# A FUTURE-PROOF CULTURAL HERITAGE: A HOLISTIC MIXED METHODS APPROACH


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## Abstract

*Mitigating environmental impacts has been a centre of attention for international commissions, legislative bodies and policy makers. The UK has signed up to an 80% reduction in carbon emissions by the year 2050 compared to 1990 baseline to meet this target at a national level. Energy used (primarily for heating) in the housing sector contributes 27% of all carbon emissions in the UK. Energy performance improvements of existing homes play a substantial role in the achievement of this national target, due to the low demolition rates and construction rates. The UK is facing a major challenge to address retrofit measures in this sector as it inherits the oldest and one of the most culturally rich yet most poorly performing housing stocks in Europe. The aim of this ongoing research is to propose a framework to intervene in traditional listed buildings to improve their environmental impact and shape a more future-proof heritage. A mixed methodology has been adopted using C19$^{th}$ case studies listed dwellings to investigate their current energy performance and the possible improvements in different scenarios of responsive and effective energy retrofits. A literature search, secondary data collection and analysis, visual and measured surveys, questionnaires, interviews, energy bills, meter readings, data logging, thermal-imaging and energy simulation are used to fulfil the research objectives. Providing a brief overview of this research methodology, the paper presents the detailed development of the methods utilised in this study up to date. It explains the measures, strategies and techniques, which were adopted to achieve simulation results of the status-quo energy performance of the selected case studies. This includes calibration of the models – used to ensure that the datasets collected or generated from different sources corroborate each other – and a brief report on the initial results of the current stage of research.*


## INTRODUCTION

### Research background

The UK has committed to lowering carbon emissions by at least 80% by 2050 against 1990 baseline (Climate Change Act, 2008). 27% of all $CO_2$ emissions, in the UK, stem from the residential sector (BEIS, 2018), the main source of emissions from this sector being the use of natural gas for heating and cooking (BEIS, 2017). Approximately 75% of the housing stock will still be in use by 2050 (Wright, 2008), therefore, it can surely play a major role in mitigating climate change. Roughly one quarter of the total number of dwellings in the UK, are traditionalbuildings (STBA, 2012), built before 1919 with solid permeable walls (Historic England, 2011).

Most of these buildings are generally considered poorly performing (Boardman, 2007). About one quarter of this traditional stock is listed or within conservation areas (Bottrill, 2005). The listing increases the challenges inherent in the energy upgrade of this part of the stock, as any retrofit measure needs to be weighed against the damage it may cause to its heritage value. In addition to the regulatory difficulties of intervening in listed buildings, the actual effect of such interventions on the historic fabric is not yet totally predictable (STBA, 2012). To be able to properly evaluate the outcome of any retrofit intervention on traditional listed dwellings (TLDs), more research is needed to thoroughly investigate their fabrics and understand how they behave. Responsible and effective retrofit solutions for these buildings will only be possible using a holistic approach, capable of balancing energy upgrades with potential impacts on the characteristics and heritage value as a result of such interventions in this part of the stock.

**Aim and Objectives**

This paper sets out to provide an insight into the methods utilised and a brief overview of the results achieved to date, in a research aimed at improving the environmental impact of TLDs, thereby reducing their energy consumption and carbon emissions to shape a more future-proof heritage. The main contribution of the study, which is reported in this paper, lies in the development and application of a mixed methods approach, which utilises multiple case studies, multiple units of analysis and multiple methods of data collection/generation to provide comprehensive, validated and holistic answers to the problem of retrofitting heritage dwellings. The methods here described are used to fulfil the first three objectives of this research: (1) to establish the most applicable method for carrying out energy analysis to best serve the purpose of this study; (2) to establish the actual energy use and thermal behaviour of the case studies (CSs) selected in their unimproved condition; (3) to devise a strategy to ensure that the data generation process is reliable, valid and replicable in similar or identical contexts.

