

# digital cultural heritage: FUTURE VISIONS

Edited by Kelly Greenop and Chris Landorf

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The symposium Convenors received a total of 33 abstracts. All abstracts underwent a double-blind peer review by two members of the Symposium Organising Committee. Authors of accepted abstracts (24) were invited to submit a full paper following presentation of their draft papers at the symposium. All submitted full papers (8) were again double-blind peer reviewed by two anonymous reviewers and given the opportunity to address reviewer comments. Papers were matched as closely as possible to referees in a related field and with similar interests to the authors. Revised papers underwent a final post-symposium review by the editors before notification of acceptance for publication in the symposium proceedings.

Please note that the paper displayed as an abstract only in the proceedings is currently being developed for an edited book on digital cultural heritage.

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Innovative new data collection and digital visualisation techniques can capture and share historic artefacts, places and practices faster, in greater detail and amongst a wider community than ever before. Creative virtual environments that provide interactive interpretations of place, archives enriched with digital film and audio recordings, histories augmented by crowd-sourced data all have the potential to engage new audiences, engender alternative meanings and enhance current management practices. At a less tangible level, new technologies can also contribute to debates about societal relationships with the historical past, contemporary present and possible futures, as well as drive questions about authenticity, integrity, authorship and the democratisation of heritage.

Yet for many, gaps still exist between these evolving technologies and their application in everyday heritage practice. Following the success of a sister conference in Brisbane, Australia in April 2017, this symposium focused on the emerging disciplines of digital cultural heritage and the established practice of heritage management. The symposium aimed to provide a platform for debate between those developing and applying innovative digital technology, and those seeking to integrate best practice into the preservation, presentation and sustainable management of cultural heritage.

The symposium was designed to encourage critical debate across a wide range of heritage-related disciplines. We welcomed papers from practitioners and academics working in cultural heritage and related fields such as architecture, anthropology, archaeology, geography, media studies, museum studies and tourism. We particularly encouraged papers that explored the challenges of digitising tangible and intangible cultural heritage, those that identified issues with digitisation and digital interaction, and those that addressed the theoretical challenges posed by digital cultural heritage.

**Kelly Greenop and Chris Landorf**  
EDITORS and SYMPOSIUM CONVENORS

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### Abstract

*There is an increasing acceptance that dealing with the existing built environment is critical if carbon reduction and energy consumption targets are to be met. Computer modelling has become an important and accepted tool in the assessment of the environmental performance of historic buildings. While the results have been questioned by many it remains an important part of any sustainable strategy for the improvement of buildings.*

*This paper focuses on one particular case study that compares three strategies for assessing the energy consumption improvements of a Victorian urban dwelling.*

*The study compares the computer-modelled results from the carbon emissions and energy consumption computer simulation program NHER against previous datasets of improvements against the real-life actual improvements. The paper discusses the issue of computer modelling as a method of assessment of environmental improvement in the historic built environment. The paper will show the limitations of the software in the decision-making process and the importance of intangible factors that affect the environmental performance of a historic dwelling. It will show that while it is difficult to match the exact energy use of the building using computer modelling, it is an effective tool in showing the impact of sustainable improvement interventions.*

**Keywords:** Computer energy modelling;  
Sustainable refurbishment; Historic housing;  
Energy use; Human behaviour

# A Comparative Analysis of Modelling Techniques for the Reduction of Energy and Carbon Emissions in a London Victorian Dwelling

## Introduction

There is now an acceptance that if any of the sustainability targets are to be met, the environmental performance of the existing built environment has to be improved. However, much of the advice given to historic homeowners is at best ineffective or, at worst, damaging to the historic fabric. This paper looks at the largest stock of the UK's historic dwellings, the Victorian suburban dwelling. This paper is part of a larger study into the environmental benefits of conservation-based building maintenance and benign improvements to this type of housing stock.

One of the key tools used to assess options for energy consumption reduction is computer modelling. This paper will look at the issues when these maintenance and benign based interventions are applied using a computer energy modelling package. Results from this model are compared with outputs from other datasets; all of these are then measured against the actual energy reduction results in the dwelling. The study highlights the difficulties in computer modelling small changes to the building that not much can have impacts on the energy performance of the dwelling.

