Post Occupancy Evaluation of social housing designed and built to Code for Sustainable Homes Levels 3, 4 and 5

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Abstract

In the housing sector, carbon emissions arise primarily through the consumption of energy to heat, light and ventilate our homes. Significant improvements in UK housing energy performance have been driven both by changes in legislation, and by the introduction of the Code for Sustainable Homes in 2007. Compliance with certain levels of this Code has been adopted as policy by Local and Regional Authorities, and social housing providers. The evaluation of the performance of low carbon housing requires the assessment of increasingly complex building services technology, and occupant behaviour. This added services complexity, and the expectation that tenants understand how to use it, has led to a number of unintended consequences which have resulted in a higher risk of performance failure. This study comprises the detailed evaluation of seven new social housing dwellings, designed and built to Code levels 3, 4 and 5, including comprehensive environmental monitoring, measurements of the consumption and generation of resources, and social surveys of the occupants. The results show that as the Code levels increase there is a reducing energy and water consumption rate, and an increasing energy generation rate, but only at the expense of a significantly increased risk of services system failure.

Keywords

Code for Sustainable Homes, social housing, carbon emissions, sustainability, building performance evaluation

1. Introduction

The threat of climate change is now globally recognised, with human activity being the primary cause of elevated greenhouse gas emissions [1]. The latest published statistics from the UK Government show that in the UK over 50% of carbon dioxide emissions come from buildings and around 25% from dwellings [2]. In the domestic sector, these emissions arise primarily through the consumption of energy to heat, light and ventilate our homes and there has been a significant improvement in energy performance requirements in the UK, driven by progressive changes in the Building Regulations since 1965. Carbon emissions are considered in detail within Approved Document Part L of the Building Regulations [3] which requires heat gains and losses to be limited, and accounts for the efficiency of the building services systems. The current proposals for changes in Part L of the Building Regulations will require all new dwellings in the UK to be net zero carbon in 2016.

Building Regulations in the UK control mandatory standards of compliance for all new buildings. However, in many sectors of the market there has long been a drive towards raising the performance of dwellings beyond the basic compliance level of the regulations to higher levels of environmental performance, driven by a number of domestic and non-domestic environmental assessment methods and Codes. In the residential market in the UK this began as the EcoHomes rating system, which was launched in 2000, and soon became a mandatory standard, at certain rating levels, for social housing. The Ecohomes standard was phased out and subsequently replaced by the Code for Sustainable Homes [4]. The Code has undergone various changes since it was first introduced and was described at the time as 'a step change in sustainable home building practice'. The most recent version of the Code was published in November 2010 [5] and in early 2014 the UK Government confirmed that the Code would be abolished and rules on energy efficiency would be incorporated into the Building Regulations.

Since the 1990's there has been a significant rise in the number of building environmental assessment schemes across the globe. Some of these schemes are mandatory, required by legislation, and some go beyond mandatory legislative requirements, are discretionary and represent good practice in the development of an increasingly sustainable built environment. There is significant variation in the methodology adopted by different schemes, some being generic, and some designed for specific building typologies. Some of the generic schemes, which have originated in one country, have been adapted and adopted in other countries and have a global reach, LEED and BREEAM being two systems that are widely adopted outside of America and the UK respectively. The NHBC Foundation [6] has published comprehensive information relating to relevant codes that are being adopted in the housing sector for 20 countries across the world. The most widely adopted systems include the Leadership in Energy and Environmental Design (LEED) green building certification system, which includes a rating system for homes, adopted in America; the Green Star rating system, launched by the Green Building Council in Australia; the National Energy Code for Houses (NECH) and the National Energy Code for Buildings, which has provisions for housing, in Canada; the Regional Energy

Efficiency Codes for Residential Buildings and the Evaluation Standard for Green Building (ESGB) in China, and the Comprehensive Assessment System for Built Environment Efficiency (CASBEE) which includes a rating system for homes. In the European context, the establishment of the Energy Performance of Buildings Directive (EPBD) in 2002, and the subsequent update in 2012, requires member states to ensure reductions in energy consumption and carbon emissions as well as introduce building energy certification schemes [7]. Systems adopted across Europe, in the housing sector include the PassivHaus standard, developed in Germany, but also adopted by other countries including Austria and Denmark; the Haute Qualité Environnementale (HQE) in France; and the MINERGIE standard in Switzerland which has two relevant versions, MINERGIE-P for ultra-low energy buildings, and MINERGIE-Eco which also includes broader environmental considerations.

The Code for Sustainable Homes (CfSH), like many of the environmental assessment methodologies developed by the Building Research Establishment (BRE), assesses the sustainability of a building under a number of broad categories and awards credits under each. Different categories have different overall weightings and for some there are mandatory minimum requirements. There are six levels of compliance from level 1 which exceeds the basic requirements of the Building Regulations, up to level 6 which represents a zero carbon dwelling. The Energy and CO_2 Emissions category is the most significant in the current Code, representing 36.4% of the total credits available.

Compliance with certain levels of the Code have been adopted as policy by some Local and Regional Authorities as part of their Planning and Sustainability strategic plans, and, where funding for social housing is provided by the Homes & Communities Agency (HCA) there has been a minimum requirement of compliance with Level 4 of the Code.

Previous studies have shown that low carbon housing requires the use of more complex technologies, that occupant behaviour has a significant effect on performance of the building and that most low carbon schemes have been carried out by, and for, enthusiasts and experts [8]. Other studies have shown that as we have increased the environmental standards, housing is no longer one of the least complex building types [9] and that the added services complexity has led to a number of unintended consequences which have occurred directly as a result of the drive towards lower carbon buildings [10]. In a study monitoring the performance of two new low energy dwellings in the UK, it was found that the performance of these dwellings relies heavily, not only on the as-built quality of the envelope but also on the correct installation and functioning of the building services [11]. The same study, which focused on social housing, highlighted that achieving high levels of performance was partly due to problems in the construction process which required significant vigilance and scrutiny from the design team. The impact of occupant behaviour on energy consumption cannot be underestimated. It has been reported that there can be significant variations in gas consumption rates in identical homes with different occupants [12]. In a study of 25 dwellings, evaluating energy and water performance in affordable housing in the UK, it was found that water consumption varied by a factor of more than seven, and energy by a factor of more than three, in similar design and specification buildings [13]. Similarly, it has been reported that usability of services system control interfaces in low carbon housing also plays a significant role in building user behaviour and that clear design and labelling, and guidance and handover procedures for heating and ventilation systems is necessary [14].

Social housing providers, as landlords, are expected to provide a level of support to tenants in terms of commissioning, maintaining and dealing with service system failure if it occurs, but this can be problematic if the tenants do not understand how to properly operate the systems, or are unable to recognise when they are not working properly. There is also the issue of who has the responsibility for dealing with service system problems when they occur, particularly in newly built dwellings; whether it is the landlord or the installation contractor. Findings from a previous study [9] showed that housing occupants are often treated as Facility Managers, and are expected to operate their homes with limited support, training and clear guidance. The same study demonstrated the need for a formal induction for new tenants in order that they can inhabit and interact with their building properly. It also revealed uncontrollable and excessive heating, unbalanced Mechanical Ventilation with Heat Recovery (MVHR) airflow, the breakdown of the solar thermal system which was then not replaced, and, electrical meters connected to photovoltaic (PV) systems which failed to show when energy was being consumed in the dwelling and when it was being exported to the grid.

A key element of this study was to test whether higher levels of the CfSH led to reducing levels of resource consumption. At the same time the study tested whether higher levels of the Code were only achieved at the expense of an increased risk of breakdown and failure of the services systems that were installed to achieve this higher level of carbon efficiency in the first place. Given that many of these systems are designed to operate as an integrated part of a whole house strategy, when failure occurs in even one, it can be detrimental to the fundamental environmental strategy and can have more serious consequences than not installing the complex technology in the first place. A study commissioned by the Joseph Rowntree Foundation, assessed the performance of an exemplar low carbon housing scheme, and concluded that not only should services focus on whole system performance, but also that improvements are required in their commissioning, testing and monitoring to ensure effectiveness [15].

Very little consideration is given to the design life of service systems installed in low carbon homes, their initial commissioning and balancing, their controls, the appropriateness of the operation and maintenance manuals relative to the occupants and their knowledge and needs, the maintenance regime required to maintain operational efficiency, proactive rather than reactive responses to breakdown, and sensible replacement strategies for different elements of the overall environmental systems in dwellings.