**Critical Literature Review- The Research Gap**

A critical review of literature underlines all the phases of this study to aid in the definition of the research gap, research questions, aim and objectives, research design, methodology and methods. It evidenced how the use of dynamic energy simulation is extensive in research concerning the energy performance of buildings and proves to be the most applicable method also for the energy analysis required to fulfil the aim of this research (Panayiotou, 2014; Porritt, 2012 to cite some). The choice of CSs allows for a powerful validation tool for any research using simulation as main method because it consents triangulation of findings and a better reliability of the results generated. (Ascione et al., 2011; Blecich et al., 2016; Georgiou, 2015; Ingram, 2013; Mohammadpourkarbasi, 2015; Sahin et al., 2015). The studies conducted on heritage buildings constitute only a minority of the whole body of research about energy efficiency, often failing to take a comprehensive approach to the problem for historic/listed buildings. In this context, they have been mainly limited either to the investigation of potential retrofit interventions or of their heritage value and rarely taking account of both. However, a transdisciplinary and more multifaceted approach has been repeatedly called for as one potentially capable to aid in the decision-making concerning successful and conscientious retrofit measures for this part of the stock. Conspicuous is the body of research produced by Historic Scotland and Historic England on the subject of heritage buildings and energy efficiency. However, it mainly looks in detail at one or more elements of the external envelope like windows (Baker, 2008a; Wood at al., 2009), walls (Baker & Rhee-Duverne, 2013), specifically at envelopes U-values (Baker, 2008b; Baker, 2011), or investigates the potentialities of energy simulation software for the evaluation of the building energy performance (Barnham et al., 2008; Heat et al., 2010; Ingram & Jenkins, 2013; Jenkins, 2008). Most of the studies that deployed a more comprehensive approach on this subject were often aimed at investigating one specific CS, frequently a public building (Ascione et al., 2011; Ogando & Fernandez, 2017; Sahin et al., 2015) therefore remaining limited in scope, applicability and generalizability. Little has been done on traditional heritage dwellings. The researches conducted on traditional dwellings by Ingram (2013) in Scotland and Moran (2013) in Bath, are rare but relatively good examples. However, they use limited number of cases and a validation strategy only based on energy consumption and only for part of the cases. More in-depth studies have been conducted on heritage dwellings in the Mediterranean area (Flores, 2013). However, the limits implicit in the geographic context, together with the similarity between the case studies investigated and the limited methods adopted, restrict the richness of data, narrowing the depth and breath of findings, which makes the generalization of them more difficult.

Finally, it is noted that, due to the wide range of uncertain input data and assumptions necessary to model traditional buildings, the potentiality of such models to accurately represent the thermal behaviour of the real building is strictly linked to the range of data used for calibration. Only a few researches have calibrated their results with real data but frequently limited to a single CS (Ascione et al., 2011; Ogando & Fernanez, 2017; Sahin et al., 2015). The review of literature showed a lack of in-depth studies on the subject of energy performance and retrofit interventions for TLDs in the South East of England where the materials and construction methods differ from elsewhere. It also evidenced the lack of a comprehensive validated, layered methodology, capable of integrating a whole set of methods for data collection, generation and analysis to apply to multiple cases of TLDs using multiple units of analysis in the context of the UK.

## METHODOLOGY

### Case study Design and Mixed Methods Approach

Centred on multiple CSs and using four subsequent phases of simulation, this research uses a combination of different methods of data collection, analysis and generation for the configuration of a baseline scenario of performance and of successive potential retrofit scenarios. CSs design has been chosen as it allows for a powerful validation tool for the energy simulation, consenting the calibration of the results using real data. A mixed methods approach has been adopted to couple the insights provided by quantitative and qualitative research and generate more comprehensive answers to the research questions (Johnson & Turner, 2003). Literature review, measured surveys, field observations, questionnaires, interviews, qualitative and quantitative thermo-graphic surveys, gas and electricity consumption monitoring, temperature and relative humidity (RH) data logging and energy simulations were used in combination for multiple CSs to facilitate the triangulation of findings and aid in the generalization of the results generated. The diagram in Figure 1 illustrates the research framework specifically outlined for this study, the methods of data collection, generation and analysis (in rectangles), the data gathered or generated (in bullet points), the sequential objectives achieved (Obj1-6), to provide an overall understanding of the research design.