## Context

There are over 4.7 million pre-1919 dwellings in England alone (EHCS, 2009); this would require over 325 home refurbishments every day from now until 2050 if UK carbon reduction and other sustainable goals are to be met. The pre-1919 housing stock in the UK has, on average, the worst SAP score and the highest carbon emission of any house age group, and typically, over twice the maintenance costs compared with modern housing for basic repairs. However, historic houses usually have a higher market value because they have intrinsic historic value and are valued more by potential purchasers (EHCS, 2009).

The context of sustainability also needs discussing. For a project to be sustainable in this context, it has to meet the requirements of environmental factors, respect the heritage and cultural importance of the building and remain within the financial limitations

of the dwelling owners. This interpretation of the sustainable triple bottom line is key to understanding the context of this paper and the wider study. It should also be recognised that while this study is focused on energy consumption, there are many other factors that need to be taken into account across all three categories of the sustainable triple bottom line. These factors include waste production, water usage, upfront costs, changes in lifestyle, impact on house value and planning guidance. Many of these are not easily defined and are therefore difficult to model, hence require professional judgement.

Dwellings are perhaps the most heterogeneous of all of building stock and they are the most continually adapted buildings. Different people have varying levels of comfort in terms of heating and similar dwellings may have very different lifestyle occupancy and usage. This variety adds an increased complexity to accurate computer modelling. Each set of owners of a dwelling make their own changes to the property, therefore the properties that may have originally been built to the same design are in fact unique via these various updates and alterations. This continual process of renewal allows for houses to adapt to changes in lifestyle which means the building can remain a viable dwelling. It could be argued that dwellings have survived decades and centuries are inherently adaptable because of their continued successful use. This is recognised by national conservation and heritage bodies as defining building conservation as the management of change rather than simply the preservation of a heritage asset.

## Project aims

This paper comes out of a larger study looking at how conservation-based principles can help improve the environmental performance of historic dwellings. The wider project hypothesis is '*The most sustainable strategy for owners of historic suburban housing does not lie in sustainable focused refurbishment of their dwellings but in historic building maintenance and benign improvements.*' The overall aim of the

project is to show that by improving building maintenance and carefully selected interventions, the environmental performance of historic dwellings could be significantly improved and at the same time be economically viable and culturally beneficial to the preservation of the historic asset thus meeting the triple bottom line. As part of that process, computer modelling was used extensively, alongside other techniques within the project. This paper focuses on the variances between the modelling results, existing datasets and the combined findings from the rest of the study. This paper looks at the difficulties of computer modelling software in modelling the energy performance improvements of these smaller changes typically used in this methodology.

#### Historic building maintenance and benign changes

It is important to understand that the fabric and the appearance of a historic dwelling has a cultural significance - the building itself is an artefact and historical asset (EH, 2007). Preventative maintenance is internationally recognised and has been central to building conservation legislation and charters (Forster and Kayan, 2009). Building maintenance and conservation plans are an accepted part of building conservation work. However, they are rarely carried out in historic dwellings. In fact, it is much more common for reactive repair to be implemented, rather than preventive maintenance (Forster and Kayan, 2009).

It is important to emphasise that the terms 'maintenance and repair' should not be as interchangeable as they might be for other building types. This is because no matter how well thought of the repair is, it will involve some form of damage, removal or replacement of the historic fabric (Dann and Worthing, 2005). Maintenance is important in protecting cultural significance because correct maintenance is the least destructive of all the interventions take place in the process of conserving the historic built environment. The idea of approaching work from a minimum intervention

methodology is best summarised by the Burra Charter 'as much as necessary, as little as possible' (ICOMOS, 1999). The methodology for this study is the improvement in energy saving and carbon reduction with as little damage or change to the inherent heritage of the historic dwelling. In the case study house used in this paper, the changes were changing electricity supplier, replacement of insulation in the roof space, replacement of the gas boiler and the replacement of windows (the reasoning for changing the windows will be discussed later in the paper).