2. Methodology

This study set out to evaluate the performance of a number of new domestic dwellings, in the social housing sector, designed and built to levels 3, 4 and 5 of the Code for Sustainable Homes. Comprehensive environmental, energy and water consumption data was collected in seven dwellings over a full year.

The dwellings were designed and constructed to comply with varying levels of the Code, with one dwelling being certified to level 3, 2 dwellings to level 4 and four dwellings to level 5.

The CfSH requirements for carbon emission predictions require that all of the dwellings tested were designed to perform beyond the Building Regulations current at the time. As such they incorporate a number of low energy fabric and building services systems. The dwellings are all highly insulated, airtight and incorporate a wide range of innovative technologies including PV systems, grey water recycling, mini Combined Heat & Power (CHP), high efficiency boilers with flue savers, MVHR and intelligent controls.

The dwellings were monitored during the period 15th March 2013 to 14th March 2014 and during this period dataloggers were used to collect hourly readings of temperature and relative humidity in four locations in each dwelling: the living room, kitchen, bedroom and outside. Data was collected using a combination of HOBO H8 and LASCAR EL-USB-2 dataloggers, which are shown in Figure 1. HOBO H8 dataloggers have an accuracy of ±0.7°C at 21.0°C and ±5.0% RH. LASCAR EL-USB-2 dataloggers have an accuracy of ±0.5°C at 21.0°C and ±3.0% RH. In addition to this, during regular visits to each dwelling for the collection of data, gas, electricity and water consumption readings were taken, where possible, together with data from renewable energy generating systems installed at each location. Social surveys were also carried out at the start of the project, where the occupants were interviewed in order to assess how they use their homes. The basic specifications of the seven dwellings in this study are shown in Table 1.

Figure 1: HOBO H8 and LASCAR EL-USB-2 dataloggers

Ref:	39OB	138NG / 139NG	94SR / 96SR	249MR / 249aMR
Unit	3B6P	3B6P	3B6P	3B5P
GFA	113	99	95	100
CSH	3	4	5	5
Fabric	Traditional masonry construction; double glazing	Traditional masonry construction' 150mm filled cavities; double glazing, extra thick for sound insulation	Insulated timber frame, ventilated cavity, masonry outer leaf, occupied insulated timber roof; double glazing	Insulated timber frame, ventilated cavity, cementitious cladding board, occupied insulated timber roof; triple glazing
MEP	High efficiency gas boiler, extract fans to wet rooms, trickle vents, 1.38 kWp PV system roof mounted	High efficiency gas boiler, intelligent controls, extract fans to wet rooms, trickle vents, 3.24 kWp PV system roof mounted	Baxi Megaflow gas boiler, Titon MVHR system, Ecoplay micro grey water system, 4.085 kWp PV system roof mounted	Baxi Ecogen mini CHP (249) Baxi Megaflow (249a) gas boiler, Titon MVHR system, Ecoplay micro grey water system, 3.6 / 3.84 kWp PV system roof mounted

Table 1: Dwelling specifications

Figure 2: The dwellings, clockwise from top left, 39OB (Code level 3); 138NG / 139NG (Code level 4); 94SR/ 96SR (Code level 5); 249MR / 249aMR (Code level 5)

To ensure anonymity, the dwellings are given simple reference numbers and these are used throughout this paper. The table shows the basic dwelling unit configuration in terms of number of bedrooms and occupants, the floor area and the CfSH level. It also describes the fabric and building servicing strategy for each dwelling giving details of the technology installed into each home. Figure 2 shows the four dwelling types tested in this study.

3. Results and evaluation

3.1. Social Surveys

The monitoring of environmental conditions inside and outside, and the measurement of resource consumption and production in each dwelling, commenced in March 2013. During the first visits to each home the occupants were met and introduced to the aims and objectives of the project. During these meetings, structured interviews took place, with the main householder, in order to evaluate how they used their home. Table 2, shown in Appendix A, shows the information that was collected in each home during these interviews.

The social survey data collected indicated a number of broad findings:

- Occupants were generally comfortable in their homes although about half of them stated that they felt too hot occasionally, particularly in the upper floors.
- The occupants stated that they understood how the heating system worked but, in fact, they rarely used automatic controls, opting for manual control most of the time.
- Where MVHR systems were installed, occupants did not understand how to properly use or maintain them.
- Use of electrical systems was very variable, with some occupants very conscious of consumption and others not.
- The performance of water recycling systems was variable with about half working throughout the monitoring period and half not.
- The occupants were generally ignorant about the benefits of the PV generation systems installed in the dwellings, how they operated and how to recognise malfunctions.

The information collected during the social surveys is critical in understanding how the occupants perceive their home environment and how they understand the various services systems installed. As highlighted previously, housing occupants are often expected to operate their homes with limited support, training and clear guidance.

The surveys show that the occupants are generally comfortable in their homes although one occupant complained that there was significant stratification of temperatures with the ground floor being perceived as cold and upper levels as hot. All of the tenants stated that they understood how to use the heating system even though the majority of tenants did not use the programmers, thermostats and radiator TRVs to control the heating, but manually switched heating on and off as and when they felt it was needed. It is clear that the heating control systems were not being used as they were designed to be used. There was significant variation in the responses to whether the homes felt too hot, with about half the occupants saying they did, and half saying they did not. Generally, the occupants were satisfied with their heating and satisfied therefore with the way that they manually controlled it. Most of the occupants said they controlled temperatures in different zones separately. All of the occupants said they understood how the hot water system worked, and used automatic control for this, with some overriding this when extra hot water was required.

The ventilation strategy in the Code level 3 and 4 dwellings was natural ventilation with extract ventilation provided to wet room areas. The occupants in these dwellings opened windows when they needed fresh air and also generally used the adjustable trickle vents when required. The Code level 5 dwellings all had whole house MVHR systems which were designed to operate continuously. The evidence collected during the survey demonstrated that none of the occupants fully understood how the systems worked, how they were set up, and how they were maintained. One of the tenants sometimes turned the MVHR off because of cold air supply and noise issues. Another wasn't aware that it was operating all the time and used the boost function occasionally when fresh air was required. None of the occupants knew how to use and maintain the MVHR system properly, and were unaware of the impact of opening windows on the system, something that they all stated they had to do when necessary.

In terms of electricity use, all of the occupants knew that they had low energy lighting. About half of the occupants left electrical items on standby and half switched everything off when not in use. Similarly, about half the occupants used tumble driers and those that didn't occasionally dried clothes indoors.

In terms of water consumption, most occupants preferred the use of showers rather than baths. The majority of occupants did not know whether their appliances were designed for low water use, with only one occupant using a dishwasher. The Code level 3 and 4 homes did not have any water recycling features, apart from a water butt in the garden in one home. The Code level 5 homes all had Ecoplay grey-water recycling and when the survey was carried out one system was reported as having problems that required regular maintenance work, another had been so problematic that it had never worked properly and was bypassed by directly connecting the mains water supply to the toilets. The other two systems were reported to be working well.

The occupants were asked whether they considered what they pay for energy as reasonable. In two of the dwellings the occupants said they felt the energy costs were reasonable. In all of the other dwellings the occupants felt that the energy costs were high. One of the tenants was unsure about the benefits they were getting from the solar PV system installed on the roof and this was queried with the landlord. It transpired that because these systems were installed using a grant from the HCA and GLA, during periods when electricity is being generated, the electricity is primarily used to supply appliances in the dwelling. Any electricity generated above this instantaneous demand is automatically exported back into the National Grid. The occupants were unaware of this and might have changed their behaviour, for example by programming washing machine and dishwasher use in the middle of the day, if they had known. Another of the occupants had a very high energy bill, £840 for 6 months, but this was the same occupant who had complained about the boiler not working throughout this period and it appeared that all hot water was being provided by electrical immersion heating which is likely to be one of the reasons why.

3.2. Monitored environmental conditions

Hourly temperature and relative humidity data was collected in all dwellings at four locations: the living room, kitchen, bedroom and outside. This generated a significant number of collected data points which have been downloaded, cleaned where necessary, and used to assess various trends in environmental conditions, energy consumption and energy generation.

Figure 3 shows the average monthly monitored conditions for all dwellings, internally and externally, superimposed onto a psychrometric chart.

