase of simulations for each case study, in order to strike a sensible balance between performance improvements, conservation of historical/architectural values and cost implications of those solutions so that an overall feasible and sustainable approach to such measures can be taken.

6. Envisaged problems and solutions

6.1. Human factor

This research will use questionnaires and interviews to gather data concerning the lifestyle, pattern of use, temperature set points for each case study to replace those suggested by the simulation software. In case these data are not possible to obtain or not exhaustive, the approximate estimates as suggested by CIBSE guides (Butcher et al. 2015) and used for the second phase of simulations stage 1, will be adopted. A similar approach will be adopted for the meter reading in case the data collected was not inclusive.

6.2. Fabric factors

A consistent body of research currently agrees on the importance of a clear understanding of the construction of the building envelope, which is used primarily for heat loss calculations (Barnham et al. 2008; Heat et al. 2010; Ingram and Jenkins 2013; Jenkins 2008). The area of external wall can be the largest contributor to this (Ingram 2013). The IES-VE model that will be used requires the assessor to input construction details, and the software calculates the wall U-value based on thickness, conductivity, density, heat capacity and resistance of each material (Ingram 2013). However, research conducted by Glasgow Caledonian University for Historic Scotland (Baker 2008 2011) and by the Society for the Protection of Ancient Buildings (Rye 2010) has demonstrated how the U-values achieved with the standard calculation method used for modern constructions, are not representative of the actual values for traditional constructions. Instead, they frequently overestimate them, therefore underestimating the actual performance of the building. The previously cited research has been conducted in Scotland on typical traditional masonry stone buildings. However, the construction materials and techniques of the external walls in dwellings in the city of Brighton and Hove during the 19th century were certainly peculiar and not easy to assimilate to any modern envelope, made by homogeneous layers of different materials. The typical compound used in this area was called Bungaroush and was mainly used for garden walls and party and rear walls of terraced houses, although it is also found in the front elevations. The Regency Society describes Bungaroush as “made principally of lime, gravel, coarse sands and flints, often with some brick fragments or other rubble added. The combination forms a type of mortar, or reinforced concrete” (Regency Society 2016). For this matter, it has also been considered whether or not to collect primary data from the real cases to calculate the U values of such a construction material using heat flux-meters coupled with internal and external temperature sensors (Baker 2008, 2011; Rye

2010). This could be an option which adds to credibility of the study but might not prove to be the most practicable as it will have cost implications and may involve more time or repeated visits which may not be welcomed by the participants. The contingency plan would be to calculate the average U-value for a layer of wall combined of Bungaroush components. This is not an easy task but it is not impossible to carry out. Furthermore, if the risk of using a calculated U-value for traditional buildings in this is to be overestimated (Baker 2008, 2011; Rye 2010), then the results obtained adopting it would still describe a scenario that sits on the safe side.

6.3. Technological factors

Researchers currently agree on considering the biggest uncertainty and simplification in any building energy simulation to be associated with the ventilation rate predictions (Hong et al. 2006). Air tightness of the dwelling is used in the energy assessment when determining the heat lost through infiltration. For the first stage of simulation, initially, average infiltration rates from the CIBSE Guide A, will be used (Butcher et al. 2015). The gap eventually found between the energy consumption as a result of simulation and the one deduced from the meter reading, together with the thermal-image analysis of the external envelope, could help (considering any case in its own context and specific settings) to calibrate the modelling, adjusting the assumptions about air leakage to be used in the software. The discrepancies between model and real scenario, remaining after these calibrations, if any, could be later applied to the results obtained from the modelling of the retrofit interventions on the selected dwellings.

