

## Utilising resident feedback to inform energy-saving interventions at the Barbican

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The introduction of the Green Deal provides evidence of the UK Government's commitment to improving the energy efficiency of our ageing and underperforming housing stock. However, the issue of what to do with those buildings which for reasons of historical or architectural significance do not lend themselves to conventional fabric interventions has not been addressed fully. A residents' survey was conducted at the Grade II listed Barbican Centre in London, to characterise levels of occupant comfort and satisfaction, to identify any problems experienced by the residents, and to explore possibilities to improve the energy performance of the estate without compromising its status as an iconic example of post-war architecture and planning. This paper explores how occupant feedback surveys can inform the development of energy-saving interventions at an atypical case study site.

**Keywords:** post-occupancy evaluation; feedback; retrofit; housing; energy efficiency; iconic architecture

### Introduction

#### *Context*

The main driver for this research is the need to drastically reduce the carbon dioxide (CO<sub>2</sub>) emissions associated with our building stock, in order to mitigate against the threat of climate change (IPCC 2008). The Climate Change Act 2008 states that by 2050, UK's total greenhouse gas emissions must be reduced by at least 80% to limit average global temperature rises below 2°C. The Act also mandates a reduction in emissions of at least 34% by 2020, with both targets set against a 1990 baseline (Anon 2008). In the urbanised UK, buildings account for half of all CO<sub>2</sub> emissions, while 25% of CO<sub>2</sub> emissions can be attributed to our ageing housing stock (Palmer and Cooper 2011). As 70% of this housing will still be standing in 2050, there is a clear imperative to take steps to significantly reduce the CO<sub>2</sub> emissions associated with our existing housing (SDS 2006).

The challenge of reducing CO<sub>2</sub> emissions will need to be addressed at both the supply and demand levels, if we are to stand a chance of meeting Government targets (DTI 2007). The decarbonisation of the grid supply is a long-term goal that will only be achievable if our demand for energy is also dramatically reduced (DECC 2009). Much research has been carried out on designing, testing and implementing retrofit solutions in UK housing (see for example, Lowe 2007, Roberts 2008, Lomas 2010). However, most of this work relates to identifying cost-effective solutions that can be rolled out across the stock,

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based on a few standard housing typologies. Such solutions that are not necessarily appropriate for buildings with architectural or historical value, which are often atypical in form or may utilise unique construction methods and materials (Moorhouse and Littlewood 2012). Furthermore, there is an inherent tension between the drive to use less energy and the value of preserving our built heritage (Davies and Osmani 2011).

This paper presents the findings of a post-occupancy evaluation (POE), which was used to identify technical and behavioural energy efficiency interventions at an iconic and historically significant post-war housing development. A small yet significant part of our housing stock is made up of such buildings: there are currently 9300 conservation areas and 374,081 listed buildings in England, which account for 4.6% and 1.5% of existing properties, respectively (English Heritage 2003, CLG 2008).

A POE of 2056 residential dwellings was carried out at the Grade II Listed Barbican Centre in London. The purpose of the study was to characterise occupant satisfaction, energy use and behaviour in the dwellings, as a means of investigating retrofit options that might reduce energy consumption without compromising the heritage value of the buildings.

### **Research aims**

The following three research questions were asked at the outset of the investigation and form the basis for the discussion:

- How can the energy performance of the Barbican be improved, given its iconic status and the fact that it is protected by listing?
- How effective is the building use studies (BUS) methodology occupant satisfaction survey as a diagnostic tool for identifying treatable problems and solutions at a case study site?
- How well do the residential areas of the Barbican perform in terms of design, environmental performance and perceived personal control, and how do these results compare to benchmark data from other UK housing projects?

### **Literature review**

#### **POE**

POE is defined as a method of rigorous auditing and evaluation of “buildings in-use”, in order to create a feedback loop “whereby information fed back through continuous evaluation leads to better informed design assumptions, and ultimately, to better solutions” (Preiser and Vischer 2005, p. 3). Bordass and Leaman (2005a) argue that POE must become routine in all new buildings so that the performance gap “between predicted and actual energy consumption can be quantified and reduced”.

POE should be undertaken when the building has “settled into routine operation” (Bordass *et al.* 2006). Techniques include monitoring of energy consumption, occupant satisfaction surveys and methods to evaluate and improve the design and construction processes (Bordass and Leaman 2005b). This feedback can then be incorporated into the design and procurement of new buildings so that the same mistakes are not repeated (Stevenson and Rijal 2010).

The case has also been argued for the use of POE as a diagnostic tool, to determine what is happening at a particular case study site and to inform remedial measures to target specific problems (Becker 1989, Preiser 1995, Vischer 2001). A further application of POE is as a vehicle for benchmarking building performance against best practice data (Cooper 2001).

POE developed after the end of World War II (WWII), as a branch of behavioural and social science, in order to “deepen our understanding of human relationships with (...) our environment”. In 1963, the Royal Institute of British Architects (RIBA) included POE in its plan of work, the administrative framework for planning and managing building contracts. Architects were now required to revisit completed office projects two years after completion as part of “Stage M: Feedback”. Unfortunately, by 1972, Stage M was no longer part of the RIBA architect’s appointment and POE was reduced to an academic pursuit within the discipline of environmental psychology (Bordass *et al.* 2004a). Designers and constructors were no longer involved in the feedback loop.<sup>1</sup>

The post-occupancy review of buildings and their engineering (PROBE) comprises a series of POEs of recently completed commercial buildings carried out between 1992 and 1995. The scope, methodology, and results of the studies are reported in detail elsewhere, see, for example, Bordass *et al.* (2010). The key finding of probe was that the *performance gap* between the predicted and actual building performance was even greater than expected (Bordass *et al.* 2004b). Based on this discovery, the dissemination of PROBE urges that feedback must become routine in all new buildings (Bordass *et al.* 2001).

### **BUS methodology**

The BUS Office Environmental Survey was developed in the 1980s as part of a study of sick building syndrome in offices.<sup>2</sup> It was then modified for use in PROBE, when it became known as the BUS methodology, or BUS. BUS is one tool from the portfolio of POE methods which is used to undertake user surveys of occupied buildings. It is frequently employed to evaluate the occupant satisfaction of recently completed buildings, and can also be administered before alterations or renovation work are planned, to find out how the occupants feel about the building, and to pinpoint any areas of concern which could be addressed as part of the intervention (Bordass *et al.* 2006).

Since its inception, BUS has developed into a tool for the “rapid and comprehensive study of user needs in a range of building types”. The domestic version of BUS was launched in 2006 with the aim of collecting a body of data about how well homes are working from the users’ perspective (UBT 2011). A questionnaire is administered to evaluate to what extent the building meets the residents’ needs in terms of thermal comfort, perceived control, lighting, noise, and satisfaction. The questionnaire collects both qualitative and quantitative data, which can be used to evaluate the success of the project. Once enough studies were carried out using the methodology, the data were compiled to create empirical benchmarks, so that performance can be compared to other sites. However, only 10 studies had been carried out using this methodology at the time that this research was conducted and the domestic benchmarking process in its infancy.