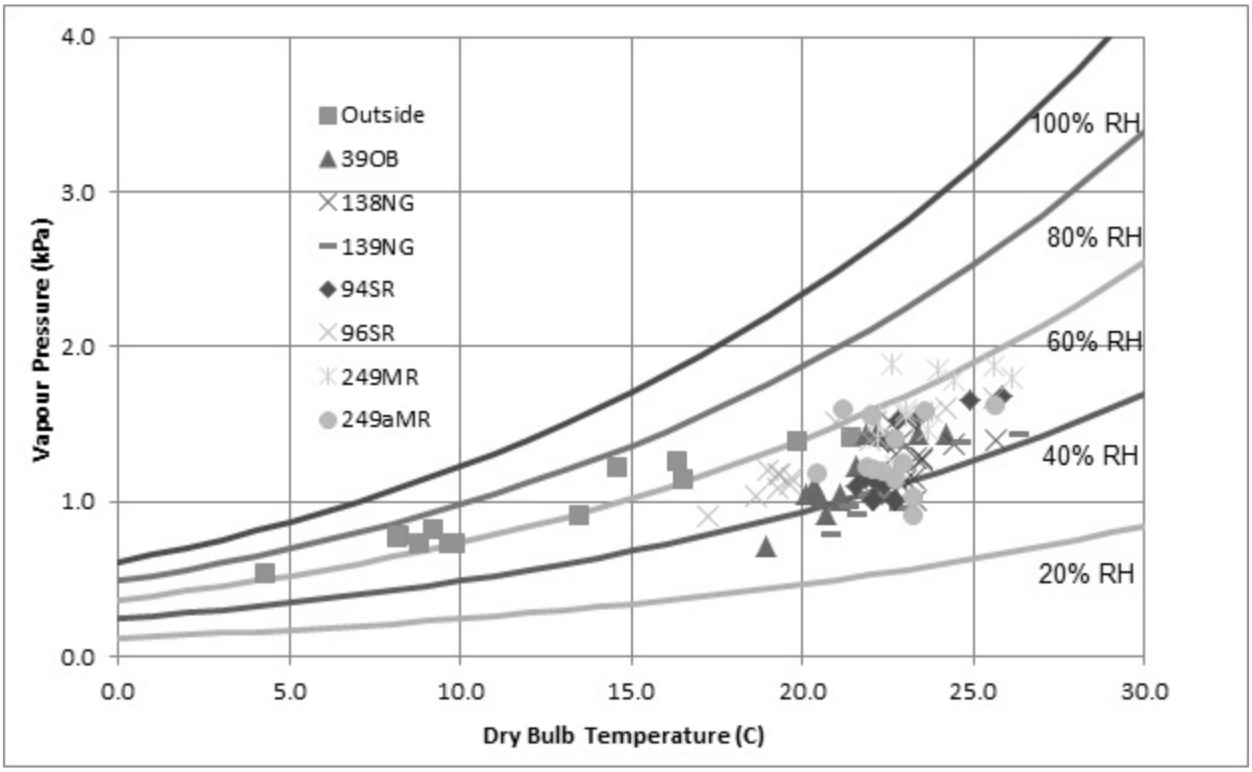

Figure 3: average monthly monitored conditions for all dwellings, internally and externally

The data shows a relatively wide range of average external temperatures measured during the period, between approximately 4°C and 22°C. A significantly reduced range of temperatures were measured inside the dwellings, most of the data within the range of 20°C and 25°C. It is evident that the dwellings were heated to different levels of comfort, dwelling 96SR having seven months when the average internal temperatures were less than 20°C, and dwelling 249MR where the average monthly temperatures never fell below 22°C and for two months the average temperatures were above 25°C. Similar variations have been reported in published literature [8] which questions the assumption of a comfort temperature of 21°C in domestic dwellings in the UK. Comprehensive monitoring studies have shown that there are a significant number of UK dwellings where the occupants set demand temperatures much higher than this [16].

In general, the monthly average levels of external relative humidity are consistent, ranging between 60% and 80%, and corresponding internal relative humidity levels are less than this, as would be expected as the temperature rises, typically between 40% and 60%. The monthly averages of internal relative humidity indicate that levels were not sufficiently high in any of the dwellings for there to be a significant moisture related risk to the health of the occupants, for example from mould growth, which occurs when the airspace relative humidity exceeds 70% for extended periods [17].

Figure 4 shows the annual average temperatures in the living room, kitchen and bedroom for each of the seven dwellings.

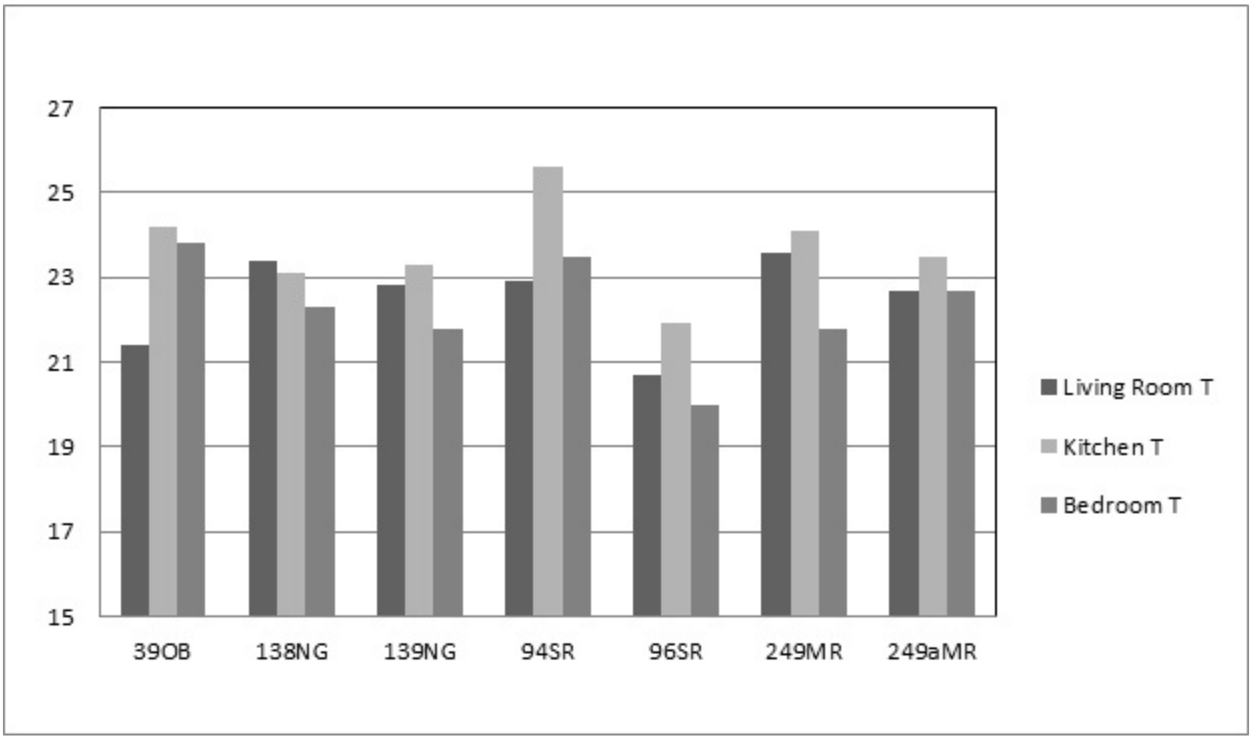

Figure 4: Annual average temperatures in Living Room, Kitchen and Bedroom

The data shows, again, that the average temperatures in all dwellings were relatively high with the living room average of 22.7°C, the kitchen average of 23.5°C and bedroom average of 22.7°C across all dwellings. In six of the seven dwellings monitored the kitchen temperatures were higher than the living room temperatures.

The hourly readings for all dataloggers have also been converted to daily averages and Figure 5 shows the daily averages of temperature and relative humidity for a typical dwelling (139NG) and includes the externally measured conditions at that location.