7. Conclusions

Benbasat et al. (1987) believe that a clear description of data sources and the way they contribute to the findings of the research is an important part of the study that guarantees the reliability and validity of the findings. Therefore, the main aim of this paper is to illustrate the research framework specifically designed for this study, the methods of data collection, the qualitative and quantitative data to be collected; such methodology has been explained and graphically represented in one diagram (figure3) to help provide an overall understanding of the research design for this study. The research questions and objectives have defined the methods and approaches for data collection. The study could be divided in four phases, designed in line with the research objectives; these are set out to be fulfilled in sequence, using the combination of methods previously selected to gather, collate and analyse a comprehensive set of qualitative and quantitative data. In each subsequent step, the findings achieved in the earlier stage serve as a milestone for the following one and data previously gathered or generated are added to new datasets in the configuration of new feasible scenarios.

In the first phase, qualitative methods of data collection (questionnaire and semi-structured interviews) are used concurrently with quantitative ones and the qualitative data obtained from the interviews are quantified in order to become input variables in the first simulations set. Therefore the first stage uses an embedded concurrent mixed-methods design, which happens in the data collection and analysis. A form of sequential mixed methods also happens at this stage when quantitative data obtained from data logging are used to quality control the qualitative data previously obtained from the interviews and quantified to serve as input data in the simulation. A second set of simulations follows within this phase, where the quantified data obtained from the interviews are substituted by quantitative data obtained from secondary data collection in order to provide, from each case study, quantitative results that can be compared.

Finally, within the same stage, a sequential mixed-methods design takes place when quantitative data from the meter reading are analysed together with quantitative results from the simulation and qualitative data from thermal imaging to adjust the assumptions concerning air leakage.

In the second phase of this study, new qualitative data are collected making use of literature review, secondary data collection, questionnaires and semi-structured interviews with experts and these are analysed together with some of the qualitative data previously obtained from the interviews carried on during the first stage. As a result of such phase, qualitative data concerning potential interventions on the cases study selected, are gathered and analysed to give a qualitative output.

The third phase of research makes again use of a concurrent embedded mixed-methods design in which qualitative results from the previous phase are quantified to be inputted in a third stage of simulation together with the quantitative data obtained from the previous stage of simulations.

In the fourth phase of research, new quantitative data are provided making use of secondary data collection and are analysed together with the qualitative data from the second phase and the quantitative data obtained from the third stage of simulation in order to obtain new quantitative data to input in the last stage of simulation. Therefore this stage sees again a concurrent mixed-methods design happening in the data analysis.

Concurrent mixed methods happens also finally in the discussion of the subsequent findings from the four stages.

With such carefully and comprehensively developed methodology, as discussed in this paper, the results of this study are expected to be contributing to support homeowners, tenants and stakeholders in the decisions involving energy upgrade measures for this part of the housing stock, thus decreasing the risk of non-cost-effective interventions and negative impacts on the heritage value. The methodology has been developed such that the study can take account of the performance of these buildings in their unimproved condition to assist the owners or tenants in diagnosing areas where energy savings could be made more effectively. Finally, previous research in this sector has highlighted the lack of local policies and guidance on these issues; the modular structure of this methodology also allows for repetition in identical or similar situations so that the outcomes can contribute to making policies or devising new regulations, guidance or incentives for local or central governments.