It has recently been suggested that evaluation methods should also take into account occupant behaviour, which has been found to account for up to a factor three increase in domestic energy use (Stevenson and Rijal 2010). It is people, and not buildings, who use energy (Janda 2011), so that “asking questions about the way the building performs is no longer sufficient for POE of dwellings” (Vale and Vale 2010, p. 578). For POE to be instrumental in reducing the environmental impact of dwellings, a rating of whole household performance that takes into account occupant behaviour should be included (Stevenson and Leaman 2010).

An occupant behaviour questionnaire that can be administered alongside the domestic BUS questionnaire was developed by Gill *et al.* (2010), in order “to distinguish between and quantify frugal and profligate patterns of consumption”. The study carried out using

this combination of methods found that domestic behaviour was responsible for differences in heat, electricity, and water use, of 51%, 37%, and 11%, respectively. The behavioural questionnaire was based on the theory of planned behaviour model, which proposes that our actions are derived from a combination of attitude, perceived control and subjective norms (Ajzen and Madden 1986). The study documented herein is one of the three completed to date which uses the two questionnaires together.

### ***Housing and retrofit***

Retrofit strategies can be split into two types: there are interventions that improve the thermal properties of the existing building fabric, as well as those that reduce the carbon intensity of building services, such as boiler upgrades and on-site microgeneration using renewables. It is usually recommended that a “fabric first” approach is taken so that fabric improvements precede building service upgrades. In 2010, the UK building regulations were revised to include the requirement for any improvements or renovation such as the addition of extensions or conservatories to comply with new build standards (HM Government 2010b). However, listed buildings and those in conservation are exempt from this requirement, if there is a risk to their architectural or historical integrity (CLG 2008).

Until recently, Government support for low-energy retrofit was provided by the Decent Homes, Warm Front, and Carbon Emissions Reduction Target schemes (CLG 2008). The Green Deal was launched in early 2013 to provide a cost-effective financial mechanism for making improvements to new homes. The innovative scheme allows residents to take out a loan to fund energy-saving home improvements, which is to be repaid through savings to energy bills. Additional financial assistance will be available to the residents of older homes, or those people on benefits or lower incomes, in the form of the energy company obligation (ECO). ECO will be funded by utility companies and includes provision for cavity and solid wall insulation, as well as other interventions (DECC 2012).

The Green Deal and ECO appear to be geared towards the improvement of individual homes in an incremental fashion; no reference is made in the documentation about how to deal with privately owned or rented apartment blocks, where improvements should be made to the whole building rather than to individual dwellings, something which would require considerable cooperation between different groups of residents.

A barrier to carrying out energy efficiency improvements to existing homes is the capital cost of deep retrofit projects, which are unlikely to be repaid with sufficiently short payback periods to appeal to investors (Jenkins 2010). For example, in 2003 the refurbishment of the Grade II listed Trelick Tower, a 1960s high rise apartment block in west London, to Decent Homes standard, cost nearly £17 million, including £7million for the installation of new double glazing (Buxton 2008). Although it may be unrealistic to expect as deep reductions in energy consumption from hard-to-treat dwellings as for the rest of the UK building stock, this example demonstrates that it *is* possible to improve the environmental performance of historic dwellings without damaging their architectural value, albeit at a cost.

### **Case study site**

#### ***Site description and design***

The Barbican Centre is a large mixed-use residential and cultural development, located in central London, which has been described as the “greatest piece of combined urban planning and architecture in Britain in the twentieth century” (Gough 2011). It occupies a 25

hectare site and comprises two theatres, a concert hall and other leisure and cultural amenities as well as 2056 residential units, which are spread across 21 buildings (Figure 1). There are over 100 different housing typologies, ranging from modest studios to spacious triplex penthouses, as well as a small number of terraced houses.

The estate has an active residents community, the Barbican Association (BA), who represent the interests of people living on the estate (BA 2011). Subcommittees include: planning, communication, security, access and environment, and ecology. The BA sustainability group (BASG) was established to develop strategies to reduce the Barbican's energy consumption (BASG 2010). The group works closely with the Barbican Estates Office (BEO), who looks after the overall facilities, maintenance and management of the residential parts of the Barbican.

The idea for the development was born in the 1950s, to fill a site left vacant by WWII bomb damage. The architects Chamberlin, Powell, and Bon were appointed to lead the project. Construction on the residential blocks took place between 1962 and 1973, and the Barbican Centre opened to the public in 1982 (Pevsner and Bradley 1997). The centre was conceived as a piece of modernist, utopian architecture, influenced by the architect Le Corbusier and designed to facilitate modern living, with clean lines and utilitarian spatial planning (Harwood 2011). At the time of construction concrete was a relatively new material that enabled the construction of taller buildings and a more open floor plate. Today, the estate has attained iconic status, epitomising the pervasive Brutalist style of the 1960s (Rugg 2012).

In 2002, the Barbican Centre was awarded Grade II listing. The listing includes the overall structural design, external doors and windows, landscaping and some original internal fixtures (COL 2005). This has significant implications for the extent of

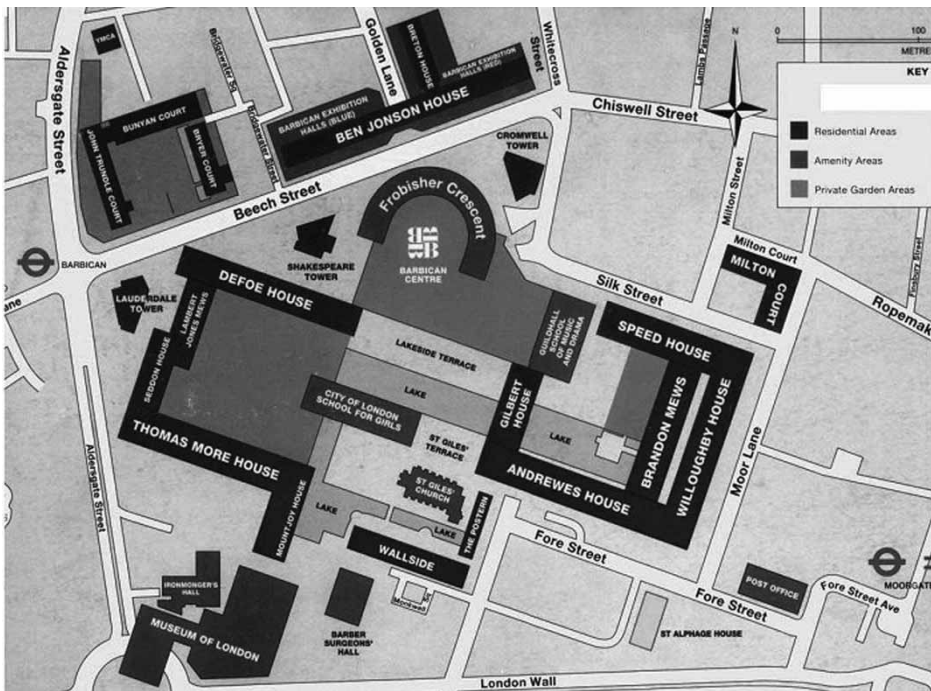


Figure 1. Site plan of Barbican Estate.

refurbishment work that can currently be carried out at the Barbican and ensures that Listed Building Consent is sought for any alterations to the building fabric.

