Developing a database of energy use of historic dwellings in Bath, UK

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Abstract:
Historic dwellings in the UK make up 20% of all homes. In the Georgian city of Bath this rises to 30%. These buildings are amongst the most poorly performing part of the English housing stock in energy use terms, with the lowest SAP rating and highest average annual CO₂ emissions.

The UK legal aim to reduce CO₂ emissions by 80% by 2050 will involve all existing dwellings, including historic buildings. The degree to which proposals to retrofit the UK housing stock can reduce emissions depends on how much energy they currently use, what it is used for and how much CO₂ they emit.

This paper establishes a benchmark of gas and electricity energy use and CO₂ emissions for 102 pre 1919 (historic) dwellings in Bath, permitting comparison of their energy performance against other parts of the housing stock.

The level of energy use found was less than expected using SAP values; it was also less than national, regional and local authority averages. The benchmark established allows a base line from which to monitor future performance and to gauge the direct benefits of retrofit adaptations.

Keywords: carbon emissions, energy use, historic dwellings.

1 Introduction

In the UK, dwellings account for 26% of CO₂ emissions (DECC, 2010) and are at the centre of the governments focus to reduce emissions, along with transport and industry. Within this new low carbon paradigm (Royal Academy of Engineering, 2010), one central thrust of research is how to decarbonise the built environment (Oreszczyn et al., 2010).

But given that the majority of homes in England that will be standing in 2050 have already been built, although the exact percentage can only ever be an estimate, consequently figures vary (85% Palmer et al., 2006; 80% Sustainable Development Comission, 2006; 70%, Lowe, 2007), it is clear that CO₂ savings in the existing domestic sector could make a significant contribution to the overall reduction of national emissions (CLGC, 2008).
This paper considers Historic dwellings, they can be defined as all buildings constructed prior to 1919, as this is the date generally accepted for the introduction of cavity wall construction in the UK and the wide spread use of a damp proof course (DPC). Though it is noted that there remains a portion of the 1920-45 stock that has the same characteristics (solid wall and no DPC), using the date of 1919 wholly focuses on solid walled buildings constructed with a permeable fabric that both absorbs and readily allows the evaporation of moisture. Figure 1 shows that in England, 22% of all dwellings were built before 1919.

![Figure 1](image)

**Figure 1**  Number (000s) and percentage of homes by age in 2007  
(Source: English House Condition Survey, 2007)

The city of Bath was chosen because it has a higher than average concentration of pre 1919 dwellings, with 30% of all dwellings constructed before 1919 compared to a UK average of 22%, see Figure 2.

![Figure 2](image)

**Figure 2**  Breakdown by Dwelling Type  
(Source: BANES House Condition Survey, 2004)
2 Literature Review

Performance of Historic buildings

Government statistics show higher CO$_2$ emissions for historic dwellings yet there are differences of opinion on how the energy efficiency of these buildings is viewed. Their energy efficiency is either regarded as good (English Heritage, 2009) or poor (EHCS, 2007; Boardman, 2007).

The English House Condition Survey (EHCS, 2007) uses the Standard Assessment Procedure (SAP)\(^1\) to reveal a close correlation between the age of a building and its energy performance. Homes built before 1919 have an average SAP rating of 39 (Band E), the effect of this is demonstrated by their average 9 tonnes CO$_2$ emissions for heating and lighting, twice those of the post 1990 stock (Figure 3).

![Figure 3 SAP and CO$_2$ emissions by building age](source: EHCS 2007, p 106)

From Figure 3 it can be seen that houses built before 1919 accounted for higher levels of CO$_2$ emissions per dwelling, evidence of their poor energy efficiency. To put this in to perspective in energy use and emission terms, using Elmhurst 2009 software, a SAP rating of 39(E) equates to approximately 320 kWh/m$^2$/yr and 81 kg CO$_2$/m$^2$/yr.

The UK has been producing benchmarks for several decades, but these have focused mainly on new domestic dwellings and the commercial sector. There is very little benchmark data on the energy consumption of the domestic stock (Oreszczyn et al., 2010), and a lack of reliable data for historic dwellings (English Heritage, 2009). In direct response to this situation, the aim of this paper is to produce a normalised benchmark of the annual energy consumption and CO$_2$ emissions annually.

CO$_2$ emissions in Bath

Using data from DECC 2007 Local Authority Carbon Dioxide figures, the total CO$_2$ emissions for BANES in 2007 were 1,048,000 tonnes, of which the domestic stock is

\(^1\) SAP rating is calculated from an estimate of annual heating, hot water and internal lighting costs per m$^2$ of a property. The SAP scale runs from 1 to 100, with 100 being the best (BRE, 2005).
responsible for 39% of the total emissions, see Figure 4. The average for the domestic stock in the UK is 28% (DECC, 2010).

The reason for the higher domestic emissions is unexplained. There may be a number of reasons- one may be the higher distribution of pre 1919 dwellings in Bath, but this will require further investigation.