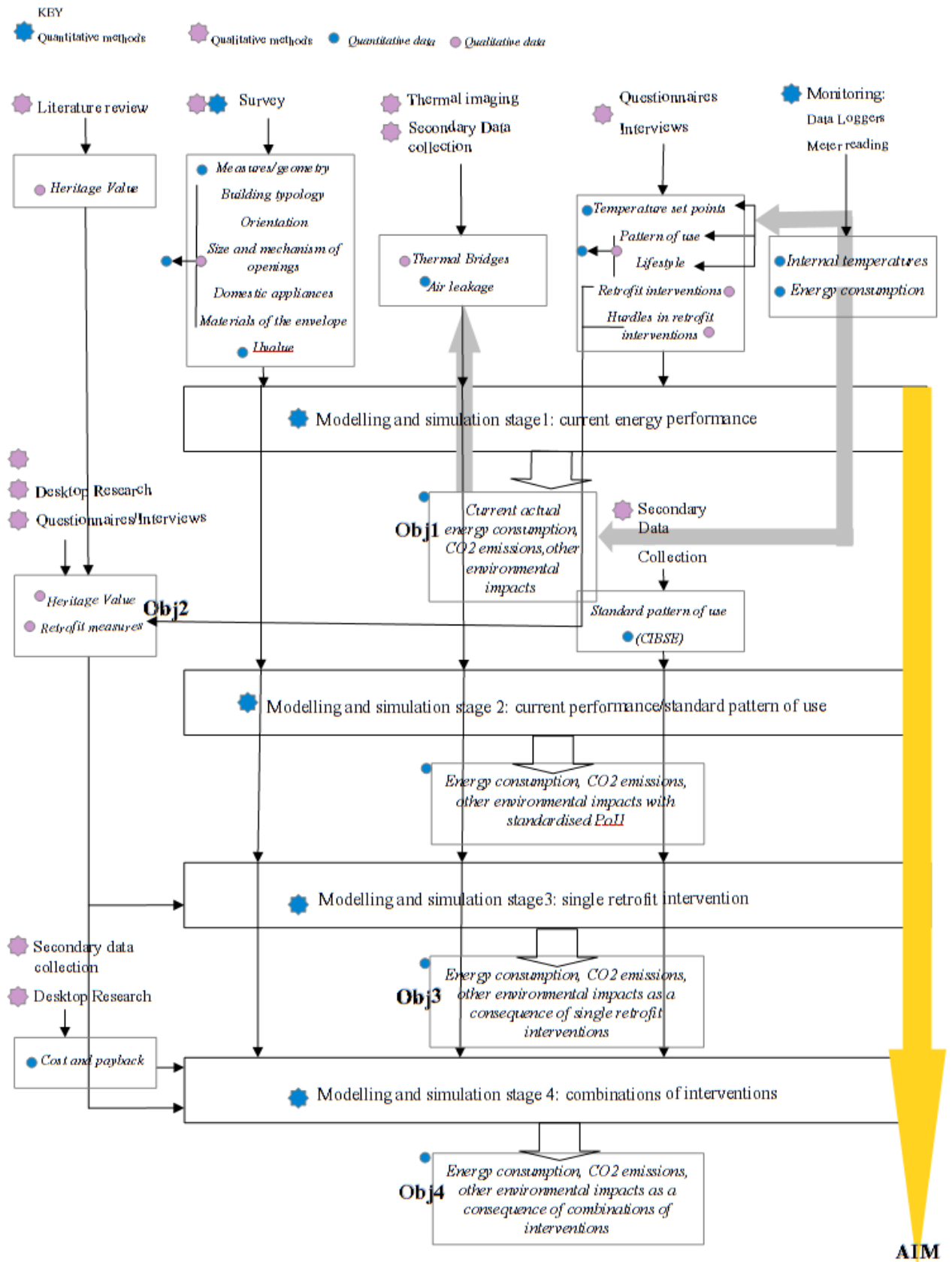


Figure 3: Framework of the research design

8. References

- AKANDE, O. K., ODELEYE, D., CODAY, A., JIMENEZ BESCOS, C. 2015. Energy Performance and Improvement Potentials for Selected Heritage Building Adaptation in England. *British Journal of Environment and Climate Change*, 5, 189-201.
- ANTRAM, N. & MORRICE, R. 2008. *Brighton and Hove*. New Haven: Yale University Press.
- ASCIONE, F., DE ROSSI, F. & VANOLI, G. P. 2011. Energy retrofit of historical buildings: theoretical and experimental investigations for the modelling of reliable performance scenarios. *Energy & Buildings*, 43, 1925-1936.
- ASCIONE, F., BIANCO, N., DE MASI, R. F., DE'ROSSI, F. & VANOLI, G. P. 2015. Energy retrofit of an educational building in the ancient center of Benevento. Feasibility study of energy savings and respect of the historical value. *Energy and Buildings*, 95, 172-183.
- BAKER, P. 2008. *Historic Scotland Technical Paper 2: In situ U value measurements in traditional buildings*. Edinburgh: Historic Scotland.
- BAKER, P. 2011. *Historic Scotland Technical Paper 10: U-values and traditional buildings: in situ measurements and their comparisons to calculated u-values*. Edinburgh: Historic Scotland.
- BAKER, P., RHEE-DUVERNE, S. 2013. *Research into the Thermal Performance of Traditional Brick Walls*. London: English Heritage.
- BARNHAM, B., HEATH, N., PEARSON, G. 2008. *Historic Scotland Technical Paper 3: Energy modelling analysis of a Scottish Tenement Flat*. Edinburgh: Historic Scotland.
- BENBASAT, I., GOLDSTEIN, D.K. & MEAD, M. 1987. The Case Research Strategy in Studies of Information Systems. *MIS Quarterly*, 11, 369-386.
- BOARDMAN, B. 2007. Examining the carbon agenda via the 40% House scenario. *Building Research & Information*, 35, 363.
- BOTTRILL, C. 2005. *Homes in Historic Conservation Areas in Great Britain: Calculating the Proportion of Residential Dwellings in Conservation Areas*. 40% House background Document K. Oxford: Environmental Change Institute.
- BRIGHTON AND EAST SUSSEX 2008. *House condition survey* [Online] Available from: http://www.sussexhousingpartnerships.org.uk/uploads/BEST_Final_report_stock_condition_survey.pdf [Accessed September 2015].