The Historic Town Forum (2011) supports this methodology stating that 'One of the most energy efficient ways to preserve historic buildings is to ensure that continued, regular maintenance is carried out to safeguard its historic fabric.' Both the Historic Town Forum and English Heritage encourage the use of benign changes to improve the environmental performance of a historic dwelling. Benign changes are changes to the building that either have little or no effect on the heritage of the dwelling, or do not damage the dwelling fabric itself or the way it needs to perform or react.

The key part of this methodology involves professional and knowledgeable inspection of the property. This inspection should involve highlighting any necessary repairs, and identifying the vulnerable parts of the dwelling that need regular inspection and maintenance (such as clearing of rainwater goods and painting of exterior woodwork). Along with these inspections of the fabric, inspections of the dwelling services identifying such elements as the age of the boiler and quantifying key areas of heat loss and energy wastage throughout the building are required. The report from such inspections should then identify preventative maintenance strategies for the individual historic dwelling, identify any urgent repairs and suggestions for benign environmental improvements to the historic dwelling. It is also important that any benign sustainable improvements suggested are forward-looking, for example, if a new hot water

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cylinder is required, the one that is recommended/fitted is one with multiple in-lets/heating coils to allow for future integration of renewable technologies.

### Computer modelling

Energy modelling software packages can be roughly divided into two major types: static and dynamic. The main difference between static and dynamic simulation is that static modelling packages assume that variables are constant with respect to time. This means that in static modelling packages there is no accumulation in the system model so factors such as thermal mass are not correctly modelled. Conversely, dynamic modelling packages account for the mass and energy rate of accumulation within the system which leads to a closer modelling to actual building behaviour (Da Silva, 2015). Static modelling packages model the material aspects of the building such as the wall, roof construction and window and door types. They also include fuel type and heating sources. Dynamic modelling packages are more complicated. As well as taking into account aspects of static modelling criteria, they also add on other factors depending on the package these include air movement (TAS, IES-VE) and people movement and activity.

Newer packages are also now integrating past energy usage to provide more accurate modelling results. The modelling package used in this study was NHER, which is a static modelling package. It was chosen as it is one of the energy modelling programmes that UK government approved to provide energy performance certificates and ratings (SAP) for residential buildings (NES, 2012). It is worth noting that the UK government currently only allows certain static modelling packages to be used in the residential energy assessment process. While NHER is a static modelling package it does have limited dynamic features such as occupancy rate and limited usage modelling (Bothwell et al 2011). NHER Plan Assessor focuses on energy use and gives a location-specific model. It models basic occupancy behaviour and the geometry of the building along with space and water heating, lighting, hot water tank size and insulation and cooking appliances.

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Modelling will presume a generic typical usage because this allows for comparison between buildings. However, this does lead to inaccuracy when compared to actual energy usage. Each modelling package makes various assumptions regarding behaviour of the occupants and how the building is used, which creates a typical error when comparing predicted energy consumption to actual. The modelling packages were designed for modern buildings and, therefore, U-values of some of the construction elements within traditional buildings is inaccurate (Baker 2011). This, along with other factors such as thermal mass, can lead to inaccurate energy performance results from the static computer modelling packages. The NHER package is SAP based so certain assumptions are made: heat loss through party walls, the energy consumption of non-listed appliances and forms of secondary heating are given a set figure, which may not match the real-life building; again adding to the inaccuracy of the results.

Due to the limited range of options available in the NHER package, it was difficult to model all of the benign changes. It was also difficult to model the lifestyle changes that the occupant had discussed during the refurbishment process. Each of these issues would have had an impact on the differential between the modelling results and the actual energy consumption readings.

The limitations of computer modelling need to be understood. Energy modelling packages calculate the energy consumption and carbon emissions of a building and predict the impact of various interventions on the building. The package itself does not suggest what interventions to include or what would be suitable for a particular dwelling and cannot discuss various planning and heritage implications of such an intervention. This is an important context to understand as it is up to the professional to decide what interventions to model. This leads to important points of the study of understanding which key interventions are most likely to have a positive reduction on the energy consumption of the building while still meeting the planning heritage requirements

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as well as the budgetary limitations of the client.

