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Energy Efficiency Benchmarks For SuperHomes:

A Normalised Performance Index Approach

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Executive Summary

SuperHomes is a network of properties that have been renovated by their owners to save at least 60% of their carbon emissions and which are then opened to the public to educate and inspire. This multi-awardwinning project has been inspiring householders since 2007. Since that time more than 75,000 people have visited a SuperHome, over 817,000 users have visited our website and many have gone on to undertake their own renovations. SuperHomers are all individuals and have undertaken renovations which suit their properties and their lifestyles. These bespoke renovations usually include superior insulation, upgraded windows and renewable energy systems. A selected list of technologies employed can be found in Appendix A.

A critique of SuperHomes has been that they aren't low-energy homes, but rather low-carbon ones. Whilst this might have been true it is something we have disputed for a very long time and this report sets out to dispel this myth.

The main objective of the SuperHomes project is to inspire reductions to carbon emissions. Whist our criterion for inclusion is a 60% minimum reduction, many SuperHomes have far exceeded this. In fact the mean carbon reduction of those used in this report is some 74%. If all homes in the UK achieved similar reductions then there would be little need for extra energy production.

Clearly there is a potential for a home to dramatically reduce its carbon emissions whilst not simultaneously affecting its energy use. Swapping heating fuel from coal to gas would have a profound effect on carbon emissions but might make little or no change to the energy use in the property. Replacing fossil fuels with renewables, unless accompanied by energy efficiency measures, will often affect carbon emissions but not energy use per square metre.

However, our research shows that SuperHomes have all decreased their energy use as well as their carbon emissions. Our analysis demonstrates that SuperHomes are over 40% more energy-efficient than average. The SuperHomes considered in this study showed average energy use of 104kWh/m² per year compared to a UK average of 177kWh/m²/yr.

The analysis has not been as easy as we had hoped. Many homes which are heated with wood, especially those where waste wood is used, do not have any records of the volumes used. Wood has a positive effect on carbon emissions, especially as in many SuperHomes it replaced oil heating, but it is highly energy intensive and therefore has a negative effect on energy data. We have found it almost impossible to elicit accurate data for electrical energy use where SuperHomes have extensive PV systems. Solar thermal (ST) has also made it difficult to calculate true hot water energy use. Where possible, we have modelled the missing data, though this introduces other difficulties. Sadly these issues, detailed below, have markedly affected our data set and have, in many cases, made inadmissible the most energy-efficient, and lowest carbon, SuperHomes. It is likely, therefore, that our study underestimates energy savings from SuperHomes, but even this limited data shows beyond doubt that SuperHomes are both carbon and energy-efficient.

The same cannot be said of most British houses. This is why the SuperHomes project is so vital. It encourages homeowners to retrofit their older homes to meet, or even exceed, current building regulations in terms of energy use efficiency. Though this programme has been running for a number of years now, there has been no comprehensive research to benchmark the specific energy efficiency of participating homes. Rather, SuperHomes have hitherto been assessed on their carbon emissions reductions.

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1. Introduction

1.1 Overview of domestic energy in the UK

Since the beginning of the 21^{st} century, the UK's energy policy has revolved around carbon reduction rather than solely energy security and cost efficiency. The United Kingdom aims to reduce CO_2 emissions by 80% by 2050, from a 1990 baseline, without sacrificing the welfare and livelihoods of the population. These concerns become even more pertinent in the current period of austerity and at a time when the country's economic competitiveness also needs safeguarding. This calls for innovative modes of energy generation and usage. Government institutions, private sector entities and households must all become involved in the pursuit of energy solutions which work for both people and their environment, reducing CO_2 emissions without sacrificing the reliability of supply.

Whilst the importance of efficient energy generation cannot be overlooked, the patterns of consumption and energy-saving measures, especially those undertaken by homeowners, are also critical in terms of overall energy demand. Current estimates suggest that the 27.6 million homes in the UK consume 27% of all the country's energyⁱ.

Furthermore, space heating alone accounts for over 60% of residential energy use. This statistic is against the backdrop of a relatively old UK housing stock in which only 25% of houses are considered "modern". An older building stock intrinsically affects the extent to which the building fabric is able to conserve space heating energy. To create a comfortable living space for users without losing a large amount of energy to the external environment, the fabric of buildings must be insulated adequately.

To bring older homes up to the required environmental standard, prevent space heating energy loss and meet economic demands, major retrofitting will be required. These retrofits have been supported by Government programmes like the Green Deal, CERT, and CESP, and by other stakeholders for specific groups of homeowners in different locations of the country, including Social Landlords and Local Authorities. In addition, some individual homeowners, such as those participating in the National Energy Foundation (NEF) SuperHomes Project, are also carrying out home retrofits unaided. This report is based on SuperHomes directly involved in the NEF programme.