### ***Building fabric***

The primary construction material used at the Barbican is concrete, formed from Pen Lee crushed granite (COL 2005). The scheme uses a mixture of reinforced, pre-stressed, and precast reinforced concrete. Most external walls, and some internal ones, are load bearing, and all are made from concrete. Floor levels are also constructed from concrete, with ceramic tiles used as a finish in communal areas. Internal spaces were designed to be carpeted although some residents report that carpet is increasingly being replaced with wooden or laminate flooring, allowing the transfer of sound between floors.

These solid concrete walls are uninsulated, rendering them effective transmitters of heat, and reflecting the cheap energy prices and less stringent environmental requirements of the 1960s. The only insulation in the scheme comprises a 38–50 mm layer of expanded polystyrene beneath the heating elements buried in the ground floor levels.

Blower door tests measuring airtightness at three flats in Shakespeare Tower are reported in Galeazzi (2010). The average value of  $6 \text{ m}^3/\text{h}/\text{m}^2$  is low ( $\sigma = 2.1$ ), even by today's standards where values up to  $10 \text{ m}^3/\text{h}/\text{m}^3$  are acceptable in new dwellings (HM Government 2010a). However, thermal bridges, which enable heat to flow through areas of effective heat transmission, are prevalent throughout (Figure 2). Much of the exterior façade comprises floor-to-ceiling timber-framed windows and doors, which allow daylight into the flats, as well as providing pleasant views to the residents. The majority of the windows and doors are single-glazed, allowing heat to escape from the flats. Table 1 presents estimated  $U$ -values for each of the thermal elements of the building envelope alongside acceptable values in homes built today (Table 1).

### ***Building services***

#### *Heating, cooling, and ventilation*

Underfloor heating is provided to all dwellings. A series of electric cables are embedded in the 50 mm screed layer that tops each floor plate (115 mm on ground floors). This is part of the original design, specified by the architects to “eliminate pipes, radiators, equipment, boilers and mechanical plant” (Barretts Solicitors 2012). Each dwelling has its own circuit (Figure 3). There are no switches or thermostats. Instead, the system is controlled

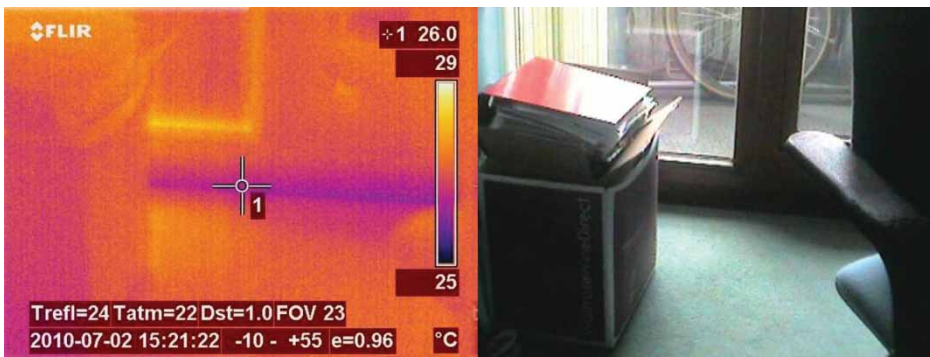


Figure 2. Photo and infrared image showing heat losses around sliding door.

Table 1. Estimated  $U$ -values of Barbican building envelope compared to current standards.

| $U$ -values of Barbican building envelope compared to current standards ( $W/m^2 K$ ) |          |                     |
|---|----------|---------------------|
| Building element  | Barbican | Current regulations |
| Walls   | 0.81–1.6 | 0.3                 |
| Floors and roof   | 0.9      | 0.2–0.25            |
| Windows   | 3.31     | 2                   |

Source: Galeazzi (2010).

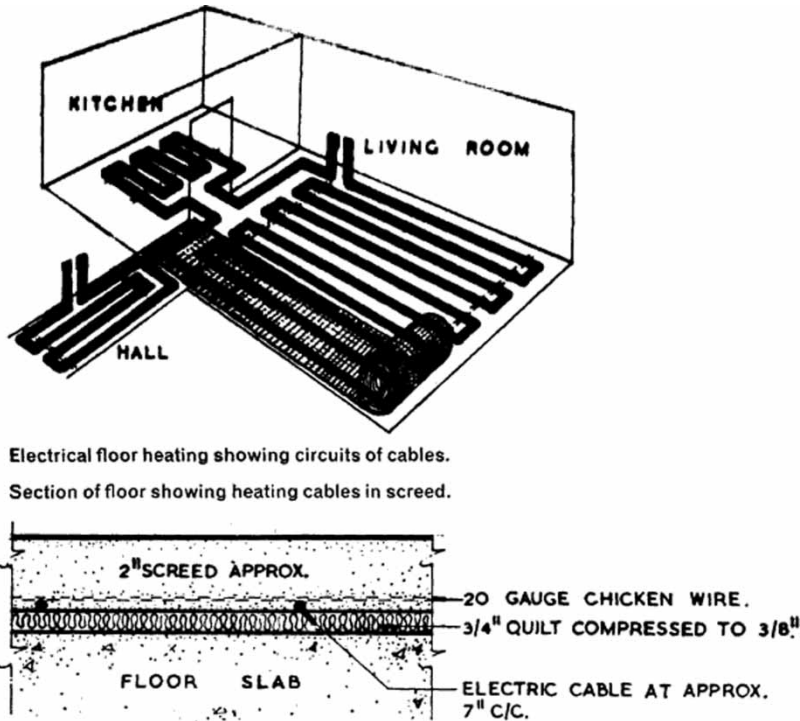


Figure 3. Barbican underfloor heating schematic.

using a timer, set to deliver heat at certain times. The heating season runs from approximately 1st October to 30th April, when a pre-set schedule determines whether the heating is on or off. The heating schedule is designed to use only off peak electricity, with two boost periods in the evening and early morning providing all the heat for the day. Occasional mid-day boosts are provided when external temperatures fall below  $9^{\circ}C$ .

The system was originally designed to maintain an internal background temperature of  $15.6^{\circ}C$ , to be supplemented by the residents as necessary, using freestanding heaters. In practice, many of the flats are heated to a much higher temperature and rarely require additional heating.