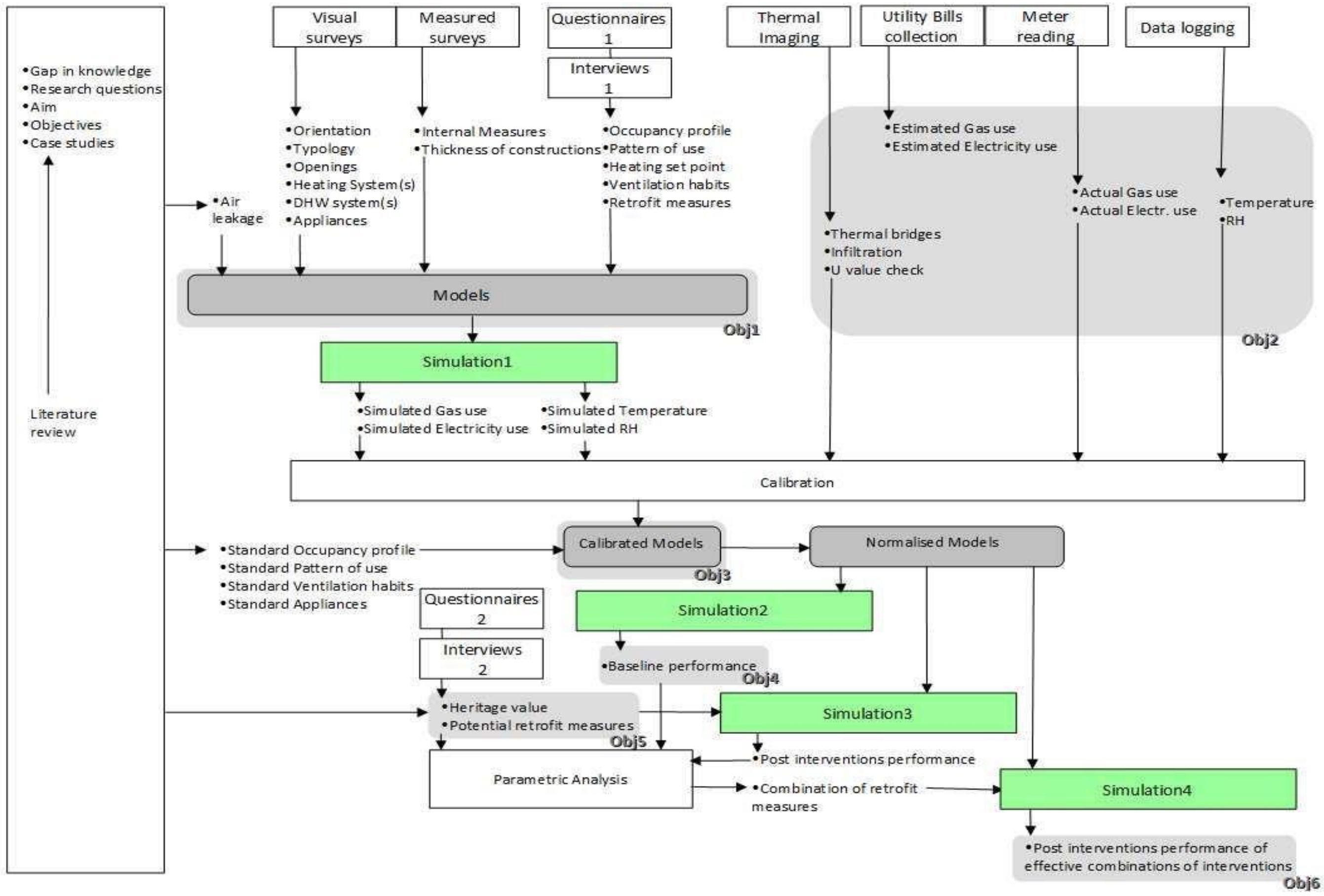



Figure 1. Research framework: methods (in rectangles), data gathered or generated (in bullet points), and objectives (Obj1-6).