Retrofitting older homes, whether government-sponsored or through individual household initiatives, comes at a cost. After retrofitting, the costs incurred can, to some extent, be recovered through savings made from efficiency gains as the building saves or generates energy. It is therefore imperative that such efficiency gains are assessed and the benefits of investments calculated.

One way of analysing the energy usage and efficiency of any home is to compare it with other properties of similar size, location, occupancy and usage. For SuperHomers, who have a primary objective of saving energy or reducing their carbon emissions, it is critical to have a measure which allows them to audit their own consumption and compare it to other SuperHomers, as well as historical, regional and national averages. Such calculations have the potential to provide useful information on whether or not retrofits are worth their initial investment, in terms of financial payback and the magnitude of efficiency gains.

Although an energy efficiency audit could provide useful information to non-SuperHomers and might encourage them to adopt energy-saving practices, there are fundamental challenges when it comes to finding a reliable measure to make comparisons across homes. For example, two similar properties within the same geographical area might be used differently. Consider any two three-bedroom homes in the same community with similar floor space. The natural expectation is that these two houses should have similar energy usage, if they have similar heating installations and similar investments have been made to improve energy efficiency. However, this is not always the case, because the occupancy levels and lifestyles of the users might differ widely. Though we cannot eliminate the differences in building characteristics and their environmental effects, with careful consideration of each specific home we can develop an approach that tends towards a true reflection of energy consumption, and hence improve the accuracy of our comparisons.



This report presents the results of a three-month benchmarking exercise undertaken at the National Energy Foundation to examine the energy use of SuperHomes. The next section presents the main objectives of the study. This is followed by a description of the methodological approach for the study in section 3. In section 4, we present the results from the survey and compare SuperHomes' energy consumption levels with those across the UK. Section 5 concludes the report by drawing some inferences from the results.

This report presents results from a research assignment commissioned by the Foundation in February 2015 to conduct an energy efficiency performance audit of SuperHomes and benchmark them against the performance of buildings across the country. Using a Normalised Performance Index methodology, the study found, among other things, that SuperHomes on average use about 104kWh of energy per square metre per annum compared with 177kWh for the average UK home. Similarly, the average SuperHome emitted 1.2 tonnes of carbon per person per year, whilst the average UK home emitted 1.9 tonnes per person per year. These main findings suggest that the retrofits undertaken by participants in the SuperHomes project are having a positive effect on both their energy use efficiency and carbon reduction.

1.2 Overview of SuperHomes Project

SuperHomes is a network of owner-occupied properties whose carbon emissions have been reduced by a minimum 60%, since the owner moved in, via changes to the fabric and the installation of energy generating technologies. The homes are usually found after the renovations have been undertaken and an assessment of current energy use and carbon emissions is completed. The assessment is then downgraded to provide the 'before' scenario and the percentage carbon reduction is then calculated.

The 60% reduction criterion was commensurate with the government target in place at project inception in 2007. It is appreciated that our homes will eventually need to go much further than a 60% reduction, but when behaviour change and decarbonisation of the grid are included we believe that a 60% reduction is a reasonable target.

SuperHomes was initially instigated by the Sustainable Energy Academy (SEA) in partnership with the National Energy Foundation (NEF). In March 2014 SEA announced that it would merge into NEF. John Doggart, the charity's founder and chairman, is currently an NEF trustee and remains patron of the SuperHomes project.

There are now 200 SuperHomes across the UK. These include homes in England, Scotland, Wales and Northern Ireland which each open to the public. Many of the homes open on an annual basis to coincide with Heritage Open Days or London Open House, others will open to coincide with local events and more still will open on an irregular or by request basis.

2. Objectives of the Study

The main objectives of this energy benchmarking exercise were to employ some of the most current and reliable measures of energy use efficiency to examine how SuperHomers' energy consumption compares with other homes in the UK and to demonstrate that SuperHomes display large reductions of both carbon emissions and energy consumption.

Specifically, the study aimed to estimate energy use efficiency of SuperHomes after the home improvements were undertaken by calculating:

- i. kWh/square metre/annum (actual)
- ii. Total tonnes of CO₂ for the home and percentage carbon saving
- iii. Tonnes of CO₂ per person



3. Method, Data and Limitations

3.1 Empirical Approach: The Normalised Performance Index (NPI)

To assess the current performance of SuperHomes, two methods of energy audit were considered: the regression method and the Normalised Performance Index (NPI). The regression method establishes trends in energy usage by plotting energy consumption against environmental temperature measured in degree days, and requires detailed weekly consumption data¹. In contrast, the NPI calculates the overall energy usage per square metre, accounting for the weather conditions and exposure of the building. Though both methods can be equally effective, in our case we adopted the NPI for its simplicity².