Residents have only limited control over the heating of their homes: It is possible to increase or decrease the amount of electrical charge entering each circuit by adjusting the "trimmer" switch associated with the flat. However, the trimmers are located in a locked cupboard in communal areas and are not accessible to residents, who must call

the maintenance engineer if they wish to adjust the trimmer settings for their flat. The engineer can also be asked to remove certain fuses, which has the effect of isolating parts of the circuit so that certain rooms are not heated. Another option the residents have is to use free-standing electric heaters or cooling units to regulate the internal temperature. Finally, they can open or close windows and external doors as a means of controlling temperatures and airflow. This last option has considerable repercussions in terms of energy consumption.

Each dwelling has a mechanical extract fan in the bathroom and kitchen areas. In addition, all windows and balcony doors incorporate a cord-operated ventilator system, with a small gap left permanently open. There was no provision for active cooling in the original design of the flats, although as discussed later, some of the current residents are using fans to cool their homes.

### *Metering*

Electrical appliance and lighting use is metred separately from the heating, with residents charged individually for their actual consumption. Residents also pay a quarterly service charge, which includes heating, maintenance, management, and any other expenditure. Heating charges are based on metred consumption per block normalised by floor area. Heating costs account for around 20% of the annual service charge.

## **Methodology**

### *A mixed method case study*

A mixed method approach was adopted at a case study residential site of architecturally significant buildings in Central London. A case study investigation is particularly appropriate when trying to understand complex social interactions, which may not be observed in a more controlled environment (Yin 2009). The data collected were both quantitative and qualitative, combining metred heating energy consumption with an occupant survey which provided space for qualitative comments alongside questions which required quantitative responses.

Average annual heating energy use was calculated per block, based on metred heating electricity consumption data, which were available for the period 2002/2002–2008/2009. A very strong positive correlation was noted between internal floor area and annual energy consumption per block ( $r^2 = 0.97$ ), suggesting that variations between the orientation, massing, and construction of individual blocks was not affecting heating energy performance, although detailed set point temperature data would be required to confirm this.

The survey comprised both pretested and purpose developed research instruments. This method of combining the statistically sound BUS questions with bespoke questions which may have been lacking in robustness but that were specifically tailored to the particular context of the case under investigation was found to be particularly fruitful. Indeed, this paper argues that his approach was instrumental for drawing out some of the most significant and interesting findings of the study. The different methods are described in more detail below.

### *Survey design*

The aim of the questionnaire was to characterise occupant satisfaction across the site, according to a number of environmental variables, which included thermal comfort,



light, noise, and indoor air quality as well as spatial considerations such as location, layout, and provision of storage. The BUS methodology was chosen as it is tested being both reliable and robust, as well as reducing the risk of question bias and nonresponse by frustrated residents. Another advantage of using BUS is that responses can be compared to benchmark data from other housing developments that have used the methodology (Gill *et al.* 2010). Using an existing questionnaire was a rapid and cost-effective strategy, compared to developing a completely new set of site specific questions.

Additional questions were included to attempt to quantify environmental behaviours at the site. This set of questions had been previously developed by Gill *et al.* (2010) to complement the BUS questionnaire. The reason for the addition of these questions was to compare the energy and resource use behaviours of Barbican residents with those at two low-energy UK housing developments. If Barbican behaviours were found to compare favourably it might indicate that residents were open to behavioural energy-saving interventions, an appealing prospect given the listed status of the buildings and the associated difficulty of making fabric alterations at the site.

The design of the final form of the questionnaire was an iterative process between the BASG, the BEO, and the research team where the residents' group was asked to provide feedback on the proposed questionnaire. Feedback took the form of both suggestions for changes to existing questions, and for the inclusion of additional questions relating to specific issues of concern. As a result of this consultation, several of the behavioural questions were altered and a few of the BUS questions removed, because they were not felt to be relevant to the Barbican case. Additional questions were added to cover satisfaction with local external air quality, the means adopted by residents to control internal temperatures and to gauge interest in the possibility of providing energy use monitors to individual dwellings.

Particularly relevant to this paper were the two questions relating to the strategies adopted by the residents to control the heating and cooling of their homes. Responses to these two questions led to arguably the most interesting findings of the study and the heating question formed the basis of the recommendation of an energy-saving behavioural intervention which was made to the BEO and BASG. The additional questions are reproduced below:

- How do you rate external air quality? (Likert response scale, where 1 = unsatisfactory and 7 = satisfactory).
- Do you have a medical condition which you believe is affected by poor air quality? (response options yes, no).
- Do you use any of the following to control your heating? (response options: trimmers, removing fuses, opening windows, ancillary heating, other).
- Do you use any of the following to control cooling? (response options: air conditioners, dehumidifiers, humidifiers, other).
- If possible, would you be interested in household electricity use monitoring? (response options yes, no).

### ***Survey administration and analysis***

During the first week of March 2011, one printed copy of the questionnaire was distributed to each of the 2056 dwellings at the Barbican, via the internal main system. Prior to their distribution, questionnaires were marked with a code relating to the block to which they would be delivered, so that comparisons could be made across the site. Respondents

were provided with a sealable envelope and asked to return completed questionnaires to either the porter (towers) or parking attendant (rest of site) at their block, who was responsible for passing them on to the BEO. A reminder poster was displayed at the entrance to each block by the BASG, who acted as gatekeepers to the residents.

Among these, 395 completed questionnaires were returned, which is equivalent to a response rate of 19.2%. Although fairly low, the investigative nature of the study, which was concerned with understanding a particular case rather than making generalisations about the wider population, enabled the use of statistical analysis methods with an acceptable degree of confidence.

Data obtained using the BUS questions were passed to the license holder for analysis and the behavioural questions were analysed by the individual researcher who had developed the survey. The additional questions were analysed by the author. A sub-analysis was also carried out to investigate differences across different parts of the site. The site was split into three areas. The first group comprised the low blocks to the north of the Beech Street tunnel; this acts as an effective barrier between the two parts of the site, separating the residential blocks from the main cultural and leisure amenities to the east of the tunnel. This group accounts for 27.9% of dwellings at the site and 23.9% of responses. The three towers formed the second sub-group, based on the premise that the dwelling in the towers is of similar construction, size, and layout. The towers account for 16.7% of dwellings at the site and 21.3% of responses. The third group included the remaining low blocks on the main site. This group accounts for 55.4% of dwellings at the site and 54.8% of responses.

## Results

This section presents the key findings of the study, according to the research method employed to gather the data. Observations drawn from triangulating data from the different components of the investigation will be examined towards the end of each section.