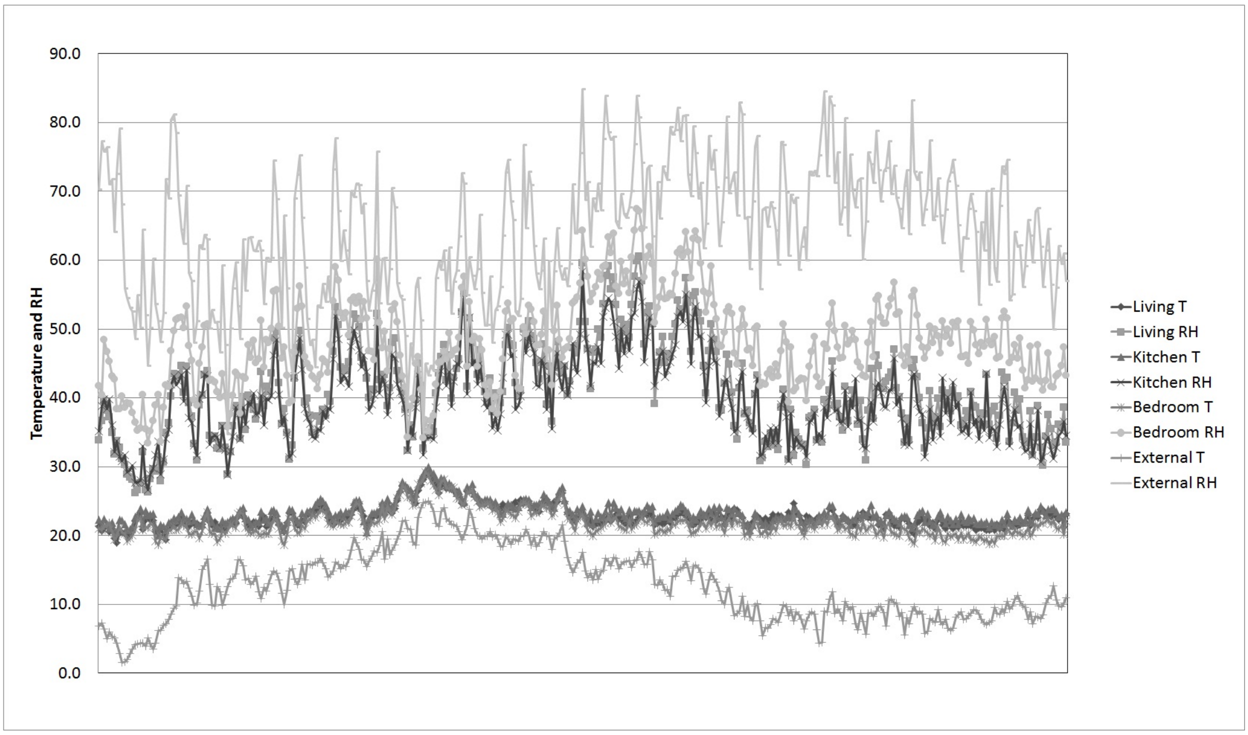

Figure 5: Daily averages of temperature and relative humidity for a typical dwelling

The data in Figure 5 shows the seasonal and daily variability of the data collected. As expected, the lines at the top and bottom of the chart represent the external conditions of relative humidity and temperature respectively. The humidity tends to be the lowest and the temperature the highest in the summer period where space heating systems are unlikely to have been used at all. In this particular dwelling the relative humidity levels in the bedroom are the highest and generally about 10% above the relative humidity measured in other spaces in the house. This suggests that the ventilation in this space was not as high as in other spaces.

The daily average data has also been converted to monthly averages and Figure 6 shows the monthly averages for the same typical dwelling (139NG) including the externally measured conditions at that location.

Similar trends can be identified in the monthly average data to those for the daily average data. In this dwelling the temperatures measured in all spaces were very consistent, but there is an elevated level of relative humidity in the monitored bedroom. This level of relative humidity is not considered to be a problem and would not lead to any significant health risks for the occupants.

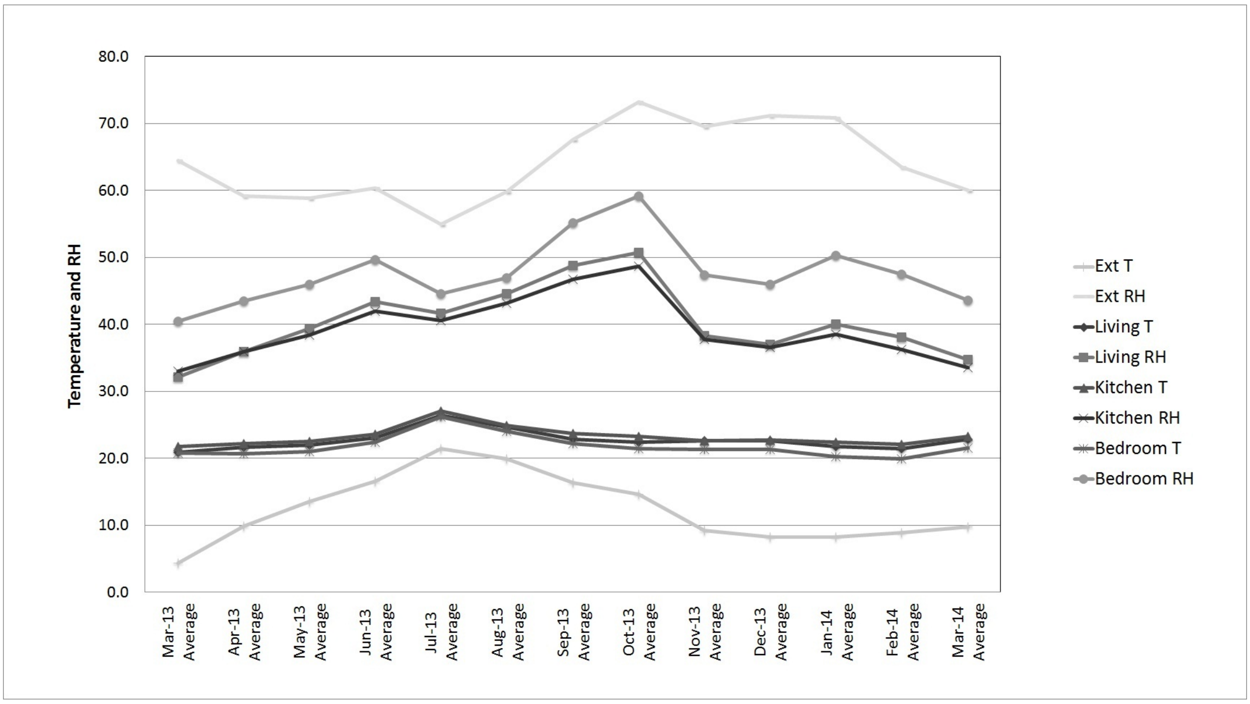

Figure 6: Monthly internal and external Temperature and Relative Humidity for a typical dwelling

Figure 7 shows the monthly averages of temperature and relative humidity measured in each of the seven dwellings by room type.

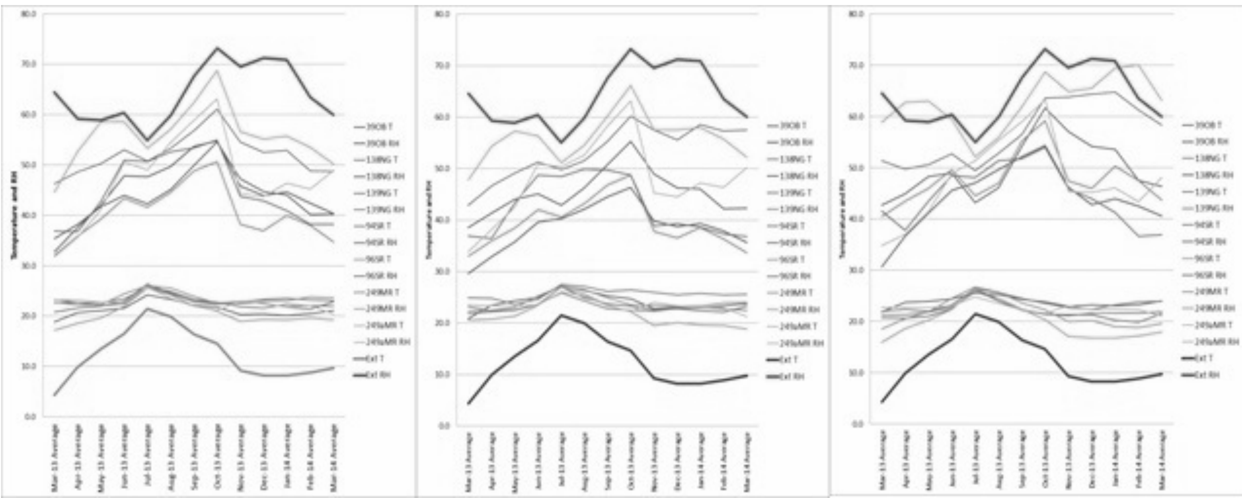

Figure 7: Monthly averages of temperature and relative humidity in all dwellings by room type; left to right, Living Room, Kitchen, Bedroom

The data shows that in all seven dwellings, the results show a strong consistency in the measured conditions of temperature but a far wider range of data for the measured levels of relative humidity. Further analysis shows that the highest levels of relative humidity, measured in all three room types, belong to the same dwellings (reference 249MR and 249aMR). This suggests that it is not just the room type that determines the elevated levels but the occupancy behaviour. These two dwellings have consistently elevated relative humidity levels and the occupant surveys show that the dwellings are both occupied by families with pre-school children and occupancy is high during the day and night.