- BRIGHTON AND HOVE CITY COUNCIL 2009. *Supplementary planning document – Architectural features* [Online] Available from: http://www.brighton-hove.gov.uk/sites/brighton-hove.gov.uk/files/downloads/local_plan_2005/Architectural_Features_SPD_09_-_adopted.pdf [Accessed September 2015].
- BRIGHTON AND HOVE CITY COUNCIL *Housing* [Online]. Available from: <http://www.brighton-hove.gov.uk/content/housing/general-housing/private-sector-housing> [Accessed May 2016].
- BUILDINGS PERFORMANCE INSTITUTE EUROPE (BPIE) 2011. *Europe's buildings under the microscope: Report*. October 2011. Brussel: BPIE
- BUTCHER, K., CRAIG, B. & CHARTERED INSTITUTION OF BUILDING SERVICES, E. 2015. *Environmental design: CIBSE guide A*. London: CISBE.
- Climate Change Act 2008*. London: The Stationery Office.

CRESWELL, J. W. 2014. *Research design: qualitative, quantitative, and mixed methods approaches*. London: SAGE Publications.

Department for Communities and Local Government (DCLG) 2012. *Definitions of general housing terms* [Online] Available from: <https://www.gov.uk/guidance/definitions-of-general-housing-terms> [Accessed September 2015].

FESANGHARY, M., ASADI, S. & GEEM, Z. W. 2012. Design of low-emission and energy-efficient residential buildings using a multi-objective optimization algorithm. *Building and Environment*, 49, 245.

GARBER, R. 2009. Optimisation Stories: The Impact of Building Information Modelling on Contemporary Design Practice. *Architectural Design*, 79, 6-13.

GAY, L. R., Airasian, P. 2000. *Educational research: competencies for analysis and application, Sixth Edition*. Columbus, Ohio: Charles E. Merrill.

HEATH, N., PEARSON, G., BARNHAM, B., ATKINS, R. 2010. *Historic Scotland Technical Paper 8: Energy modelling of the Garden Bothy, Dumfries House*. Edinburgh: Historic Scotland.

HERMANN, C., RODWELL, D. 2015. Heritage significance assessments to evaluate retrofit impacts: from heritage values to character-defining elements in praxis. *Heritage for the future*. Florence-Lublin.

HISTORIC ENGLAND, 2011. *Energy Efficiency and Historic Buildings - Application of Part L of the Building Regulations to historic and traditionally constructed buildings*. London: Historic England.

HISTORIC ENGLAND, *Listed buildings* [Online] Available from: <https://historicengland.org.uk/listing/what-is-designation/listed-buildings/> [Accessed September 2015].