### *Heating energy use*

Average heating energy consumption across the blocks was found to be 194 kWh/m<sup>2</sup>/year over the period 2002/2003–2008/2009. This figure was calculated based on metered data from 18 of the blocks, as data for the remaining 3 were not available. There was some variation across the blocks, with values ranging from 147 to 253 kWh/m<sup>2</sup>/year ( $\sigma = 23.6$ ). As a comparison, a recently constructed dwelling built to comply with 2006 Building Regulation UK Building Regulations consumes around 100 kWh/m<sup>2</sup>/year for space heating, compared to 300 kWh/m<sup>2</sup>/year for dwellings built in the 1970s and 1980s and approximately 450 kWh/m<sup>2</sup>/year for dwellings dating from the 1960s (Jones 2012). Therefore, although the Barbican is underperforming compared to current new build standards it appears to be more efficient than other homes built at the same time and is probably performing better than the average UK home, where 60% of dwellings were constructed before 1960 (Palmer and Cooper 2011).

Data regarding electricity consumption for lighting, hot water, and appliance use were unavailable; therefore, it is not possible to make a meaningful comparison of whole dwelling energy consumption figures.

### *BUS questionnaire*

The results of the BUS questionnaire summary variables are presented in Table 2. The benchmark symbol relates to how well the average score at the site compares to the

Table 2. Summary data from BUS variables.

| Variable                       | $\mu$ | $\sigma$ | Benchmark | Scale                             |
|--------------------------------|-------|----------|-----------|-----------------------------------|
| Air in summer: overall         | 5.52  | 1.36     | ▲         | Unsatisfactory:satisfactory [1-7] |
| Air in winter: overall         | 5.26  | 1.54     | ●         | Unsatisfactory:satisfactory [1-7] |
| Comfort: overall               | 6.23  | 0.87     | ▲         | Unsatisfactory:satisfactory [1-7] |
| Design                         | 5.82  | 1.2      | ▲         | Unsatisfactory:satisfactory [1-7] |
| Health (perceived)             | 4.47  | 1.35     | ●         | Less healthy:more healthy [1-7]   |
| Lighting: overall              | 5.49  | 1.52     | ●         | Unsatisfactory:satisfactory [1-7] |
| Residents needs met            | 6.09  | 1.01     | ▲         | Very poorly:very well [1-7]       |
| Noise: overall                 | 5.23  | 1.76     | ▲         | Unsatisfactory:satisfactory [1-7] |
| Temperature in summer: overall | 5.42  | 1.52     | ▲         | Uncomfortable:comfortable [1-7]   |
| Temperature in winter: overall | 5.25  | 1.64     | ●         | Uncomfortable:comfortable [1-7]   |

average scores at the other sites which have been assessed using the BUS methodology. A triangle represents a score that is significantly better than the benchmark, a square represents a score that is significantly worse than the benchmark, and a circle represents a score that is within the benchmark critical limits. Overall the Barbican is performing very well in terms of resident comfort and satisfaction, with all the variables scoring within or above the benchmark critical limits.

The two key areas where residents expressed significant discomfort and dissatisfaction were thermal comfort and perceived personal control (Tables 3 and 4). The specific areas of concern relating to thermal comfort were dry air during summer and winter and variable internal temperatures during winter. The Barbican scored poorly in terms of the residents perceived ability to control the cooling, heating, and noise; however, the higher standard deviation for the cooling and noise control variables indicating some variation in opinion.

The sub-analyses indicate that although overall rates of satisfaction and comfort across the site are fairly consistent, there are two groups of variables where notable differences were observed between the towers and the lower blocks located to the north of the site. This difference was observed by looking at the benchmark comparison

Table 3. Thermal comfort BUS variables.

| Variable    | $\mu$ | $\sigma$ | Benchmark | Scale                           |
|-------------|-------|----------|-----------|---------------------------------|
| Summer      |       |          |           |                                 |
| Temperature | 3.64  | 0.96     | ●         | Too hot:too cold [1-7]          |
|             | 5.42  | 1.52     | ▲         | Uncomfortable:comfortable [1-7] |
| Air         | 4.22  | 1.68     | ▲         | Stable:varies [1-7]             |
|             | 3.09  | 1.34     | ■         | Dry:humid [1-7]                 |
|             | 3.21  | 1.38     | ▲         | Fresh:stuffy [1-7]              |
|             | 3.06  | 1.69     | ●         | Odourless:smelly [1-7]          |
|             | 3.16  | 1.47     | ●         | Still:draughty [1-7]            |
| Winter      |       |          |           |                                 |
| Temperature | 4.02  | 1.34     | ▲         | Too hot:too cold [1-7]          |
|             | 5.25  | 1.64     | ●         | Uncomfortable:comfortable [1-7] |
|             | 4.72  | 1.89     | ■         | Stable:varies [1-7]             |
| Air         | 2.58  | 1.36     | ■         | Dry:humid [1-7]                 |
|             | 3.56  | 1.44     | ●         | Fresh:stuffy [1-7]              |
|             | 3.22  | 1.74     | ●         | Odourless:smelly [1-7]          |
|             | 3.7   | 1.89     | ▲         | Still:draughty [1-7]            |

Table 4. Perceived personal control variables.

| Variable                 | $\mu$ | $\sigma$ | Benchmark | Scale                         |
|--------------------------|-------|----------|-----------|-------------------------------|
| Control over cooling     | 3.29  | 2.15     | ■         | No control:full control [1–7] |
| Control over heating     | 1.99  | 1.48     | ■         | No control:full control [1–7] |
| Control over lighting    | 5.69  | 2.43     | ▲         | No control:full control [1–7] |
| Control over noise       | 2.26  | 2.26     | ■         | No control:full control [1–7] |
| Control over ventilation | 4.67  | 2.13     | •         | No control:full control [1–7] |

Table 5. Differences in satisfaction with space, storage provision, and perceived air movement between the sub-groups.

| Towers |          | North of Beech Street |          | <i>t</i> -Test<br><i>p</i> -Value |
|--------|----------|-----------------------|----------|-----------------------------------|
| $\mu$  | $\sigma$ | $\mu$                 | $\Sigma$ |                                   |
| 4.03   | 1.71     | 3.61                  | 1.93     | 0.07                              |
| 6.14   | 1.33     | 4.88                  | 1.83     | 0.000003                          |
| 4.57   | 1.68     | 3.54                  | 1.88     | 0.0003                            |
| 6.28   | 0.95     | 5.67                  | 1.03     | 0.0002                            |

indicator for each of the variables and noting where differences occurred between the three sub-areas of the site. Student's *t*-test was then used to check for statistically significant differences in the scores. During the summer, the air quality was felt to be significantly more draughty by residents living in the towers, than by residents in the lower buildings on the site, who were more likely to perceive it as stable ( $p = 0.07$ ). Second, residents in the towers appear to be more satisfied with the amount of space and storage they have in their homes, as well as with the way their needs are met at the property ( $p = 0.000003$ ,  $p = 0.0003$ ,  $0.0002$ ) (Table 5).