3.3. Measured energy consumption, energy generation and water consumption

During the year that the dwellings were monitored, each site was visited every two months to collect data from the loggers and to check that all the monitoring equipment was working properly. At each visit to each property readings of the electricity, gas and water meters were made (where possible), together with readings of the electrical generation meter for the PV systems installed in each dwelling, and the mini CHP system installed in one.

Table 3, shown in Appendix B, shows all of the data collected during the year for electricity, gas and water consumption and solar PV generation.

3.3.1. Electricity

The amount of electricity consumed in each dwelling for each of the six two month periods, and the total of the electricity consumed in the year, is shown in Table 3. The electricity consumption data is likely to have been influenced by the electrical generating (PV) systems in varying degrees depending upon the level of appliance use during electrical generation periods, and this is likely to have been significantly influenced by occupancy patterns through the typical day.

The highest level of consumption (138NG) was found in one of the Code Level 4 dwellings, occupied by two adults and three children, where one parent and pre-school child where generally at home day and night. The lowest level of consumption (96SR) was found in one of the Code Level 5 dwellings, occupied by two adults and two children for part of the year (one of the adults passed away during the period of monitoring). The results show that there are large differences in the consumption of electricity in similar specification dwellings and this highlights the fact that occupancy patterns and behaviour have a significant impact on energy consumption. At two of the sites, where one of the dwellings was an end-terrace and one was a mid-terrace (138NG/139NG and 94SR/96SR) the consumption of electricity in each of the homes was significantly different, although this factor alone is unlikely to have had an impact as significant as the measured data suggests.

Figure 8 shows the electricity consumption data graphically for all seven dwellings together with a bar chart showing the average electricity consumption by Code level. The charts demonstrate clearly how the measured consumption of electricity across the dwellings was variable and sporadic.

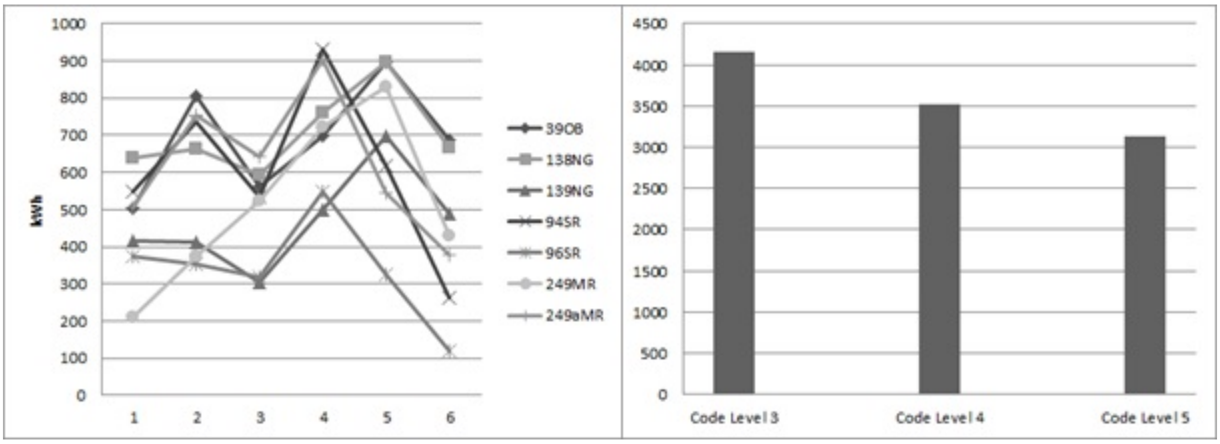

Figure 8: Electricity consumption for all dwellings with a bar chart showing the average electricity consumption by Code level

The results indicate that whilst there is variability in the consumption of electricity across all seven dwellings, and given the limitations of only seven dwelling samples, there appears to be a downward trend in consumption of electricity with increasing levels of the Code.

3.3.2. Gas meter readings

The amount of gas consumed in each dwelling for each of the six two month periods, and the total of the gas consumed in the year, is shown in Table 3.

Gas consumption is also variable across all of the dwellings, with the highest consumption found in the Code Level 3 dwelling (39OB) and the lowest consumption found in one of the Code level 5 dwellings (96SR). Similar variations in gas consumption between dwellings at the same site are, again, quite clear from the measured data in the table. It is interesting to note that at one site (138NG/139NG), one of the dwellings consumes a lot more gas but a lot less electricity than the other a vice versa. Again, there is no obvious explanation for this, except that the occupant behaviour in each dwelling has a significant impact on how energy is consumed. It appears that one is primarily a gas consumer and the other tenant is primarily an electricity consumer. This is an issue that warrants further investigation in future similar projects.

Figure 9 shows the gas consumption data graphically for all seven dwellings together with a bar chart showing the average gas consumption by Code level.

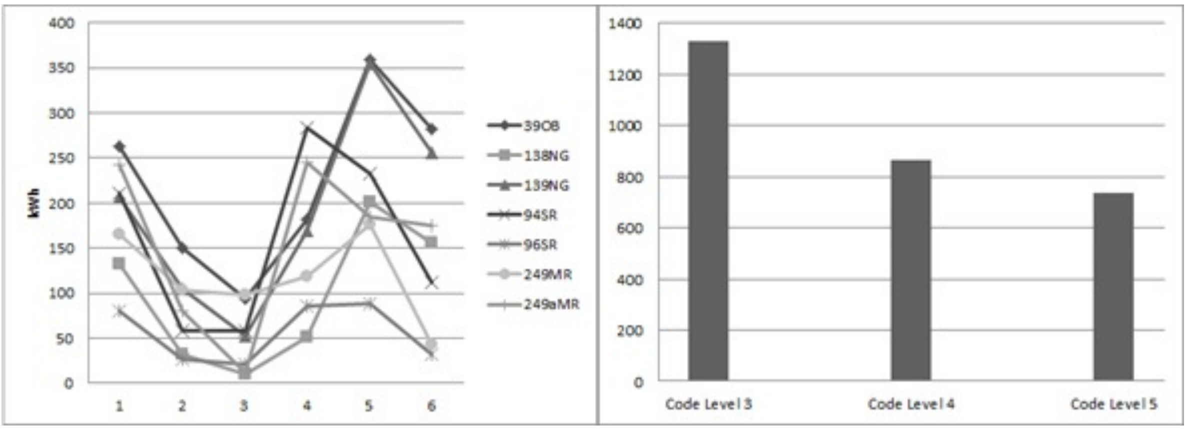

Figure 9: Gas consumption for all seven dwellings with a bar chart showing the average gas consumption by Code level

The gas consumption chart shows how gas consumption varies throughout the year. Given that the primary need for gas in these dwellings is space heating, it is not surprising that the level of consumption is at a minimum across all seven dwellings during the period July to September, and a maximum during the period November to January. It is interesting to note that for two of the Code level 5 dwellings (94SR and 249aMR) the gas consumption during period 4 (September to November) is significantly higher than other dwellings for this period in the year, and the reason for this is unknown. During the following period 5 (November to January) the gas consumption in the same two dwellings drops to a position that would be expected.

The results indicate, again, that whilst there is variability in the consumption of gas across all seven dwellings, there is a downward trend in consumption of gas with increasing levels of the Code. The variability in gas consumption for each of the dwellings is primarily related to the variability in the behaviour of the occupants. The Code level 3 dwelling (39OB) has the highest gas consumption figures for all of the seven dwellings. The average Code level 4 dwelling gas consumption is lower but of the two dwellings in this category, one consumed 583 kWh (138NG) and the other 1147 kWh (139NG); a two-fold difference.

3.3.3. Water meter readings

The amount of water consumed in each dwelling for each of the six two month periods, and the total of the water consumed in the year, is shown in Table 3. Unfortunately, we were unable to take any water meter readings at one of the sites (94SR/96SR) due to a lack of access to the meters in the pavement outside each dwelling. The water meter covers were fixed down and required a special tool to open them. Despite reporting these difficulties, we were unable to resolve this issue and so water consumption in these two dwellings is unknown.

Water consumption is variable across all of the dwellings, with the highest consumption found in the Code Level 3 dwelling (dwelling 39OB) and the lowest consumption found in one of the Code level 4 dwellings (139NG).

Figure 10 shows the water consumption data graphically for the five dwellings where water meter readings were possible, together with a bar chart showing the average water consumption by Code level.