To ensure that a common numerator is being used throughout the NPI calculations, all energy types used in the building for heating and non-heating purposes are converted into kWh using existing factors for different fuels. Then the energy used for space heating is calculated, and the weather and exposure of the building are accounted for. This gives a heating energy figure which is not distorted by external factors. Non-heating energy use is added to that figure, and the hours of use factor of the building accounted for. However, in our case we assume that homes within our sample are used throughout the year, and that the days of non-use are not significant. The floor area is found in m² and then the NPI is calculated.

The exposure factor of a building is, by convention, 1 for urban buildings, 1.1 for sheltered buildings, and 0.9 for exposed buildings. This is to compensate for the fact that, independent of the thermal or energetic properties of their design, an exposed building will tend to need more heating and a sheltered building less, simply by virtue of their locations and geographical circumstances. The weather correction factor adjusts the energy consumption figures to account for whether the year in question was particularly hot or cold. It compares the number of degree days in a particular region for a particular year to the twenty-year average for that region to say how much energy would probably have been used in an average year.

The total energy used per annum can be divided by the number of occupants in the house to give the energy consumed per person. NPI and emissions per person can then be compared with national averages of properties with similar floor areas. Table 1 gives a breakdown of this calculation process.

¹ Heating degree days are a measure of the severity and duration of cold weather. The colder the weather in a given month, the larger the degree-day value for that month. They are, in essence, a summation over time of the difference between a reference or 'base' temperature and the outside temperature.

² It is important for us to keep it simple so that homeowners can easily relate to it.



	A		
	В		
0.66	С		
B*C	D		
B-D	E		
	F		
	G		
F/G	Н		
D*H	I		
	J		
l*J	K		
E+K	L		
m ²	Μ		
8. Find normalised Performance Indicator (NPI, in kWh/m ²) L/M N			
	0.66 B*C B-D F/G D*H I*J E+K m ² L/M		

able 1: Procedure for calculating NPI

9. Compare with yardstick

3.2 Data Collection and Management

Primary data on total fuel consumed in 2014, the number of occupants in the house during 2014, and the floor area of the house in m² were mainly obtained directly from SuperHomers through a structured questionnaire. Some of the data sets were already held by NEF, whilst others had been supplied by the SuperHomers on *i*measure⁴ or other platforms. Where consumption data on renewables could not be collected they were, where possible, modelled. This was the case, for example, where the SuperHomer had no solar PV generation meter, but the size of the array was known. See below for a more detailed discussion. Secondary data such as degree days were obtained from <u>vesma.com</u>, a site which provides degree day data by month, year and region.

We contacted 198 SuperHomers, to each of whom we assigned a number, and gave questionnaires to 140. We knew that some of the latest additions to the SuperHomes project would not have relevant 'after' data as their renovations had been completed more recently. There were many positive responses, but many did not provide data which could be quantified or modelled with sufficient precision to be used for this exercise (see section below on limitations). Using the NPI approach, we have successfully calculated energy use for 28 SuperHomes. This is less than the original target of 50 out of 198.

3.2.1 Data Modelling

Energy data were modelled in cases where 1) precise consumption data could not be collected but 2) sufficient system or usage data were available. Low, probable and high consumption models were developed for each energy source. The figures produced by the "probable" model have been used by default throughout this report, but reference will occasionally be made to the other figures to show the possible

³ This fraction is based on the mean space heating factor for the UK between 2001 and 2011

⁴ A web-based application with which home owners track their energy consumption trends



range. This range, it will be seen, is not great. Even using the highest plausible figures, SuperHomes average 114kWh/m²/yr, compared to a national average of 177- a saving of 36%.

i. Solar PV (PV)

Using the kWp and generation data for homes in our survey that did accurately measure their PV energy production, a real efficiency rate was produced of 807kWh/m²/year per kWp of system. This falls perfectly in the range stated by the Chartered Institute of Building Services Engineers (CIBSE)ⁱⁱ of 780-850kWh/m²/yr. In recognition of the range of possible actual amount of energy delivered, the higher and lower CIBSE figures were used in the high and low models. In all cases, modelled or not, PV generation figures were halved to give consumption figures, to account for energy exported rather than used. This is in accordance with government guidelinesⁱⁱⁱ.