## The geographical location

The City of Brighton and Hove, centrally located within the South East coast of England, has been chosen as the geographical setting for this study due to the wide combination of different influential factors that it provides, proving to be an extreme case within the UK housing context. Almost 40% of the city's housing stock is traditional; a considerable proportion compared to the rest of Britain where traditional dwellings amount to approximately 25% (BPIE, 2011).

Many traditional dwellings in the city belong to the early 19$^{th}$ C, when Brighton, as many other coastal towns in the South East of England, was transformed into a seaside resort and embellished with unrivalled examples of Regency architecture (Antram & Morrice, 2008; Collis & Carder, 2010). These buildings are considered of great value as part of the town's historic heritage; hence comes the significance of the special care due to the preservation of their character. In fact, a substantial number of these traditional dwellings are listed. Most of these residential estates perform poorly (Brighton and East Sussex, 2008) because they were built at a time when very low living and energy standards were applied, when construction materials and technologies were limited and because of lack of investment in this sector.

Such setting for this study can give results that will likely prove to be easy to tailor or amend, to propose valid solutions for similar listed properties elsewhere in the South of England. The methodology proposed, once tested and proved successful in this setting, will also be valid to apply anywhere else in the investigation of retrofit measures for heritage dwellings.

**Case studies selection**

In this study, a multiple case approach has been considered the most suitable to enable cross case analysis and the triangulation of findings. Representative CSs have been selected using a non-probability sampling strategy obtained by carefully balancing purposive and convenience sampling approaches.

A first filtering was made to find potential participants adopting a convenient sampling technique that made use of emails (circulated within the University of Brighton mailing list) calling for all residents or owners of listed 19thC dwellings interested to take part in the study. The second part of the CSs search used purposive sampling. Invitation letters were delivered door to door in two main areas of investigation, Brunswick Town and Kemp Town. The case studies found there, are part of the first residential grand developments, built at the beginning of the 19th C. These two areas are located on the East and West of the city seafront respectively, containing the finest examples of Regency and early Victorian planning and architecture (Antram and Morris, 2008). The buildings typology, materials and constructions found there constitute an example followed for the rest of the century in the rest of the town and in the South of England.

To maximize what can be learnt from the cases, the decision concerning the number of dwellings to investigate was made upon the analysis of the variables expected in the population from which they are drawn in order to cover all the main characteristics of such population. Such variables can been described as follows: Period of construction (first or second half of the 19th C); Aspect (dual or single); Floor level (Lower Ground Floor, Ground Floor, Middle Floor, Top Floor); Orientation. Nine CSs were finally selected; they attempt to cover all the variables to investigate while being well distributed geographically in the two Eastern and Western areas of research. Therefore, although not intended to be a statistically representative sample, they allow detailed exploration of a snapshot of the C 19th TLDs typical of Brighton, as well as of many seaside towns in the South-East of England.

## METHODS OF DATA COLLECTION AND GENERATION

**The simulation software**

The research methodology involves the use of dynamic energy simulations to identify, for each CS dwelling, the current energy consumption and carbon emissions. To take a decision concerning the simulation software to use, a literature search was conducted together with a desk survey of the available data and conversations with experts in the sector. IES-VE has been chosen as a suitable software to use in this research because, 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; it is an application developed in the UK and its use is widespread in the country as well as around the world; it is easily manageable and offers a user-friendly interface.