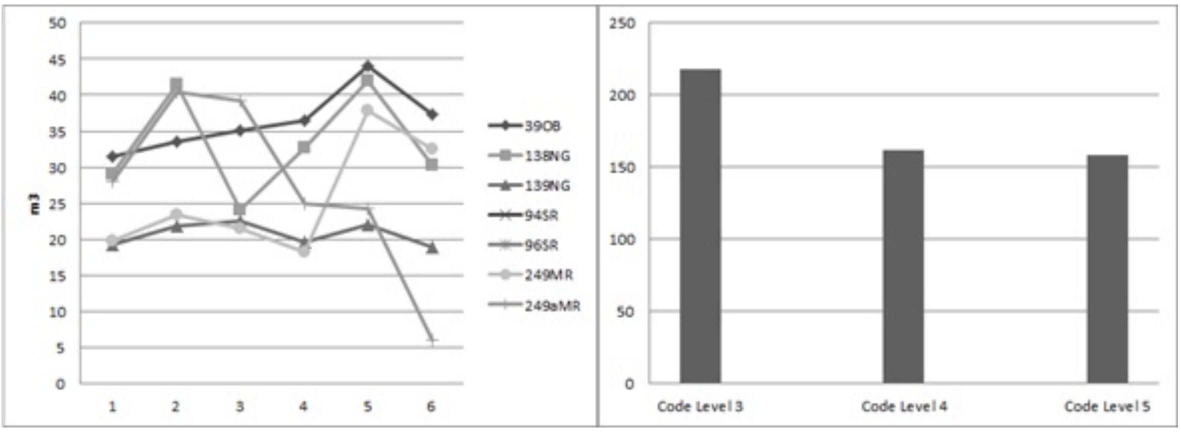

Figure 10: Water consumption for five dwellings with a bar chart showing the average water consumption by Code level

It is usually assumed that each person in a dwelling consumes 150 litres of water per day. This equates to approximately 55 m^3 of water consumed per person in a year. Given that in dwelling reference 39OB there are four occupants, and limited water saving features, the actual consumption figure of 218 m^3 measured over the year is about what would be expected. Measured water consumption in Dwellings reference 138NG and 139NG (Code level 4) are below the level expected given the levels of occupancy. The Code Level 5 dwellings, 94SR, 96SR, 249MR and 249aMR all incorporate EcoPlay grey water systems which should reduce the water consumption figures, but as mentioned earlier, we were unable to collect meter readings from dwelling references 94SR and 96SR, and, given the reduced number of data samples, it is difficult to establish any clear connection between the grey water recycling systems and water consumption figures. This will, in part, also be due to the faults reported with the EcoPlay systems during the year.

The results indicate, once again, that whilst there is variability in the consumption of water across all seven dwellings, and during the year, there is a downward trend in consumption of water with increasing levels of the Code.

3.3.4. PV generation

All seven dwellings have roof mounted photovoltaic (PV) systems, of various size and specification installed. These were funded by grants from the HCA and GLA and as a result, do not take advantage of the Government’s Feed-In-Tariff initiative. During periods when electricity is being generated, the electricity is used to supply appliances in the dwelling. Any electricity generated above this instantaneous demand is automatically exported back into the National Grid. Electrical generation readings (kWh) were taken at each dwelling at the start and end of the project and at approximately two month intervals in between and these are summarised in Table 3.

The shaded cells in the table represent periods during the year when the PV systems were faulty and not generating any energy. This caused concern, particularly in one dwelling (96SR) where, despite reporting the problems on a number of occasions, the PV system did not operate at all for the whole year of the monitoring period. For another scheme, both dwellings had problems with their PV generation at different times of the year, with one of these dwellings (249MR) having a PV system operating properly for only four months in the monitoring period.

Figure 11 shows the PV generation data graphically for the four dwellings where electricity generation was continuous during the monitoring period, together with a bar chart showing the average PV generation by Code level.

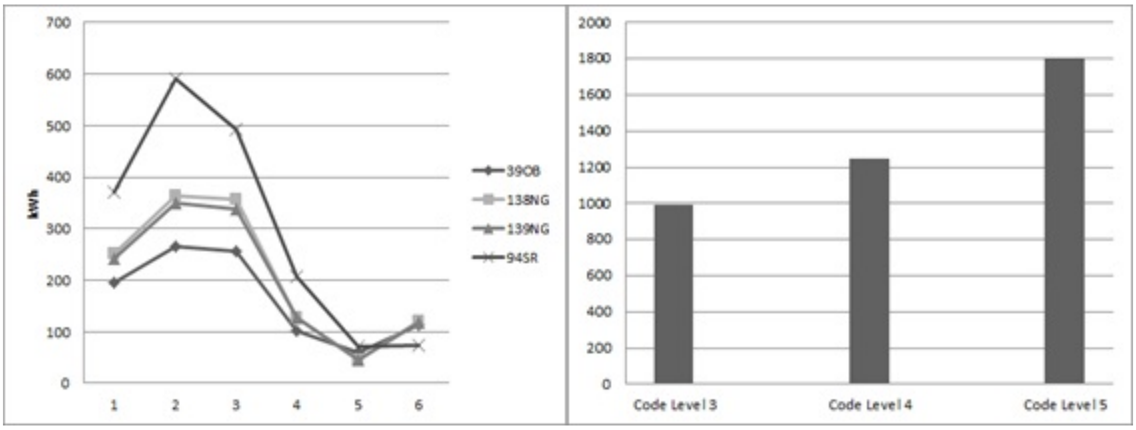

Figure 11: PV generation for four dwellings with a bar chart showing the average PV generation by Code level

The results clearly show the variation in electricity generation during the year, with all of the four PV systems showing a significant increase in the summer period and a reduction in the winter as would be expected at this latitude. The data also shows how each installation performs, relative to one another. The PV installation at 39OB is a 1.38 kW_p system and generates the least of all the systems tested. The PV systems at 138NG and 139NG are larger, at 3.24 kW_p, and have both generated similar levels of electricity, more than 39OB. The PV system installed at 94SR is larger still, at 4.085 kW_p, and this is also clearly generating more than all of the other systems.

The results clearly demonstrate, not surprisingly, that across the four dwellings where a full annual set of data was collected, there is an increasing level of electricity generation from PV installations with increasing levels of the Code. It is the Code that drives carbon emission reductions and in the domestic market PV installations are seen as one of the most obvious ways that carbon emissions can be offset. Given that PV generation is relatively inefficient, when compared to Solar Hot Water (SHW) panels, this is counter intuitive. However, SHW technology has its own risks associated with plumbing and potential leakage which is often a significant consideration in system selection. Consequently, as the measured data shows, as the Code levels get higher, the PV installation outputs (kW_p) get larger and consequently the energy generated increases.

3.4.5. Mini CHP generation

One of the dwellings (249MR) has a Baxi Ecogen Mini CHP boiler system installed, which generated electrical energy in addition to the PV installation on the roof (which worked intermittently). The heating system uses a gas fired Stirling engine to generate up to 1.0 kW of electrical energy when the boiler is being operated to produce space or water heating. The electrical generation of this system was monitored throughout the year and although it produced electricity for most of the year, it too stopped working during the last two months of the monitoring period. During the first ten months of the monitoring period the boiler generated an average of 57kWh per month. This is considerably less than the energy being generated for the PV panels in these dwellings, which equated to an average of approximately 150 kW per month.

Figure 12 shows the data collected for the Baxi Ecogen system at 249MR, and as the data shows, the electrical generation system broke down and was not working for the last two months of the project (mid January to mid March).

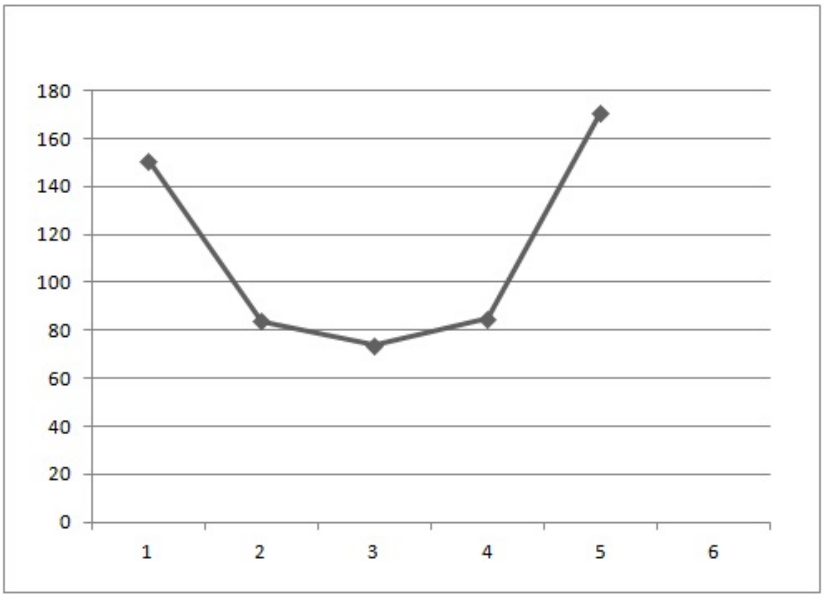

Figure 12: Energy generation for the Baxi Ecogen system at 249MR (not working for the last period of the project (6), mid-January to mid-March).