The choice of intervention is rarely down to the improvement of environmental performance alone. Other factors such as home improvement, reducing energy costs, repair and building improvement are all part of the client's decision-making process. While the professional advising the client can recommend a particular intervention, it is up to the client themselves to make the decision on whether to proceed with such an intervention.

### Case study building

The building used in this case study is a 3-bedroom Victorian suburban dwelling (Figure 1 and Figure 2). The property was in poor condition but structurally sound. The walls are solid 9-inch brick with timber floors. The roof is timber frame with slates and insulation fitted above ceiling level. The windows were single glazed and in a very poor condition with many not fitting properly. The front door was thin with no draft proofing. The boiler was at least 10 years old and not working properly. The rest of the heating had not been serviced. The kitchen appliances were at least 5 years old and probably much older. The house already had energy saving light bulbs and the roof space was insulated with old +/- 100mm fibreglass insulation.

The current owners were a couple who recently purchased the property and wanted to not only improve the condition of the property, but also improve its environmental performance. One of their first steps was to change their energy supply to a supplier that provides its electricity from wind power. The new energy supplier needed monthly meter readings from the client that were submitted and stored online. These energy readings formed the base of the actual energy consumption of the house of the building. The new owners had made the decision about what changes they wanted to make to the building; these were mostly based on lifestyle requirements rather than any energy consumption or heritage aspects. However, the owners were aware of the need to preserve the overall visual and fabric



Figure 1. Plan of the house

heritage of the building as well as being focused on improving its' environmental performance. The owners as first-time buyers did not have access to large financial resources to refurbish the property. Their first building change within the first few months after moving in was to remove the old roof insulation and refit thicker high-performance insulation. The boiler was replaced 11 months later with a high efficiency condensing boiler.

The final change was the windows. There were two reasons for the decision to change the windows for



Figure 2. Photo of the front of the house

a double-glazed version. First, the existing windows were in such poor condition that it was financially difficult to justify the refurbishment. Secondly, the security requirements of the area meant that the cost for the contents insurance of the building increased considerably by not having secured double glazing on the ground floor windows. The windows chosen were designed to match the period of the building and were

of sash timber construction with double glazed units. They were fitted to the entire front and side windows.

### Methodology

The data was collected on the actual energy consumption from the case study dwelling. These were taken directly from both the standard gas and electricity meters in the dwelling; this formed the basis for the energy consumption data.

For comparison, three further datasets were created following the same improvements to the original dwelling so that comparison could be made between different techniques used in modelling improvements to existing dwellings. For the first set the dwelling was modelled in NHER Plan Assessor in its state at purchase, then the further energy improvements were modelled. The second set was sourced from existing datasets and national databases of improvements to existing dwellings, and the third set was from original data from the wider project (Ritson 2012). These changes to the actual property were modelled via each methodology and the energy performance improvements shown in percentage terms to allow for easy comparison.

To create the NHER plan assessor model, a survey was carried out of the building and detailed notes taken and the recorded information input to the modelling package. This accompanied a series of interviews with the current occupier to gather information on occupancy rate and energy usage behaviour. Further information was also obtained via existing survey documentation when the property was purchased, and the previous occupant's information pack left with the current owner. This provided a relatively accurate set of data to construct the computer model.

An additional set of data was also created to model the behaviour changes the current owners had made. This was following the interviews with the current owners of the dwelling who had said that they were actively changing their behaviour to reduce energy consumption within their dwelling. So, for each change an additional improvement of 10% was added to model

the behaviour changes because it has been shown through various studies that behaviour change can increase the effectiveness of physical improvements to the energy performance of the building (Kelly, 2013). The reason that this had to be added as a separate set of data is that the static modelling package used could not model behaviour change.

### Results and comparison

Table 1 shows the result of the actual energy saving and the result of the different modelling techniques for each intervention to the house and the actual and predicted energy savings. The results show that there are differences between the various modelling technique results as compared to the actual energy savings recorded in the dwelling.