### Behavioural questionnaire

Overall behaviour scores appear to be high, with the majority of respondents scoring towards the higher end of the scale. However, as only two other studies have been carried out to-date using this survey, it is hard to assess what constitutes a “good” score. The results of one of the other studies, carried out at a new build low-energy residential tower in the south of the UK, were used for comparison. The scores relating to electricity use behaviours were found to be comparable across the two sites. On the other hand, heating energy consumption scores varied widely between the sites (Figure 4). This is probably because of changes made to the questions to make them relevant to the Barbican context. Changes included the addition of the question “I know how to change the hot water thermostat and to reduce heating through trimmers or removal of fuses” and the removal of two questions relating to whether residents used the radiator valves to regulate temperatures and whether residents believed switching off heating for periods when the dwelling was unoccupied saved energy. These questions were felt to be irrelevant to the Barbican residents as they do not have radiators and are not able to switch off the heating even if they wish to do so. As a result of these modifications, there was one less question in this part of the questionnaire, creating a significant bias to the results. Consequently, it is not surprising that scores are on average lower at the Barbican and it is not possible to make meaningful comparisons between the heating scores of the two cases.

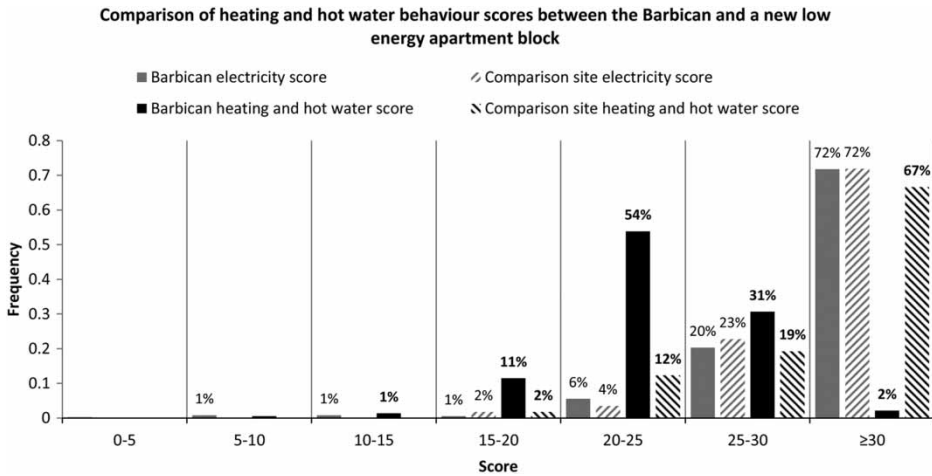


Figure 4. Comparison of heating/hot water and electricity behaviour scores between Barbican and new low-energy housing.

The heating behaviour scores were plotted against the needs, comfort, and design scores obtained using the BUS methodology to see if there was any correlation between residents' satisfaction with their homes and their perceived behaviour. No significant correlation was found between any of these variables ( $R^2 = 0.137, 0.007, \text{ and } 0.129$ ).

The result of the additional question about trimmers and fuses revealed that less than half of respondents (40%) felt that they knew how to change the hot water thermostat and to reduce heating through trimmers or removal of fuses. Although it is not clear to which part of the question (thermostat, trimmers, or fuse removal) the answers referred, the result does suggest a lack of awareness among residents of the different control strategies available to them.

### *Additional questions*

Additional questions were included in the questionnaire, after consultation with resident representatives. These questions related to how the residents perceive air quality, whether they were interested in receiving energy monitors, and what strategies they were using to control internal temperatures, given the centrally controlled nature of their heating system. Their inclusion relied on the BASG insider knowledge of issues which concerned the Barbican residents and covered topics that would not have been raised if only the standardised questionnaires had been administered. However, as will be evident from the results presented below, the analysis of these questions led to some of the most interesting insights of the study.

### *Metering, local air quality, and health*

Fifty per cent of the sample population answered that they would be interested in household energy use monitoring. This was felt by the BASG to be a positive finding which they have since used to present an argument to the BEO in favour of providing meters to residents who requested for them.

Perception of external air quality is poor, with over half (53%) of respondents answering on the "unsatisfactory" side of the scale. Furthermore, 8% of the sample population (or 10%

of those who answered the question) believe that they suffer from a medical condition that is affected by poor air quality. As around 4000 people live at the Barbican, as many as 300–400 people at the site could be adversely affected by poor local air quality.

#### *Thermal comfort and temperature control*

Seventy-three per cent of responses refer to using windows and ancillary heaters to control the heating, while only 24% mention adjusting the trimmers or removing fuses (Figure 5). These percentages refer to the proportion of the total responses for that particular strategy; as the question asked respondents to “mark all that apply” these percentages cannot be interpreted as the proportion of residents choosing these control strategies, but rather as a percentage of all heating or cooling temperature control strategies. In terms of cooling control, nine flats (10% of replies) use air-conditioners and 3.3% use dehumidifiers. Humidifiers are being used in 24% of cases, a finding that supports the dry air issues that the BUS survey identified (Figure 6).

The majority of responses relating to strategies for staying cool were in the “other” category. By looking at the responses written beside these answers it appears that the most popular cooling strategies are the use of doors and windows (41%), and active cooling using fans (41%) (Figure 7). Interestingly, residents do not seem to be making much use of the vents, which are apparently present in all doors and windows, to regulate thermal comfort.

These findings are interesting in terms of heating and cooling energy consumption as several of the strategies employed by the Barbican residents to regulate thermal comfort require the “active” use of electricity to function. These include ancillary heating devices, air-conditioners, dehumidifiers, and fans. Furthermore, other measures, although apparently “passive”, may also have some impact on final energy consumption. For example, opening the windows while the heating is on will undoubtedly waste heat energy. On the other hand, using windows during the summer to passively cool spaces, and adjusting the blinds and curtains to limit solar gains and reduce overheating, may be

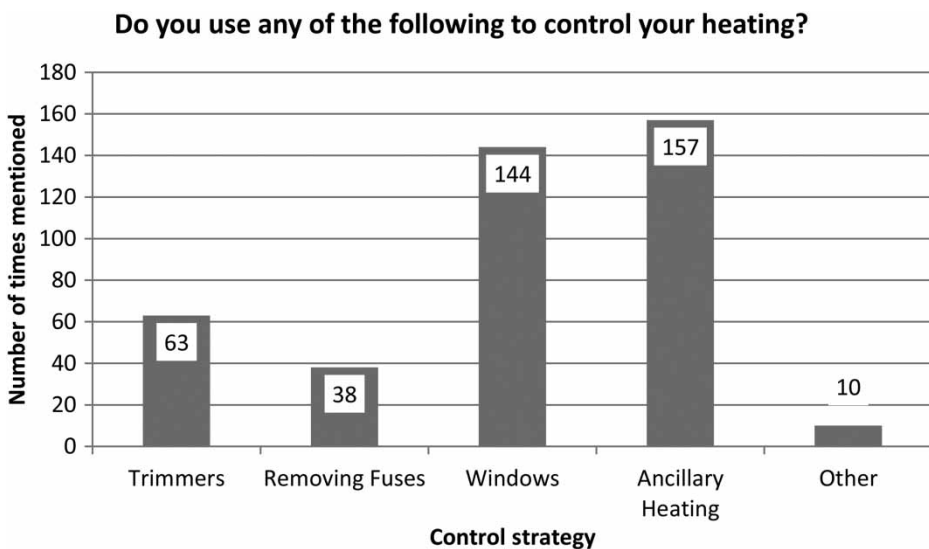


Figure 5. Temperature “heating” strategies.