4. Services system failure and unexpected consequences

This project originally set out to monitor the performance of nine domestic dwellings, for a period of a complete year. From the start of the project we were unable to engage at all with one of these residents and so we were unable to collect any data. In addition, we had considerable difficulties in keeping in touch with another resident and so the monitoring in this dwelling was similarly abandoned.

The dwellings were provided by the Social Landlord as representative of a range of new dwellings complying with varying levels of the Code for Sustainable Homes. Dwellings designed to achieve these levels of the Code require innovative technical building services systems installed in order to reduce carbon emissions to the levels required.

When additional technology becomes a necessity, it results in an additional level of complexity and an additional risk of services system failure. This is particularly true in rented accommodation where the occupants have less interest in the dwelling fabric and building services and rely on the landlord to deal with problems that arise. In this project we encountered a number of significant problems with the technical systems employed in the buildings, which in many cases, although reported to the landlord, were not repaired during the period of the study. In all cases, the landlord's Development Manager responded promptly to the problems raised, but they were constrained by third party contractors who installed the original services systems, commissioned them or were involved in some way with repair and maintenance.

In many cases, when services system failure occurred, the tenants consulted their Operation & Maintenance manual but these were not sufficiently user friendly, even to an experienced building scientist, and so it raises the question of whether they serve any real useful purpose, to those that occupy the dwellings, in this context.

During the year we encountered a significant number of problems with the services systems installed in these dwellings and these were more challenging as the installed technology became more complex, as the dwellings required higher levels of the Code. Given the very limited number of dwellings evaluated in this study, and the fact that all of the dwellings were relatively newly constructed, the following account of the problems encountered is of considerable concern.

We were unable to access the water meters to one of the schemes, due to the lack of appropriate tools to access the meters. Forcing open the meter covers was not considered appropriate and despite reporting this at every visit, the covers were not changed in order to provide easy access.

All of the Code level 5 dwellings had MVHR systems installed and traditional extract fans and trickle vents were installed in the Code level 3 and 4 dwellings. No complaints about ventilation were made by tenants in the dwellings without MVHR but a number of complaints were made relating to the MVHR systems and their operation. Early in the monitoring period one tenant (96SR) complained about living room supply being cold and another questioned whether the ventilation was working in the kitchen as condensation occurred when cooking. At a later stage one tenant (96SR) was concerned about a musty and damp smell in the downstairs bathroom, and later still the same tenant complained about the kitchen extract not working properly and elevated moisture levels. Towards the end of the monitoring period another tenant (94SR) also complained generally about the supply and extract rates of the MVHR system and stated that they were much more obvious when they first moved in. This questions whether the MVHR system was being maintained properly and whether filters were being regularly cleaned or replaced.

When we first visited the properties at one of the schemes, neither of the PV installations had generated any electricity since they were installed. This was reported to the landlord and by the second visit, one of the systems (94SR) was working properly. In the other property (96SR), despite regularly reporting that the PV systems were not generating any electricity, it was not operational until the last two months of this project. It appears that this was an on-going problem involving the original contractor and a question of who was responsible for some damage to some of the panels. At another scheme we identified a problem with one of the dwellings (249aMR) in that it generated only a fraction of what it should have during the first two months and nothing during the following two months. This was reported and the problem was sorted out for the rest of the monitoring period. In the other dwelling (249MR) the PV system worked fine for the first four months and then stopped working for the rest of the monitoring period.

Generally the heating systems worked properly throughout the monitoring period. However, one tenant (249aMR) complained at the start of the project that she had been paying excessively high energy bills (£800+ in 6 months) and couldn't understand why. It is possible that this was due to her main heating system not working properly for a long period of time and, as a result, she was using the immersion heater to heat water, for a significant period. When this was discussed with the tenant, she had no idea that using electricity for heating her water was considerably more expensive than using the gas boiler.

The water recycling units installed in the Code level 5 dwellings were problematic throughout the monitoring period. At the start of the project it was reported in one dwellings (249MR) that the system had never worked properly and so it was disconnected and water to the toilet was supplied directly from the mains from the start of the project. In the adjoining property (249aMR) it was reported that the recycling system was working well. At another scheme one of the tenants (94SR) reported some issues with the recycling system and claimed that they sometimes had to fill a bath with hot water and empty it into the EcoPlay system in order to get it to work. The other tenant (96SR) reported smells coming from the unit in September 2013. At our visit to this scheme in February 2014, one of the recycling systems (94SR) was reported to have been leaking, and when repaired the system was not turned back on again, and the other tenant (96SR) reported that the system had stopped working properly, with the alarm intermittently sounding followed by automatic flushing several times in a row. At the end of the project it was reported that, still, neither of the EcoPlay systems were working properly.

The micro-CHP system installed in one of the dwellings (249MR) worked as a space and water heating boiler throughout the monitoring period. However, during the last two month period, the electrical energy generating component of this unit stopped working.

5. Conclusions and discussion

This study set out to evaluate the performance of a number of new domestic dwellings, designed and built to levels 3, 4 and 5 of the Code for Sustainable Homes. Comprehensive environmental, energy and water consumption data was collected in seven dwellings over a full year. The results of the analysis of this collected data show a number of key findings which are summarised below.

The environmental conditions in all of the dwellings were within normal and predicted ranges and no dwelling had measured conditions that were likely to be unhealthy for the dwelling occupants. The measured conditions of temperature and relative humidity showed some variation across the dwellings indicating that occupancy behaviour is significant in determining the comfort conditions and the subsequent use of energy and water. Given the relatively small number of dwellings monitored, these variations have to be taken into account when looking at general trends in the data. The results suggest that a larger sample of dwellings should be monitored over a similar period of time in order to increase confidence in the findings and to establish clear low and zero-carbon strategies for design, construction and occupancy factors affecting social housing.

Given the limited number of dwellings monitored, and the variation in occupant behaviour, the consumption of electricity, gas and water was consistent, on average, with the Code level of the dwellings. The measured results showed that as the Code level increased, the general consumption of energy and water reduced.

A number of previous studies have been described in the introduction section, and the findings of this project generally support previous work in the field. There are broadly three key areas that are relevant, as indicated below.

(a) Complexity of installed technology

Previous studies have clearly shown that as sustainability standards have developed over the last twenty years, housing has become necessarily more complex in terms of the technology that is required to service the building and reduce energy and water consumption, which has led to unintended consequences as a result of the drive towards low carbon buildings [6] [7] [8].

In this project, in order to satisfy increasing levels of compliance of the Code for Sustainable Homes, more technology was necessarily installed, and this led to a significantly greater risk of technical failure of services systems, some of which were significant. No major problems in the services systems were reported in the Code level 3 and 4 dwellings, but technical failure was apparent across a range of systems in all four of the Code level 5 homes, at some stage throughout the monitoring period, some of which were never satisfactorily resolved. In these homes there were a number of reported problems with the PV systems, some of which were never resolved and energy was not generated for the whole period of monitoring. Given the limited number of dwellings monitored, and the problems encountered with PV generation systems, those that worked performed as expected and generated the levels of electrical energy expected for the size and specification of the installation. The MVHR systems in the Code level 5 dwellings were perceived by the tenants to be problematic, although there is no clear evidence that was the case. Tenant expectation was high for these systems and when cold drafts or condensation on windows in the kitchen occurred it was perceived by the tenants that the ventilation system was malfunctioning. It is not clear whether the MVHR systems were regularly maintained during the period of monitoring. The EcoPlay grey water systems were problematic throughout the year. In one case it was reported that rather than constantly carrying out repairs, the mains supply to the toilets was directly connected. In another recycling system there were issues with operation, with leakage intermittent alarms and automatic flushing occurring. The micro-CHP system installed into one of the dwellings performed as expected, but for the last two months of the monitoring period the electrical generation system malfunctioned.

