Energy and Buildings 75 (2014) 216–227

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

# The use of Passive House Planning Package to reduce energy use and $CO_2$ emissions in historic dwellings

Francis Moran*, Tom Blight, Sukumar Natarajan, Andy Shea

*University of Bath, Architecture & Civil Engineering, Coomb Down, Bath BA2 7AY, United Kingdom*

ARTICLE INFO

*Article history:*
Received 30 March 2013
Received in revised form 10 August 2013
Accepted 23 December 2013

*Keywords:*
Energy use
Historic buildings
$CO_2$ emissions
PHPP
EnerPHit
PV

ABSTRACT

Since historic buildings constitute 25% of the European built environment they have a role to play in delivering $CO_2$ emissions reduction targets along with the rest of the domestic stock. However, historic buildings have significant cultural value and were built with technologies and materials that promote fabric breathability. This demands solutions that will deliver enduring and radical energy efficiency savings and emissions reduction, which while maintaining their heritage value are also capable of district wide replication.

Before embarking on wide scale retrofit adaptations, affordable and accurate procedures to assess the potential for such measures to reduce $CO_2$ emissions are of primary importance. Some measures will have an impact on both fabric and aesthetics. It is therefore necessary to ensure that the reductions in $CO_2$ emissions from a set of proposed alterations are significantly higher than any actual or perceived reduction in loss of built heritage.

This paper demonstrates the use of the Passive House Planning Package (PHPP) modelling tool to assess the potential for retrofit adaptation measures in three terrace dwellings in Bath, England. It compares modelled against delivered energy use and then models energy and emission reduction following the introduction of a suite of retrofit adaptations.

Results indicate that PHPP can assess total electrical energy consumption but requires the use of a reduction factor to reflect accurately intermittent occupancy/heating patterns. The modelled results suggest retrofit adaptations in historic buildings could deliver energy savings and $CO_2$ emissions savings between 55% and 83%, but only when the thermal fabric is significantly improved and the use of PV is included.

PHPP provided assessments of the benefits of retrofit adaptations in historic buildings that can facilitate decision making on retrofit methodology in historic buildings that affect fabric and/or aesthetics.

## 1. Introduction

In Europe, historic buildings [1] account for over 25% of all buildings [2]. The scale of the problem is large, every building in Europe will have to cut its carbon emissions by 20% by 2020 [3]. The UK government has set more challenging targets with a reduction in emissions of 34% by 2020 and 80% by 2050 [4]. This is despite the UK having the oldest building stock in Europe with almost 40% of the existing residential buildings built before 1946.

This means that for every one of 25 million existing dwellings in the UK that fails to reduce its emissions by 80% another one must increase its emissions reductions by a commensurate amount. Natarajan and Levermore [5] have previously shown how difficult achieving even a 60% stock-wide reduction would be. Historic dwellings, at 21% of existing stock, cannot side step this issue and therefore must play an equal part in the effort to reduce emissions. Since most retrofit measures affect fabric, this brings the conservation of energy (and hence the reduction of emissions) into conflict with the conservation of built heritage.

Research indicates that a suite of adaptations can have effects varying from 40% to 80% [6–11]. It is also evident that occupant behaviour will have a significant effect on energy use [12].

What is less clear is a suitable methodology to produce and implement radical $CO_2$ emissions reduction solutions that are not only effective, but prove to be both durable and non-deleterious to the buildings fabric. There is a need for a model/tool to provide in a straightforward manner, at reasonable cost, accurate and reliable assessments of the benefits of retrofit adaptations in historic buildings. If this is accepted and trusted by stakeholders it will facilitate decision making based on empirical data.

The English House Condition Survey (EHS) [13] suggests a close correlation between the age of a building and its energy

---

* Corresponding author. Tel.: +44 0773 6678586.
*E-mail address:* fmoran@blueyonder.co.uk (F. Moran).

0378-7788/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.enbuild.2013.12.043

performance. Homes built before 1919 have average $CO_2$ emissions of 86 kg $CO_2/m^2$. However, this can be misleading as previous work by Moran [1] has shown that the EHS can overestimate energy use in historic buildings by 12% for gas and 44% for electricity. In either case, from an overall stock point of view, it is clear that historic buildings will have a strong role to play in attaining emissions targets.

The current heritage landscape has developed over time, so too has the approach regarding the preservation of our built heritage. Loulanski [14] set out the evolution of the protection of historical assets in the UK, showing a move from preservation to a broader concept of Conservation and Heritage. More recently, a new challenge to this orthodoxy has emerged: how do we align the conservation of energy with the conservation of heritage to the benefit of both historic buildings and occupants? This is of importance as at least 75% dwellings that will be standing in 2050 have already been built and historic dwellings will account for at least 1/3 of these [1]. This suggests that solutions to reduce $CO_2$ emissions in the UK domestic sector (as well as a large portion of the EU stock) will have to involve historic buildings.