Change House	Actual	Modelling	Modelling with behaviour changes	Wider data set	Similar from the study
	Percentage saved	Percentage saved	Percentage saved	Percentage saved	Percentage saved
<b>Base House</b>	0%	0%	0%	0%	0%
<b>Roof Insulation</b>	9%	1%	11%	6%	3%
<b>Roof Insulation + Double Glazing</b>	20%	4%	14%	20%	5%
<b>Roof Insulation + Double Glazing + New Boiler</b>	46%	29%	39%	36%	36%

Table 1. Table showing results of the various interventions on energy performance

The actual house results and the different modelling techniques all show that intervention of double glazing and roof insulation have a lesser impact on the energy performance of the dwelling. The biggest saving by far is the installation of a new boiler. This is in line with the rest of the findings in the wider study. One of the most energy-efficient improvements that can be done to any historic dwelling is making sure that the existing heating system (in this case a

gas boiler) is as efficient as possible. Overall, while the results are different, the rates of change shown by the gradient in the bar chart (Figure 3) between the changes remains reasonably consistent. There are smaller improvements in energy efficiency for the roof insulation, which increase with the double glazing and finally the largest increase due to the new boiler. The rates of change are reasonably consistent and, therefore, it can be concluded that while the modelling packages and the datasets may not be accurate in predicting precise energy consumption, they at least will show a reasonable state of accuracy in the amount of savings that will be incurred by using a particular intervention. The difficulty of modelling benign changes in behaviour can be clearly shown by the column of behavioural changes much closer matching the actual energy savings that were achieved by the real-world dwelling. This is evidence of the lack

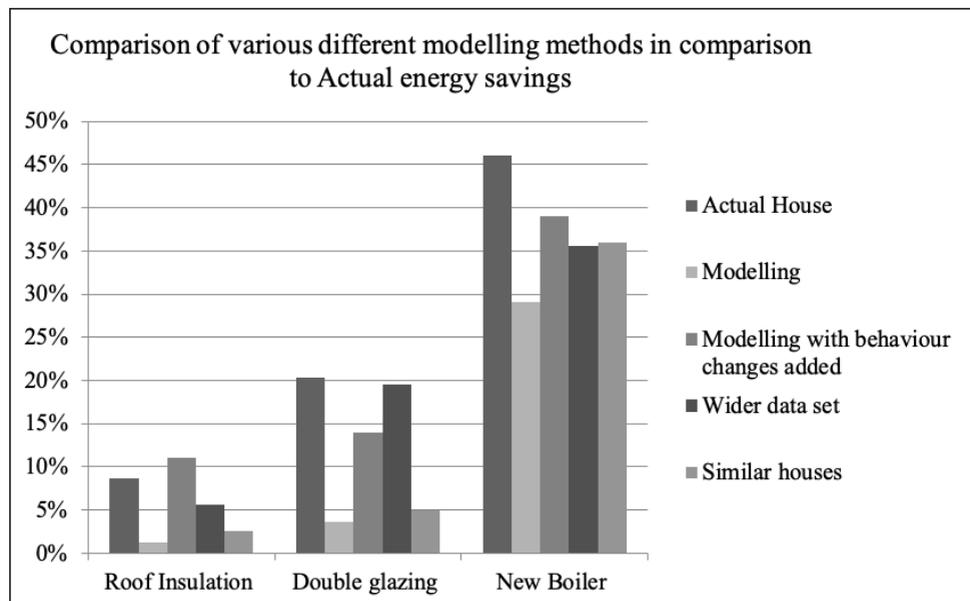


Figure 3 Table showing the results of the interventions on energy performance via the various methods

of homogeneity in the residential built environment coupled with the variances of lifestyle.