### Visual and measured surveys

Visual and measured surveys have been conducted for each CS. Each dwelling has been investigated in-depth in its orientation, typology, shape, measures, materials and construction methods, size and type of openings, heating and domestic hot water (DHW) system(s), domestic appliances, as a part of the in depth multi-units of analysis multi-case study approach chosen for this study. The collected data served as the first round of input in the energy simulation software to generate models as close to the actual dwellings as possible.

### Questionnaires and interviews

Data about the building services, appliances, occupancy, pattern of use, temperature set points, ventilation habits and retrofit interventions already executed in the dwelling, was gathered for each CS using a questionnaire which was filled by the occupants on the day of the survey. On the same day a follow-up interview was conducted with the same participants. The questionnaires already filled in by them, constituted the basis for discussion and helped to identify issues and/or unclear points. The use of interviews was fundamental to guarantee that all questions were answered, to obtain therefore a full depth and range of information, to clarify any misunderstanding or provide additional explanations where required. The data gathered this way was also inputted in the energy simulation software to generate realistic profiles of use.

### Utility bills and meter readings

The use of CSs presents an ideal opportunity to check the simulated energy consumption results against actual energy use data and therefore guarantee a higher reliability of the results generated through simulation. For this purpose, the annual utility bills were collected for each dwelling to be used as initial check of the results of the simulations.

The main household electricity and gas supply meter readings were then taken for all CSs for a period of at least one calendar year (the frequency of the readings – from every 2 months to a period up to 4 months – varies between the cases and depends on the participants actual availability or ease of contact). The simulation runs used the geometry and materials provided by the surveys and the profiles generated employing the detailed information collected through questionnaires/interviewees. Then the annual and sub-annual meter readings have been compared with the energy consumptions obtained from simulations to aid in their calibration.

### Data logging

The actual conditions of the dwellings in use were measured and recorded for each CS for two periods (during the winter and summer season) of two months each time in two different rooms, to provide a triangulation of the results obtained from the simulations and contribute to a better reliability of the findings. Hobo data loggers (model Hobo UX100-03, Temperature and RH data logger) are deployed in this study. Such data loggers have been chosen as, widely used in research (Ahrentzen et al., 2016; Altan et al., 2013; Da Cunha, 2015 to cite some), they are affordable, low-maintenance, easy to operate and durable, compact instruments that consume little power; they guarantee sufficient precision for the purpose of this study and have enough storage capacity for the periods of data collection intended.

### Thermographic surveys

In this research qualitative thermographic surveys were undertaken for each CS dwelling to provide a better understanding of the composition of the thermal envelope (which, because of the private ownership of the flats, is not possible to investigate using intrusive methods) and to identify possible thermal bridges, or areas of ventilation losses. They aided in the refinement of the assumptions concerning air leakage and in the understanding of the thermal envelope of each dwelling. Quantitative thermography was also used as a quality check of the U-values calculated by the software.

## PRIMARY DATA INPUT AND NEW DATA GENERATION

The dynamic thermal simulation operated involved creating 3D models of the CSs and their adjacencies, which were utilized to simulate the dwellings operation for a year making use of average local hourly climate data. The simulation calculates the energy used by the modelled dwelling through assessment of building operation, climate gains/losses as well as internal gains, solar & daylight penetration (IES, 2009). Therefore, the measured and visual surveys were used to compose the models, which were then added with use profiles based on the interviews and questionnaire surveys.