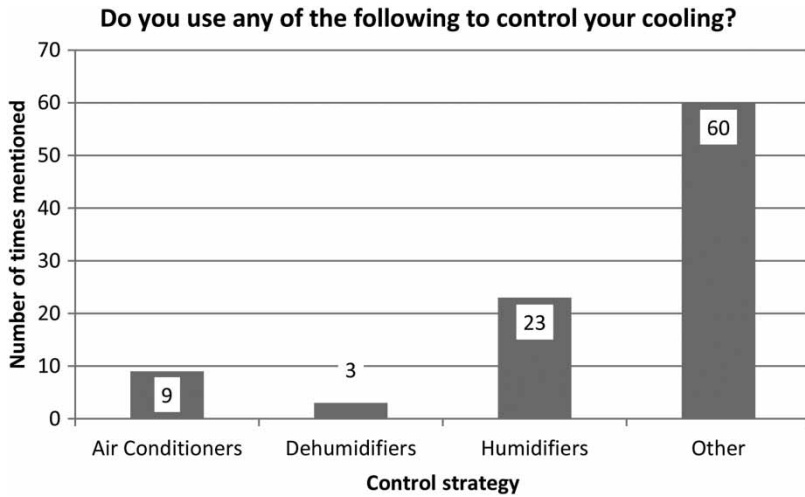


Figure 6. Temperature “cooling” strategies.

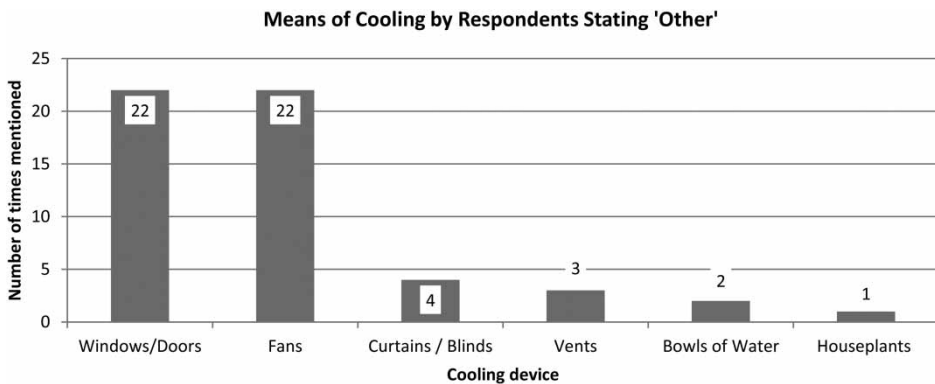


Figure 7. Means of controlling temperature (cooling) by respondents stating “other”.

employed by residents instead of using fans and air-conditioners, which will effectively conserve energy.

Eighty-nine per cent of residents who answered this question use windows to control the heating; given the energy implications of opening windows during the winter, this is an alarming result. Of the people who stated that they had used the trimmer to regulate internal temperature, a slightly lower figure of 81% of respondents also stated that they use windows to control heating. Although this difference of 8% appears small, with a population of over 2000, it was considered important enough to use statistical methods to test for significance. A two-way  $\chi^2$  test was carried out to test for significance (Table 6). The resulting  $p$ -value of 0.036 represents a 3.6% chance that the deviation from the expected value is due to chance only. Consequently, we can state with some confidence that people who use trimmers *are* less likely to open windows in winter. This is an important finding as it hints at the potential of behaviour change to be used a strategy to complement more conventional energy-saving measures.

Table 6. Contingency table showing observed and expected frequencies for trimmer and window use  $\chi^2$  test.

|                     | Count    | Use windows | Do not use windows | Total |
|---------------------|----------|-------------|--------------------|-------|
| Use trimmers        | Observed | 51          | 12                 | 63    |
|                     | Expected | 55.79       | 7.21               | 63    |
| Do not use trimmers | Observed | 251         | 27                 | 278   |
|                     | Expected | 246.21      | 31.79              | 278   |
| Total               | Observed | 302         | 39                 | 341   |
|                     | Expected | 302         | 39                 | 341   |

Table 7. No significant difference in comfort between people who use trimmers to control heating and people who use other heating strategies.

|                           | Use trimmers |          | Do not use trimmers |          | <i>t</i> -Test<br><i>p</i> -Value |
|---------------------------|--------------|----------|---------------------|----------|-----------------------------------|
|                           | $\mu$        | $\sigma$ | $\mu$               | $\sigma$ |                                   |
| Winter temperature rating | 5.38         | 1.48     | 5.17                | 1.61     | 0.37                              |
| Winter overall conditions | 5.41         | 1.48     | 5.25                | 1.53     | 0.46                              |
| Overall comfort           | 6.23         | 1.48     | 6.24                | 1.53     | 0.92                              |

A *t*-test was carried out to investigate whether there were any differences in perceived comfort variables relating to winter temperature, winter overall conditions, and overall conditions (year-round), between the residents who stated that they were using the trimmers to control the heating, and the rest of the respondents. Although average winter comfort scores were slightly higher in the group who use trimmers, this difference was not found to be statistically significant (Table 7). This is a reassuring finding as it implies that if residents were somehow encouraged to use the trimmers more and discouraged from opening windows to maintain comfortable temperatures during winter we would not see a reduction in comfort levels, which currently compare favourably to benchmarks.

A *t*-test was also carried out to see if there was a difference in summertime thermal comfort between the groups who use passive measures such as windows and blinds to stay cool, and those people who use active strategies such as fans and air-conditioning. The results indicate that summertime conditions were perceived slightly more positively by those residents who use passive strategies to regulate thermal comfort (Table 8).