In this paper, we consider this new era of low carbon and energy efficient buildings as the alignment of the *conservation of heritage* with the *conservation of energy*. Failure to deliver low carbon historic buildings will fail both occupants and the buildings and may see historic buildings becoming redundant; the price of which may be environmental obsolescence or demolition [15].

Cassar [15] also suggests aligning the principles and practice of conservation in the 21st century more fully with sustainability principles. This will involve weighing up the perceived benefits of energy savings and $CO_2$ emissions reduction against loss of fabric. Loss of fabric includes actual alteration to/or removal of amounts of the original building. They vary in scale and nature and can include cutting service chases and taking down ceilings to reach inaccessible roof voids. It also includes loss of visual fabric, this can occur where a part of the original building is covered from permanent view but remains intact, an example is internal wall insulation in front of a plastered wall with stucco features.

This paper will concentrate on historic buildings in the UK using case studies from the City of Bath in the SW of England. It is anticipated that the findings will also be applicable to the historic European stock.

## 2. Methodology

The aim is to evaluate the potential contribution retrofit adaptations can make to reducing energy use and $CO_2$ emissions in three case study historic dwellings in Bath, UK with the following identified objectives:

- Collect delivered energy use data for minimum of 12 months.
- Evaluate available modelling options and select for a balance between ease of use, cost and detail of outputs.
- Model predicted gas and electricity energy use using localised weather data.
- Estimate the energy and carbon savings for retrofit measures.
- Evaluate the potential contribution of LZC (Low and Zero Carbon) technology (solar hot water and 2.0 kWp photovoltaic array in this study).

## 3. Model selection

Three different modelling methods were evaluated for this work: Integrated Environmental Solutions (IES) software, Standard Assessment Procedure (SAP) (2009) and Passive House Planning Package (PHPP) see Table 1. SAP was adopted as it is the NCM (National calculation Method) for the UK. IES is widely used as a dynamic modelling tool. PHHP was considered as it has recently begun to be adopted more widely.

While dynamic simulation software such as IES is most likely to deliver more accurate results they are more expensive, time intensive, have complex data inputs, require a period of user training and are not specifically designed for small scale domestic use. For these reasons SAP has generally been used, and more recently the PHPP has begun to emerge as an option.

Of the remaining two packages, PHPP was selected because of its transparency regarding how results are determined, relative ease of use, inclusion of appliance energy consumption and its affordability. The perceived disadvantage of not having been readily applied to historic buildings, although a retrofit standard exists, was viewed as an opportunity to explore its suitability for this sector of existing dwellings.

For completeness both SAP and IES models were chosen to make a comparison of the base case energy use. The SAP analysis was conducted as it has historically been the default option for considering energy use in dwellings. In addition the IES simulation was run alongside the PHPP analysis in order to determine the extent of energy use detail lost through adopting a steady state analysis only.

It should be noted that it is not the intention of this paper to compare the merits of these three energy modelling packages, but rather to assess the possible merits of using the PHPP for historic buildings undergoing retrofit adaptation.

## 4. Passive House Planning Package

PHPP is a spread sheet design and compliance tool produced by the Passivhaus Institute to model the performance of a proposed Passivhaus building. It is considered an accurate tool in the Passivhaus community because it was systematically developed by comparing dynamic simulations to validated measurements in completed Passivhaus projects. Though not specifically designed to model energy use in historic buildings it is used for the retrofit of existing buildings (EnerPHit[1]) and has targets for heating and non-heating energy use.

The Passivhaus Standard has a high degree of flexibility in that energy use targets can be met using a variety of design strategies, construction methods and technologies. Monthly average local weather data can be also inserted or imported; this study used the Severn Valley data set from the BRE.[2] It also allows occupancy to be prescribed, as well as starting conditions for the performance of the dwelling (including internal temperature, infiltration level, appliances and electrical goods).

Passivhaus methodology is primarily energy driven and focuses on minimal fabric and ventilation losses, maximum passive internal heat gains and solar gain in winter (requires attention to avoid summer over heating), the use of energy efficient MVHR (mechanical ventilation heat recovery) plant (requires a very low heat load) and incorporates LZC technologies to meet the remaining energy demand.

For this study the intention was not necessarily to meet the EnerPHit standard, but to assess the potential reductions arising from retrofit adaptation for the case study buildings. There are limitations to using the PHPP either as a result of the way the software

---

[1] PHI has developed the “EnerPHit – Quality-Approved Energy Retrofit with Passive House Components” Certificate for the refurbishment of old buildings. Max heat 25 kWh/$m^2$ a, max primary energy demand 120 kWh/$m^2$ a.

[2] Available to download via http://www.passivhaus.org.uk/page.jsp?id=38 (accessed 12.12.12).