Once created the geometry of the dwellings and their adjacencies as well as the openings and shading devices use profiles, for each model were then defined specific building elements. Their constructions were based on the assumptions made using the measured thickness of the elements (whenever this measure was possible to take), on the visual and tactile inspection as well as on the literature review and conversations with experts about the typical constructions of the area at that time. The creation of specific constructions allowed the dynamic thermal models to generate U-values for the external envelope, to be used in the simulation of the current performance of the dwellings. These U-values will be modified, in the following stages of simulations, according to the new retrofitted constructions proposed in each stage. Finally, detailed specific data concerning the heating and DHW system(s), internal heat gains, occupancy and pattern of use of the heating system(s) and appliances (as provided by the surveys and questionnaires/interviews) were inputted for each model. For the air exchange rates, values of Air Changes per Hour (ACH) were inputted in each room template for each model, and modulated, within the values range found in the literature (CIBSE, 2015), depending on the exposition, the level of the flat, the age and type of windows. This data was then finetuned, in the calibration that followed, to aid in achieving correspondence between measured and simulated data.

## MODELS CALIBRATION

The results attained through simulation have finally been checked against the data collected using bills, meter readings and data logging to calibrate the models and achieve results as close as possible to the actual energy consumption and thermal behaviour of the dwellings investigated, thereby building confidence in the model's performance. Figure 2 describes the calibration process and the data collected and generated within it.

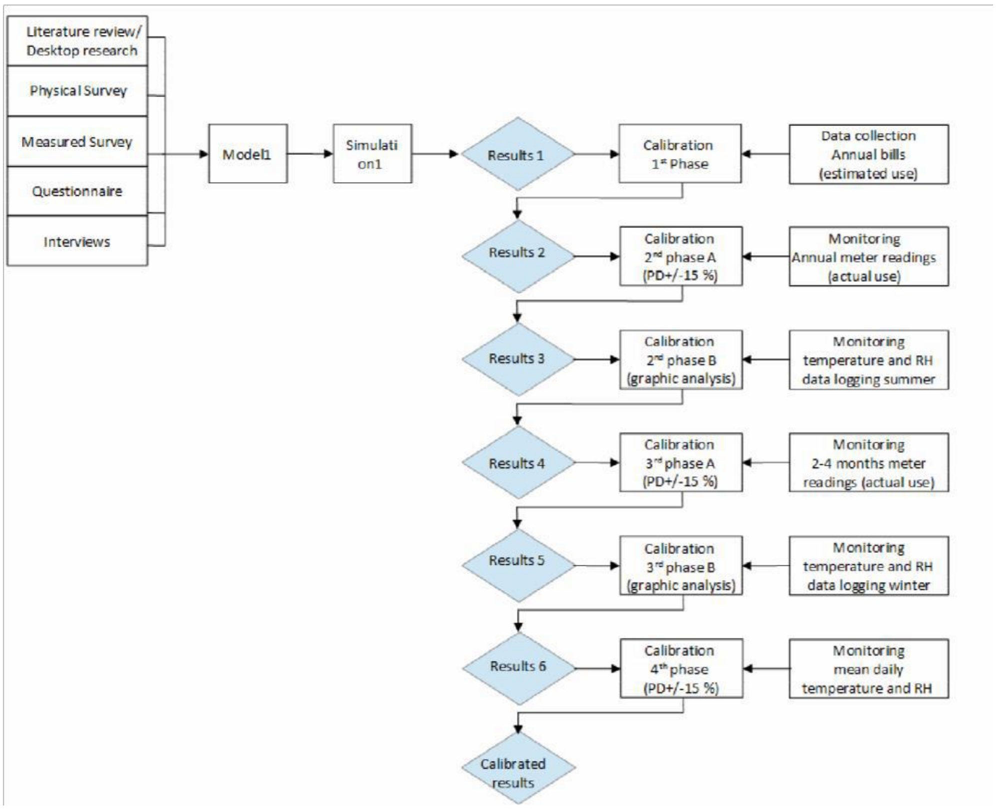
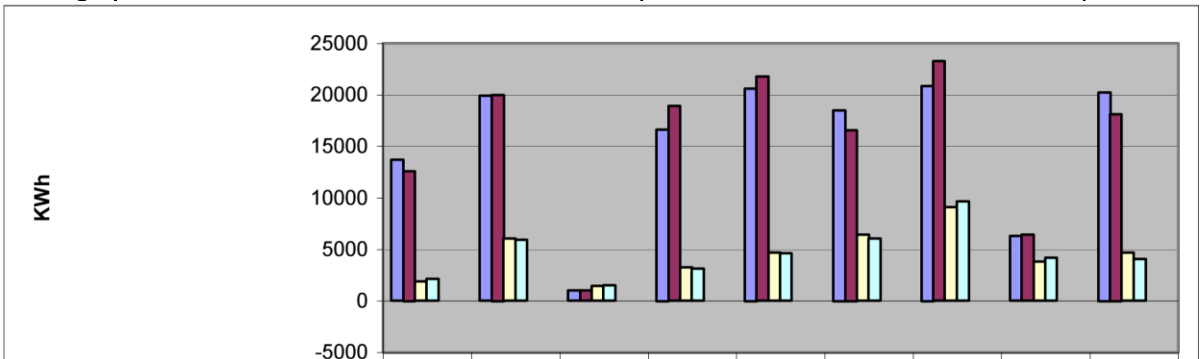