3 Research Methodology

The methodology was designed to collect data of energy use in historic dwellings in Bath that are statistically representative of the stock in order to establish a benchmark. The main elements identified were:

- Determine sample size
- Ascertain typology distribution
- Randomly select target addresses
- Gather regional and national energy use benchmarks
- Establish benchmark energy use in historic dwellings in Bath

Constraints of resource and time availability meant it was not possible to produce a detailed breakdown of energy consumed by end use.

3.1 Sample Size

The selection of strategy for sample size considered the population size, the variability of the parameters being considered and the desired level of confidence.

The simplified formula by Yamane (1967) was considered suitable to calculate sample sizes:

\[ n = \frac{N}{1 + N(e^2)} \]

Where  
N= Population  
n= sample size  
e= level of precision  
(not less than 90%)
With a total population (N) of 11,280 dwellings, 100 responses are the lowest number of returns required to achieve a 95% confidence level with a 10% error level, returns in excess of this increase the accuracy of the survey.

3.2 Typology

Figure 5 shows typology distribution in Bath.

![Building Typology Distribution for Bath](Source: BANES House Condition Survey 2004)

The dwellings were randomly selected from all pre 1919 dwellings within the city of Bath to reflect this distribution. In total, 600 household energy use questionnaires were delivered in batches of approximately 50 from March 2010 to April 2011. A return rate of 25% was achieved.

The questionnaire was kept short in order to mitigate against participant saturation and disturbance (Dejan and Mat 2009). This meant compromising the total number of questions asked, resulting in a constraint on the amount of data that could be collected on disaggregated gas and electricity use within the dwelling.

The questionnaire sought information on actual total energy use. This was a difficult question for some respondents to answer due to difficulty in reading utility bills, lack of access to information through having either changed supplier or being unable to access paperless billing.

Initially, a total of 54% of respondents provided complete energy use data. In a number of cases assistance was given to derive this information, increasing the response rate for energy use to 68%. This resulted in 102 data complete sets of energy use comprising a twelve month period.

4 Findings and Discussion

For each case the energy use was normalised for internal heated floor area based on the data provided by respondents. In order to allow direct comparison between individual dwellings all energy used discussed in this paper is delivered energy to the dwelling and is reported in kWh/m²/year and CO₂ emissions as kg CO₂ /m²/year.
4.1 Region Average

Average energy use per dwelling was established using DECC Sub-national Local Authority gas and electricity consumption statistics from 2009. The results are shown in Table 1.

Table 1 Dwelling average annual energy use

<table>
<thead>
<tr>
<th></th>
<th>GB</th>
<th>England &amp; Wales</th>
<th>England</th>
<th>South West</th>
<th>BANES</th>
<th>Carbon Factor kg CO₂/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas kWh</td>
<td>1583</td>
<td>15300</td>
<td>15306</td>
<td>13650</td>
<td>15295</td>
<td>0.19</td>
</tr>
<tr>
<td>kWh/m²</td>
<td>198</td>
<td>191</td>
<td>191</td>
<td>171</td>
<td>191</td>
<td></td>
</tr>
<tr>
<td>kgCO₂/m²/yr</td>
<td>38</td>
<td>36</td>
<td>36</td>
<td>32</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.54</td>
</tr>
<tr>
<td>kWh</td>
<td>4152</td>
<td>4149</td>
<td>4136</td>
<td>4448</td>
<td>4343</td>
<td></td>
</tr>
<tr>
<td>kWh/m²</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>56</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>kgCO₂/m²/yr</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>30</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Gas &amp; Electricity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kWh/m²</td>
<td>250</td>
<td>243</td>
<td>243</td>
<td>227</td>
<td>245</td>
<td></td>
</tr>
<tr>
<td>kgCO₂/m²/yr</td>
<td>66</td>
<td>64</td>
<td>64</td>
<td>62</td>
<td>65</td>
<td></td>
</tr>
</tbody>
</table>

Using average floor area for urban dwellings from EHCS (EHCS 2007a) the regional energy use data for domestic gas and electricity use for BANES in 2009 was 245 kWh/m²/yr. This is slightly higher than the South West average but in line with the England average.

4.2 Results

This paper compares energy use data collected from 102 pre 1919 Buildings in Bath during 2010/2011. The comparison of ranked energy use according to typology is shown in Figure 6.
The results show a wide range of total energy use, ranging from 49 kWh/m²/yr to 437 kWh/m²/yr, with a mean of 195 kWh/m²/yr.

Given that dwelling form primarily governs heat loss through the structure, the lower gas use for flats and some terrace dwellings is as expected. What is unexpected is that a large number of mid terrace dwellings gas consumption is close to that for end terraced dwellings.