Table 8. Test for significant difference in summer comfort perception between those who use A/C and/or fans for cooling and those who use other strategies.

|                           | Use A/C or fans |          | Do not use A/C or fans |          | <i>t</i> -Test<br><i>p</i> -Value |
|---------------------------|-----------------|----------|------------------------|----------|-----------------------------------|
|                           | $\mu$           | $\sigma$ | $\mu$                  | $\sigma$ |                                   |
| Summer temperature rating | 4.69            | 1.51     | 5.56                   | 1.61     | 0.01                              |
| Summer overall conditions | 4.97            | 1.22     | 5.53                   | 1.40     | 0.05                              |
| Needs                     | 5.81            | 1.17     | 6.23                   | 0.76     | 0.08                              |
| Overall comfort           | 6.03            | 0.96     | 6.19                   | 0.99     | 0.45                              |



Table 9. Test for significant difference in comfort perception between people who use windows and/or doors to control cooling and people who use other strategies.

|                           | Use windows |          | Do not use windows |          | <i>t</i> -Test<br><i>p</i> -Value |
|---------------------------|-------------|----------|--------------------|----------|-----------------------------------|
|                           | $\mu$       | $\sigma$ | $\mu$              | $\sigma$ |                                   |
| Summer temperature rating | 5.92        | 1.30     | 4.92               | 1.69     | 0.0014                            |
| Summer overall conditions | 5.86        | 1.05     | 5.06               | 1.45     | 0.0021                            |
| Needs                     | 6.16        | 0.90     | 6.06               | 1.08     | 0.62                              |
| Overall comfort           | 6.11        | 1.02     | 6.16               | 0.96     | 0.82                              |

Furthermore, people who use windows, which are a passive strategy, to control conditions during summer appear to be more satisfied with conditions than those who do not use windows (Table 9).

It is not possible to explain the reason for these differences with any degree of certainty; however, one possible explanation might be that people resort to active measures only once passive ones have failed, and are therefore automatically less satisfied that their preferred method did not work. On the other hand, it might simply be the case that using active systems in this case provided unsatisfactory comfort conditions. Overall, the results suggest that using windows may be equally effective as active measures in maintaining summertime thermal comfort, a strategy which could lead to energy savings if adopted across the site.

## Discussion

### *Recommended intervention to improve thermal comfort and conserve heating energy*

The high reported overall comfort and satisfaction scores are a positive finding of the study. However, the Barbican performs poorly in terms of thermal comfort and perceived control. Specific concerns with thermal comfort are year-round dry air and variable temperatures during winter. Heating control was the lowest scoring variable and is illustrative of the archaic heating system which does not allow occupant interaction. Furthermore, the behavioural survey revealed that most residents do not know how to change the hot water thermostat and turn down the heating using the trimmers and fuses. Perhaps, it is unsurprising then, that 89% of residents are using windows as an alternative form of heating control.

Based on these findings, a recommendation was made to the BASG and the BEO to implement a trimmer adjustment intervention to encourage residents to adopt alternative measures than window opening to regulate internal temperatures. The justification for this proposal was that if the number of people using the window to regulate thermal comfort during winter could be reduced by even as little as 8% across the whole estate, then considerable energy savings could be made at very little cost.

Furthermore, the fact that less than half the surveyed residents felt confident about adjusting the hot water thermostat or asking for help with turning down the trimmers and removing fuses, suggests that one reason that people may use windows may be due to a lack of awareness of the other options. Although this statement is based on conjecture, rather than proven results, the BASG was able to use these findings to persuade the BEO to undertake a pilot study in one of the blocks, whereby residents were made aware of the alternative options for heating control and encouraged to contact the maintenance engineer if they were experiencing temperature-related discomfort in their homes.

It may also have been possible to deduce that this behaviour was taking place based on the exceptionally low perceived heating control score (20th percentile) combined with a number of the written comments. However, obtaining data that could be analysed to reveal a statistically significant result was a useful tool for persuading the BEO that winter-time window opening was a serious problem worthy of their attention.

### *The effectiveness of BUS and methodological limitations*

POE, and in particular the BUS methodology, should not be viewed as substitutes for robust social science as POE is an industry tool rather than an academic research instrument and the BUS methodology is a licenced product administered by an engineering consultancy. Furthermore, the main focus of BUS is to compile a large dataset from multiple case studies, in order to create benchmarks for new homes; consequently, changing the wording of the questions or modifying the survey protocol may invalidate the benchmark data.

In this project, POE was used as a diagnostic tool to develop energy-saving solutions at a case study site, rather than to incorporate feedback from one project into future learning. As Becker (1989) observes, this higher level of POE is expensive and hard to carry out. Reality is complex and there is an inevitable trade-off between rapidly collecting data, and taking the time to investigate what questions need to be addressed at the research design stage, to generate high quality and meaningful data. The BUS methodology is relatively quick and inexpensive, and benefits from a good reputation based on many years of testing and refinement and is therefore useful for collecting reasonably reliable answers at relatively low cost. On the other hand, respondents were asked to answer many questions which were not particularly relevant to their situation which may have caused them some frustration.

Arguably the most important finding of this piece of research was the relationship between the (perceived and actual) lack of heating control and winter window opening behaviour. This was only discovered as a result of the additional questions developed in close collaboration with the BASG and will hopefully lead to real life energy savings. Including bespoke questions that are tailored to the particular site may enable researchers to explore issues that have been previously identified as of concern to residents, which may encourage a higher response rate and, as in the case of the research presented in this paper, may lead to more meaningful findings and subsequent actions. This process comes at the cost of validity, as the time constraints of the project meant that the questions were not tested or piloted before their deployment. For example, the question about cooling control omitted critical response categories, a risk of using questions that have not been piloted.

The Barbican POE project succeeded in establishing baseline resident satisfaction, as well as identifying several problem areas where there was a high level of dissatisfaction. The use of a quantitative survey methodology that enables the results to be compared to benchmark data is an effective way of adding meaning to a case study project, so that the findings can be situated in the wider context.

Overall this project was successful in that it combined standardised questions with more specific questions to generate a result that will hopefully lead to some real life energy savings. However, parts of the questionnaire, for example, the behavioural survey proved to be less informative, despite the fact that it had been carefully developed and tested at prior to its use in this study. Several of the questions asked did not lead to meaningful findings. The large amount of questions (131 in total) may have increased response fatigue and deterred some residents from taking part. A higher response rate would have enabled more confident interpretation of the results.

## Conclusions

This paper presents an analysis of research conducted at a case study housing development to explore how resident feedback has been used to identify energy-saving strategies at a site where, due to the buildings' architectural and historic value, conventional fabric interventions may not be appropriate and are likely to be prohibitively expensive.

Overall satisfaction and comfort were found to be high. Notable findings of the study were the widespread dissatisfaction with the limited heating controls and the high incidence of an energy intensive behavioural practice: wintertime window opening.

The use of BUS with additional bespoke questions was instrumental in revealing this result, suggesting that this particular combination of methods may have application in other cases, particularly for some of our historic and hard-to-treat building stock. However, as with all case study research, it is difficult to make far reaching generalisations based on findings at one site. Every site is unique and each of the research methods used here do have their applications for obtaining occupant feedback and contributing to the improved performance of our housing, but, like all research findings, they must be interpreted with care.

## Acknowledgements

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## Notes

1. Since 2003, the RIBA has reintroduced the concept of buildings in-use to the Outline Plan of Works (RIBA 2008), and a complete overhaul of the framework is planned for 2013. At time of writing, architects *are* responsible for reviewing in use performance; however, in practice the design and construction team are still rarely involved beyond practical completion (Way and Bordass 2005).
2. A definition of SBS is a set of "common symptoms associated with the occupation of predominantly sealed office buildings" (Burge 2004, p. 185).

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