Figure 2. Flowchart of the calibrated simulation path as operated in the study.

The first set of energy simulations were initially checked against estimated energy use data provided by gas and electricity bills, to assess the capability of the models created to predict current energy use as well as energy and $CO_2$ emission savings in the later design stages. The meter readings of each CS were in the meanwhile carried out. This allowed a second calibration to be undertaken using actual data where a whole year energy use was accounted for. Percentage differences (PD) between simulation results and measured data have been calculated for gas and electricity over a period of one year. Values of the PD in the range of ±15% have been considered acceptable in accordance with previous research (Maamari et al., 2006; Reeves et al., 2012). The input values used in the first round of simulations for each CS were therefore fine-tuned, when needed, to calibrate the energy models with metered data and obtain results sitting within the acceptable range. A further calibration stage was performed using graphic analysis, once the first winter cycle of data logging was completed, comparing the temperatures and RH acquired by the sensors with the ones outputted from the dynamic simulations for the same time-period and for the same room. The objective was to validate the thermal behaviour of the models identifying if the graphs presented discrepancies or were reliable while also aiding in the understanding of the building envelope characteristics and of the behaviour of its thermal mass. To increase the reliability of the models a further calibration was performed using sub-annual energy data and assessing the PD with the energy consumptions outputted by the simulations for the same period. Part of the summer cycle of data logging is complete as well and for those cases the calibration has been integrated adding the graphic analysis of simulated and measured summer temperatures and RHs. Temperature and RH data will finally be calibrated to meet acceptable daily mean PD acquiring the specific annual weather file relative to the time-period in which the data logging was performed.

## INITIAL RESULTS

To date, the iterative calibration process has been continued until the acceptable PD between measured and simulated annual and sub annual energy consumptions was met, and a good degree of similarity was seen between the measured and simulated (winter and summer) temperature and RH graphs. Seven out of nine CSs have already generated satisfactory results and are soon to be fully calibrated and ready to be used as baseline scenario for the application of retrofit interventions. Figure 3 shows the annual gas and electricity consumption monitored and simulated for each CS and the PDs achieved after this first stage of calibration. Figure 4 shows the graphical analysis conducted to compare simulated and monitored temperature and RH data for CS 2 (dining room), over two months in the winter period. A few discrepancies are still outstanding between these graphs. They might be caused by the difference between the averaged weather file used for simulation and the actual weather data pertaining to the monitoring period. Therefore, the next stage of calibration will be to make use of a weather file relative to the monitoring year aiming to exclude the variables potentially causing discrepancies as a result of weather. If it were proven that the weather is not the main cause of such differences, then other factors – pertaining to the building fabric, pattern of use, and heating system – were examined more confidently to find the source for such discrepancies.