HM GOVERNMENT 2009. *The UK low carbon Transition Plan*. London: The Stationery Office.

HM GOVERNMENT 2012. *United Kingdom housing energy fact file*. London: The Stationery Office.

HONG, S. H., ORESZCZYN, T. & RIDLEY, I. 2006. The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings. *Energy and Buildings*, 38, 1171-1181.

HUBBARD, D. 2011. Ventilation, Infiltration and Air Permeability of Traditional UK Dwellings. *Journal of Architectural Conservation*, 17, 59-74.

IES. *Manuals* [Online] Available from: <https://www.iesve.com/support/userguides> [Accessed June 2016].

INGRAM, V. 2013. *Energy performance of traditionally constructed dwellings in Scotland*. Thesis (Ph.D.), Heriot-Watt University.

INGRAM, V., JENKINS, D. 2013. *Historic Scotland Technical Paper 18: Evaluating energy modelling for traditionally constructed dwellings*. Edinburgh: Historic Scotland.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) 2014. *Fifth Assessment Report (AR5)*. Geneva, Switzerland.

JENKINS, D. 2008. *Historic Scotland Technical Paper 4: Energy modelling in traditional scottish houses*. Edinburgh: Historic Scotland.

- JENKINS, G. J., MURPHY, J. M., SEXTON, D. M. H., LOWE, J. A., JONES, P., KILSBY, C. G. 2009. *UK Climate Projections: Briefing report*. Exeter: Met Office Hadley Centre.
- KOLAITIS, D. I., MALLIOTAKIS, E., KONTOGEORGOS, D. A., MANDILARAS, I., KATSOURINIS, D. I. & FOUNTI, M. A. 2013. Comparative assessment of internal and external thermal insulation systems for energy efficient retrofitting of residential buildings. *Energy and Buildings*, 64, 123-131.
- LLOYD-JONES, T., ELDRIDGE, A., MULYAWAN, B., THEIS, M. 2008. *Retrofitting Soho: Improving the Sustainability of Historic Core Areas*. London: MLC Press, University of Westminster.
- LOMAS, K. J., EPPEL, H., MARTIN, C. J. & BLOOMFIELD, D. P. 1997. Empirical validation of building energy simulation programs. *Energy and Buildings*, 26, 253-275.
- MCNALLY, Y. 2014. *An investigation into energy saving via retrofit compared to replacement housing*. Thesis (Ph.D.), Ulster University.
- MEMON, S. 2014. Analysing the potential of retrofitting ultra-low heat loss triple vacuum glazed windows to an existing UK solid wall dwelling. *International Journal of Renewable Energy Development (IJRED)*, 3, 161-174.
- MORAN, F. 2013. *Benchmarking the energy use of historic dwellings in Bath and the role for retrofit and LZC technologies to reduce CO2 emissions*. Thesis (Ph.D.), University of Bath.
- MUTHESIUS, S. 1982. *The English terraced house*. London;New Haven;: Yale University Press.
- OLSEN, E. L. & CHEN, Q. 2003. Energy consumption and comfort analysis for different low-energy cooling systems in a mild climate. *Energy & Buildings*, 35, 560-571.
- NGUYEN, A.-T., REITER, S. & RIGO, P. 2014. A review on simulation-based optimization methods applied to building performance analysis. *Applied Energy*, 113, 1043-1058.
- PANAYIOTOU, G. P. 2014. *Thermal performance of dwellings in Cyprus and approaches for energy conservation*. Thesis (Ph.D.), Brunel University, London.
- PERNIGLOTTO, G., PENNA, P., CAPPELLETTI, F., GASPARELLA, A. 2012. Extensive Utilization Of Dynamic Simulation For Sensitivity Analysis And Optimization Design Of Refurbishment Measures. *International High Performance Buildings Conference*. Purdue.
- POMPONI, F. 2015. *Operational performance and life cycle assessment of double skin facades for office refurbishments in the UK*. Thesis (P.h.D.), University of Brighton.
- REGENCY SOCIETY, *Living with ... bungaroush* [Online] Available: http://regencysociety.org/images/factsheets_14_1201828411.pdf [Accessed Jun 2016].
- RYE, C. 2010. *The SPAB Research Report 1. U-value Report*. London: SPAB.
- STAZI, F., VEGLIÒ, A., DI PERNA, C. & MUNAFÒ, P. 2013. Experimental comparison between 3 different traditional wall constructions and dynamic simulations to identify optimal thermal insulation strategies. *Energy and Buildings*, 60, 429-441.
- TSANG, E. W. K. 2014. Case studies and generalization in information systems research: A critical realist perspective. *The Journal of Strategic Information Systems*, 23, 174-186.
- STAZI, F., VEGLIÒ, A., DI PERNA, C. & MUNAFÒ, P. 2013. Experimental comparison between 3 different traditional wall constructions and dynamic simulations to identify optimal thermal insulation strategies. *Energy and Buildings*, 60, 429-441.