The inability of the static modelling package to model behaviour changes can be seen in the results. When the estimated 10% improvements are added to the NHER modelling result they more closely match the results from the actual house. The lack of detail and the inability to change to key U-values of the building elements, along with the limited options such as quality of the windows add further to the inaccuracy of the computer modelling package results. The results also show that the wider data sets from other case studies were closer to matching the actual energy saving improvements of the house. The intervention that showed the biggest discrepancy was the introduction of the double glazed window. This might be explained by the poor condition of the original windows, with some not able to close properly and the inability to model these factors in the NHER 'base' model of the property. The modelling package simply assumed an improvement of single glazed to double glazed units. A positive result was that all the modelling and prediction methodologies used in the study underestimated the improvements would have had on the energy performance of the house. This is encouraging as it adds evidence that small benign changes to a historic dwelling can have greater improvement to their energy and carbon emission performance.

**Future**

While currently only static modelling packages are approved for use in residential buildings, the growth of embedded and paired dynamic modelling in packages such as Revit and IES coupled with the growth of smart meters and heating control systems creates the possibility for more accurate dynamic modelling of residential buildings in the future (Zhou and Yang, 2016). While not currently approved, the possibility of more accurate models will lead to more accurate results compared with actual energy consumption. However, no matter how accurate the

results are they will be still based on a prediction and one of the major difficulties in modelling residential buildings is that occupants all live different lifestyles. The lack of homogeneity in the residential built environment, coupled with different personal lifestyles will always lead to an inaccuracy in predicted energy consumption results compared to actual energy usage.

While the more data that can be fed into a dynamic model such as heating, timing, and temperature and electricity consumption will lead to more accurate results, the future prediction will be based solely on past behaviours.

Results from all of the methods of modelling show that benign changes can make significant improvements to the energy performance of a historic dwelling. However, they do fall short of some of the more extensive sustainably-focused refurbishments. It has to be noted, however, that these more extensive sustainable refurbishments often have a much higher impact on the heritage of the building as well as being much more financially expensive to implement. A judgement has to be made on whether the impact of the heritage justifies the improvements to environmental performance of the building.

The results above show that the impact that behaviour can have on the energy consumption of a building in real life. And while the building may very well be improved significantly by either benign or environmental focused refurbishments, it is still dependent on the occupant of the building behaving and using the building in the correct way.

### Conclusion

One of the key reasons that the results from the computer modelling package do not match the actual results is due to the lack of detailed options when inputting the information to the NHER model. As previously described the windows in the original dwelling were in a very poor condition with many of them not closing properly and in a very poor state of repair. However, NHER Plan Assessor does not

give this level of detail in the options of the original base model of the dwelling. Another key factor is the lack of detail that can be provided for other subtle changes, for example with the existing roof insulation in the original dwelling, the age and efficiency of the insulation was much reduced. Therefore, there will be a much greater saving when the new high efficient roof insulation was installed even though the thickness and the stated U-value was not that different from the previously installed insulation. Again, this shows a discrepancy between real-world building and a computer modelling package.

SAP-based models such NHER are designed to give an overall picture of a building's energy performance rather than to give an exacting and accurate figure that matches every building's actual energy consumption. It does provide a 'what if' guide to the success of typical sustainable improvements in a typical dwelling (Todd 1995). However, if the improvements are not typical or the dwelling is of traditional construction, the accuracy of the results will be reduced. However, the biggest variability in any prediction will be the occupants' behaviour and lifestyle and this variability will always be the weak point of any modelling package or prediction methodology. The future integration of smart metering and dynamic modelling could lead to a more accurate interpretation of behaviour with a dwelling. This increased data could lead to better assessments for more effective environmental improvements to dwellings.

All of the different modelling methods and the actual results show that the most worthwhile intervention was the replacement of the gas boiler. The gas boiler was used for both space and water heating which is the largest consumer of energy within a dwelling. The replacement of a boiler has very little heritage impact on the building. The smaller benign and behavioural improvements have had a positive impact in decreasing the energy consumption, however, it should be noted that different behaviour changes could have also had a negative impact on the energy consumption. As stated by Kelly (2011) 'Dwellings

are heterogeneous. A decarbonisation strategy that works well for one may not work for another.' Results from all of the methods of modelling show that benign changes can make significant improvements to the energy performance of a historic dwelling. Further improvements to the environmental performance of the building are possible but have to be justified against the impact of heritage and the financial outlay required. This decision cannot be modelled and comes down to policy and professional judgement.

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