The majority (97%) of the sample population used gas for heating and hot water; this shows a factor of 7 difference within terrace and end of terrace typology. This is a noticeable variation, given that the properties surveyed have similar construction; the explanation may lie with both the dwelling performance characteristics (insulation, windows, boiler efficiency and infiltration) and the occupant’s behaviour.

The three lowest energy users in the Flat typology were all low income households, average occupancy 1.3. The two lowest properties only heated a minimal number of rooms to keep fuel bills low.

Closer examination of the lowest gas users in Terrace dwellings revealed that they had energy efficiency retrofits within the last five years, the adaptations included good levels of roof insulation, double glazing or secondary glazing, draught proofed windows and doors, condensing boilers, some internal wall insulation and good boiler controls. Occupant attitude may also be a factor as all these occupants were very concerned about their energy use and CO₂ emissions.

The lowest End of Terrace had a gas use of 65 kWh/m²/yr. This property had good roof insulation, heating controls and new double glazed UPVC sash windows fitted two years ago. The property was occupied by a single retired person. Thermostatic radiator valves were used to heat only the main rooms; this was altered when there were additional occupants.

A similar explanation occurred in the Semi Detached dwellings. The three lowest had 99, 102 and 109 kWh/m²/yr gas use. All of these properties also had energy efficiency adaptations.

Explanations for high energy use are more difficult to explain. Looking at Semi Detached dwellings, in all cases occupancy level was in excess of three, all boilers were at least 10 years old (one was 20 years old).

### 4.3 Electricity Energy Use

This shows a smaller variance between dwelling typologies, as electrical use is less affected by built form, these variations may be a reflection of occupant behaviour with regard to electrical energy use. The highest Semi-Detached user was 135 kWh/m²/year, this provided heating. Other dwellings using electricity in excess of 60 kWh/m²/yr were attributable to either electric “Aga Stove” type cookers or under-floor heating in conservatories. Ignoring these exceptional energy uses there was a factor of 4 difference for electricity use between dwellings of the same typology.
4.4 Mean Energy Use

Table 2 shows a summary of mean energy use by typology.

<table>
<thead>
<tr>
<th>Sample Size (n)</th>
<th>Mean energy use kWh/m$^2$/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gas</td>
</tr>
<tr>
<td>Flat</td>
<td>7</td>
</tr>
<tr>
<td>Mid Terrace</td>
<td>47</td>
</tr>
<tr>
<td>End Terrace</td>
<td>9</td>
</tr>
<tr>
<td>Semi Detached</td>
<td>28</td>
</tr>
<tr>
<td>Detached</td>
<td>11</td>
</tr>
<tr>
<td>All</td>
<td>102</td>
</tr>
</tbody>
</table>

The results show that increased external surface or built form requires higher heating energy use, although there is a less than expected difference between mid terrace and end terrace dwellings. More interestingly, Table 2 shows that energy use in historic dwellings is lower than both the national and regional average. More importantly, it is considerably less than the indicated SAP value of 39 stated by the EHCS, which would result in an energy use of 321 kWh/m$^2$/yr. Only 7 out of 102 dwellings exceeded this level of energy use. Carbon emissions are shown at Table 3.

<table>
<thead>
<tr>
<th>Sample Size (n)</th>
<th>Mean CO$_2$ emissions kgCO$_2$/m$^2$/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gas</td>
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<td>Flat</td>
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<td>All</td>
<td>102</td>
</tr>
</tbody>
</table>

The average of 48 kgCO$_2$/m$^2$/yr for all dwellings is considerably lower than the figure of 65 kgCO$_2$/m$^2$/yr for the BANES average (Table 1).

4.5 Benchmark

From the distribution found it is possible to fit a performance benchmark by using the lower quartile as energy efficient or better than average performance and the upper quartile as not energy efficient or worse than average performance (Mortimer et al, 1999). A proposed benchmark for gas and electricity use in historic dwellings by typology is at Figure 7.
Conclusion and Further Research

This paper analyses normalised energy use data from 102 pre 1919 dwellings in the city of Bath and establishes average gas and electrical energy use and CO₂ emissions. The level of energy use found was less than expected using SAP values; it was also less than national, regional and local authority averages.

Within each typology there is a wide range of energy use. This will impact directly on the benefit of energy efficiency retrofit proposals in terms of the net reduction in both energy use and CO₂ emissions. The study also found that both gas and electricity consumption varied considerably for similar dwelling types, by as much as a factor of 7 for gas and a factor of 4 for electricity.

The findings reflect the benefit of retrofit adaptations and the subsequent reduction in energy use, and by proxy CO₂ emissions. The significant variation in nominally similar dwellings also points to the effect of occupant behaviour on energy use.

The advantage of a benchmark is that it allows comparisons with other similar building types. More importantly, it allows a base line from which to monitor future performance and to gauge the direct benefits of retrofit adaptations.

The next step in this research will be to model the predicted energy performance for a sample of the dwellings surveyed and compare this to actual energy use.
Acknowledgement

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