Sustainable Traditional Buildings Alliance (STBA) 2012a. *Responsible Retrofit of Traditional Buildings: report*. 20th Sept 2012. London: STBA.

Sustainable Traditional Buildings Alliance (STBA) 2012b. *Performance and Energy Efficiency of Traditional Buildings: Gap Analysis Study*. London: STBA.

TAYLOR, M., MORGAN, L. 2011. *Ventilation and good indoor air quality in low energy homes - Finding proven good practice*. London: GHA.

THOMPSON, P., BOOTLAND, J. 2011. *Good Home Alliance Monitoring Programme 2009-11: Technical Report*. London: GHA.

UK GREEN BUILDING COUNCIL (UK-GBC) 2014. *A housing stock fit for the future: Making home energy efficiency a national infrastructure priority: Report*. London: UK-GBC.

US Department of Energy 2015. *EnergyPlus Energy Simulation Software* [Online] Available from: http://apps1.eere.energy.gov/buildings/energyplus/?utm_source=EnergyPlus&utm_medium=redirect&utm_campaign=EnergyPlus%2Bredirect%2B1. [Accessed January 2016].

WANG, W., RIVARD, H. & ZMEUREANU, R. 2005. An object-oriented framework for simulation-based green building design optimization with genetic algorithms. *Advanced Engineering Informatics*, 19, 5-23.

WEI, S., WANG, W., JONES, R. AND DE WILDE, P. 2014. Using building performance simulation to save residential space heating energy: A pilot testing. *Proceedings of the 8th Windsor Conference: Counting the Cost of Comfort in a changing world*. 10-13 April 2014. Cumberland Lodge, Windsor, UK. London: Network for Comfort and Energy Use in Buildings.

WINGFIELD, J., BELL, M., MILES-SHENTON, D., SEEVERS, J. 2011. *Elm Tree Mews Field Trial – Evaluation and Monitoring of Dwellings Performance: Final Technical Report*. Jan 2011. Leeds: Leeds Metropolitan University.

WOOD, C., BORDASS, B. AND BAKER, P. 2009. *Research into the thermal performance of traditional windows: timber sash windows: report*. Edinburgh: English Heritage.

WRIGHT, A. 2008. What is the relationship between built form and energy use in dwellings? *Energy Policy*, 36, 4544-4547.

YANG, Z., & BECERICK-GERBER, B. 2014. Coupling occupancy information with HVAC energy simulation: A systematic review of simulation programs. Winter simulation Conference 2014. IEEE, 3212-3223.

YANG, Z., GHARAMANI, A. & BECERIK-GERBER, B. 2015. Iterative reassignment algorithm: Leveraging occupancy based HVAC control for improved energy efficiency. *IEEE*, 3449-3460.

YIN, R. K. 2013. Validity and generalization in future case study evaluations. *Evaluation*, 19, 321-332.

YIN, R. K. 2014. *Case study research: design and methods*. London: SAGE