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Gas Kwh/year Monitored | 13645 | 19885 | 979.2 | 16608 | 20575.1 | 18500 | 20852.1 | 6299.81 | 20220 |
| Gas Kwh/year Simulated | 12572.2 | 19982.5 | 984.2 | 18881.4 | 21733.9 | 16567.2 | 23249.8 | 6397.8 | 18086.6 |
| Electricity Kwh/year Monitored | 1840 | 6000 | 1390 | 3218 | 4655 | 6375 | 9080 | 3820 | 4659 |
| Electricity Kwh/year Simulated | 2120.5 | 5881.7 | 1437.3 | 3079.1 | 4559.4 | 5988.6 | 9659.4 | 4183.8 | 4032.04 |
| PD gas | -7.86% | 0.49% | 0.51% | 13.69% | 5.63% | -10.45% | 11.50% | 1.56% | -10.55% |
| PD Electricity | 15.24% | -1.97% | 3.40% | -4.32% | -2.05% | -6.06% | 6.38% | 9.52% | -13.46% |

Figure 3. Graph and table showing the annual gas and electricity consumption (in Kwh) monitored and simulated for each CS (1-9) and the PDs calculated between them.

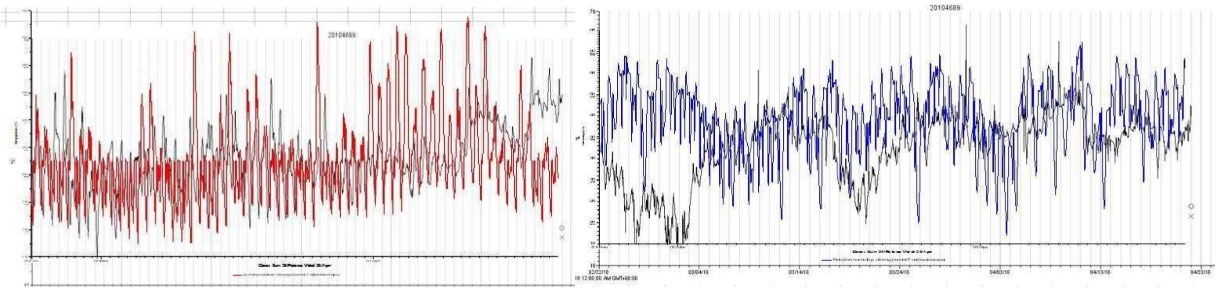


Figure 4. Graphs showing the simulated and monitored temperature and RH data relative to CS 2 (dining room), over two months in the winter period (in black: monitored temperature and RH data; in red: simulated temperature; in blue: simulated RH).

## CONCLUSIONS

The results achieved at this stage of research provide good reasons to believe that the energy simulation tool deployed is capable of reproducing the actual thermal behaviour of the dwellings selected and to investigate their status-quo energy performance with a reasonable accuracy. This method is therefore also applicable in the following stages of research to simulate retrofit interventions in the chosen CSs and compare the energy performance post interventions to the baseline scenario.

A parametric analysis will finally generate combinations of interventions aimed at achieving the best possible balance between performance improvements, and conservation of heritage values. These combinations will be investigated in the last round of simulations to achieve the aim of the study: a framework of responsive and effective retrofit interventions for TLDs.

Two main limitations were faced in the methodology devised, namely the assumptions related to the U values and air leakage values of the envelopes. However, the U values generated by the software – given the materials build ups inputted – are triangulated with those generated by the quantitative thermographic surveys of the external walls and those given by previous research on similar dwellings (Baker, 2008b; Baker, 2011, IES, 2009; Ingram, 2013; Rye, 2010) to increase the reliability of such data. The air leakage values, taken from CIBSE (2015), can be checked using a blower door test once the necessary consent, from at least one of the participants, is obtained. A further confirmation of the validity of the used U values and air leakage rates will be provided by the satisfactory outcome of the calibration process.

The methodology devised and currently tested in Brighton is modular and customizable in order to be potentially extended beyond its context of origin and applied elsewhere for similar or identical studies.

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