(b) Occupant behaviour

Previous studies have clearly described the importance of occupant behaviour as a critical element of genuinely sustainable housing, and the two main issues relate to the significant differences in energy and water consumption measured in similar homes, and to the expectation that tenants in these homes know how to operate them with little support, training and guidance [7] [10] [11].

The findings of this project show that there is significant variation in gas and electricity consumption when comparing similar dwellings and this demonstrates the enormous impact of occupancy behaviour. In one of the schemes monitored, the significant differences in gas and electricity consumption were reversed, indicating that the occupants in one were primarily consuming gas and in the other the occupants were primarily consuming electricity, albeit that the installed services systems were identical.

There was no perceived tenant incentive to ensure that electrical generation systems were working and this led to some of the installations malfunctioning for a significant period of time. The tenants were generally unclear about how they benefited from these systems, and in particular, they were completely unaware that the electricity being generated during the middle of the day would be used primarily to power the appliances in their homes at no cost to themselves.

The findings of this project show that formal handover and induction processes for the occupants of the housing is critical and that tenants require simple, clear, non-technical guidance and operation and maintenance (O&M) manuals for their homes. O&M manuals in the dwellings were comprehensive but contained a great deal of very technical information that was not useful or helpful to the tenants.

(c) Specification, installation, commissioning, handover and induction processes

Previous studies have shown that performance of sustainable housing relies not only on build quality and the correct installation and operation of the building services, but also on the usability of the various systems, with clear guidance on their design and operation and on recognising when systems are malfunctioning. Serious problems can occur with heating, ventilation, water and renewable energy systems when the user interface is not user friendly or appropriate to the occupants of the building [7] [9] [12].

This study has shown that the management of these issues is complex but a robust and structured process needs to be introduced which would allow various technologies to be installed correctly, commissioned correctly, regularly checked for operational performance and efficiency, and any failure would be detected and rapidly responded to. Ideally, this would be managed and operated in-house, rather than relying on third parties.

The project has also identified the need, in increasingly 'sustainable' dwellings, for a robust tenant induction process. These inductions would take place on site, with the tenant group, and would include simple instruction on the use of the building services systems in the home. This project has identified a number of systemic faults in the innovative technology that has been installed and a general ignorance of system operation and performance. A well designed and delivered induction could have dealt with a number of the problems that were encountered in a timely and cost effective manner.

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Appendix A – Social Survey data

	Ref	39OB (code 3)	138NG (code 4)	139NG (Code 4)	94SR (Code 5)	96SR (Code 5)	249MR (Code 5)	249aMR (Code 5)
Heating	N° of Occupants (Adult / Children)	1A / 3C	2A / 3C	4A	2A / 2C	3A / 1C	2A / 2C	1A / 2C
	Is your home cold / comfortable / warm	Varies on each floor from cold GF to hot SF	Comfortable	Comfortable	Warm	Comfortable	Comfortable	Comfortable
	Weekday heating hours	5	10	6	4	15	11	12
	Weekend heating hours	5 + more if required	10	As and when required	8	15	13	12
	Do you understand how to use your heating system?	Yes	Yes, but manually controlled	Yes, but manually controlled	Yes	Yes	Yes – induction was carried out by provider	Yes
	Thermostat setting	20°C at thermostat + 3 at TRV	30°C – but heating switched on manually when required	30°C - but heating switched on manually when required	20°C but manually switched on and off	20°C but manually switched on and off – thermostat near radiator	Used as a switch to turn heating on and off	Used as a switch to turn heating on and off
	Does your home overheat?	Yes	No	No	Yes	Yes	No	Gets warm in the summer
	How satisfied are you with your heating?	Not very – problems of heat stratification	Satisfied	Satisfied but been some issues with flue condensate	Satisfied	Satisfied	Happy	Not very – have had problems with the boiler
	Do you control zones in house differently?	Yes	No	No	Yes	Yes, different stats and TRV	Yes, living room kept warmer	Yes, GF and FF differently heated
Hot Water	How do you control your hot water?	Automatically but some issues with water temperature	Automatically	Automatically	On timer + override	On timer + override	Automatic and constant	On timer / programmer
	Do you understand how to use your hot water system?	Yes but frustratingly complicated	Yes	Yes	Yes	Yes	Yes	Yes
Ventilation	Is ventilation natural or mechanical?	Natural + mechanical extract	Natural + mechanical extract	Natural + mechanical extract	Full MVHR	Full MVHR	Full MVHR	Full MVHR
	If MVHR is this constantly operating	N/A	N/A	N/A	Sometimes turned off – blows cold air and noisy	Tenant not sure but manually uses boost occasionally	Yes	Yes
	Do you know how to maintain the system / change filters?	N/A	N/A	N/A	No	No – but aware of instructions	No	No
	Do you open windows much?	Yes, upstairs	Sometimes	Sometimes – in kitchen where extract is not above cooker	Yes – main mode of ventilation	Yes – in kitchen when necessary	No – noisy	Yes, all the time
	Do you have and use trickle ventilators?	No	Yes – open at day / closed at night	Yes	N/A	N/A	N/A	N/A
Electricity	Proportion of lamps low energy?	100%	100%	100%	100%	100%	100%	100%
	Leave equipment on standby?	No	Yes	Yes	No	No – usually switch off	Yes	Yes
	Do you regularly use a tumble drier?	Yes, condensing	No	No	Yes, vented to outside	Occasionally	No	No
	Do you ever dry clothes indoors?	No	Yes, but outside if possible	Yes, but outside if possible	No	Rarely	Yes sometimes	Yes sometimes
Water	Do you normally use bath or shower?	Both 50:50	Shower	Shower	Shower	Shower	Shower	Bath
	Are you appliances designed for low water use?	Yes, highest rating	Not sure – Indesit INDE7145K	No	Not sure – Samsung WF1804WPU	Not sure – Hotpoint WDF740	Yes - Miele W1914	Not sure – Hotpoint WDL540
	Do you use a dishwasher?	No	Yes – Beko DSKN1530B	No	No	No	No	No
	Are you aware of water recycling in your home?	N/A, but external water butt	N/A	N/A	Yes – but have had problems	Yes Ecoplay system works OK	Ecoplay system has never worked so has been bypassed	Ecoplay system – works well
Energy Bills	Do you consider what you pay for energy to be reasonable?	Quite high and not sure about what benefits from solar PV	On the high side	Yes, but waiting for winter bill	Yes – reasonable energy bills	Bills higher than expected but there are issues with the solar panels	Bills are considered to be high - £300 gas bill for last 2 months	Bills are considered high - £840 for 6 months

Table 2: Social Survey information

Appendix B – Consumption and generation data

		Mar/May	May/Jul	Jul/Sep	Sep/Nov	Nov/Jan	Jan/Mar	**TOTAL**
Electricity (kWh)	39OB	503	806	562	699	895	689	**4152**
	138NG	640	662	593	762	896	667	**4220**
	139NG	417	413	306	498	697	488	**2819**
	94SR	549	738	535	933	619	263	**3637**
	96SR	374	352	317	550	324	120	**2037**
	249MR	212	374	525	723	830	430	**3094**
	249aMR	505	753	643	903	545	377	**3726**
Gas (kWh)	39OB	262	151	94	182	360	283	**1332**
	138NG	133	32	10	51	202	156	**583**
	139NG	207	105	53	170	355	257	**1147**
	94SR	210	58	58	284	233	112	**955**
	96SR	81	27	21	86	89	32	**336**
	249MR	165	103	98	119	177	43	**706**
	249aMR	243	80	11	245	185	175	**940**
Water (m3)[1]	39OB	32	34	35	36	44	37	**218**
	138NG	29	42	24	33	42	30	**200**
	139NG	19	22	23	20	22	19	**124**
	94SR							
	96SR							
	249MR	20	23	22	18	38	33	**153**
	249aMR	28	40	39	25	24	1	**157**
PV generation (Kwh)[2]	39OB	195	266	256	102	59	113	**992**
	138NG	252	363	358	129	45	120	**1267**
	139NG	243	349	339	126	47	118	**1223**
	94SR	370	590	494	207	72	74	**1807**
	96SR	0	0	0	0	0	0	**0**
	249MR	617	405	0	0	0	0	**1021**
	249aMR	22	0	485	145	67	108	**826**

Table 3: Electricity, gas and water consumption, and solar PV generation in all dwellings

[1] Water consumption meters at 94SR and 96SR were not accessible throughout the project.
[2] Shaded areas represent PV generation systems not working, despite reporting faults regularly.