ii. Wood

Energy from wood is difficult to calculate and difficult to model. The reasons for this are discussed below in "Reliability of data". Where SuperHomers could tell us how much wood they had burned, by volume or by weight, we combined this with standard figures for wood energy density from the Biomass Energy Centre^{iv}. Where they could not, we assessed the frequency of use, size of installation, and other heating sources to determine whether wood was being burned as primary or secondary heating. In all cases where wood was providing primary heating precise figures were available. The government's Standard Assessment Procedure (SAP 2012) recommends assigning a heating fraction to secondary systems of 10%^v. This involved calculating the total energy consumption of the property, taking 66% of this as heating energy (see section 3.3.ii for details), taking 10% of the heating energy figure, assigning that value to energy consumed from wood, and adding that to the total. This in turn alters the overall total, so to avoid circular dependency or inaccurate counting, an equation was developed to carry out this process which takes that into account. (See Appendix B for details). It was known that some SuperHomers use their wood stoves more than others: some say it is largely decorative, while others say they use it all "really cold" days. In recognition of the range of possible actual amount energy delivered, figures of 5% and 15% were used in the high and low models.

iii. Solar Thermal (ST)

It is very difficult to know, retrospectively, how much solar thermal energy has been used for water heating. It is not metred, and there is no empirical indicator of how much of the water heated has, in fact, been used. Nevertheless, government and industry guidelines are available for how much energy is expected to be produced per m² of panels^{vi}. This varies depending on the orientation and angle of the panels as well as the system type. Where these data were known, they were incorporated into the industry formula, which agreed very closely with government figures. Where orientation was not known, a suboptimal, intermediate and optimal orientation was assumed for the modelling of low, probable and high energy consumption figures. Although the degree of variation was not great, it was also decided, due to the degree of uncertainty surrounding ST, to present total figures not including ST. This has been done at certain key junctures in this report, and clearly indicated. All other totals and averages do include ST energy.

3.3 Limitations and Remedies

i. Reliability of data

The numerous variables in the calculated energy data, and the way the data is measured, especially by SuperHomers themselves, can result in small discrepancies. The metering of electricity from suppliers and mains gas gives easily managed data, but there are significant challenges with measuring the energy generated and consumed by SuperHomers from renewable sources. This poses questions of reliability and validity for the energy efficiency figures calculated.

In some cases the renewable energy sources are not measured at all, particularly with heat pumps, solar thermal and small wind turbines. In cases where there is a direct feed into the main grid, such as with solar photovoltaic generation, measurements of what is generated, exported or used can overlap, making it difficult to calculate clear values for production and consumption. This is especially true if the meter in use



cannot record the net energy used by the building. In such instances, the total energy used by the building can be significantly under- or overestimated.

A similar problem arose from the use of biomass as a source of energy for SuperHomes. Wood boilers and stoves can use either wood pellets or logs, which can have different densities. This affects the energy generated per weight burnt, and therefore one cannot always be certain of the actual energy generated by each kg of pellets or logs. Though general guidelines are available, SuperHomers were rarely able to state with accuracy the density of their wood, especially when they had used waste wood or wood of their own production.

To mitigate these limitations, a significant effort was made throughout the data collection and calculation process to carefully review each SuperHome as an individual case study. We collected all possible information that could help us to accurately calculate or model the actual energy consumed by the property, including supplementary narratives from email conversations. We also looked separately at figures for renewable and non-renewable energy use, in order to evaluate both the carbon footprint and the overall energy profile of each property, and excluded SuperHomes whose data we felt was not sufficiently reliable.

ii. Issues related to the weather correction factor

In order to adjust energy data for weather conditions, two figures are needed: the specific yearly regional degree day total for the region of the building, and a standard against which to compare it. The standard used in this report is the regional twenty-year average for each home. This gives the most accurate possible comparison. However, because SuperHomes are grouped broadly towards the south of the UK, this is slightly unrepresentative of a "true" national average, bearing in mind which regions have the most homes. The figures presented here show how much energy each home would have used in an average year in their region, rather than in a theoretical UK-wide average year. There were two ways to try to deal with this: using a purported industry standard of 2462, or attempting to create a population-weighted average. The figure of 2462 was discounted because investigation of regional data shows that only one out of eighteen degree day regions has a total that high. A population-weighted average of 2140 was used, in conjunction with the "high" modelled data, to create an upper possible figure for overall energy consumption, which will be referred to on occasion in this report. In all other instances we have used region-specific data.

iii. Questions about reliability of the space heating factor

There are concerns that the 0.66 factor assumed for the separation of space heating energy from the entire energy consumption of the home might be flawed. To correct for this, the energy used for space heating could be isolated first and subsequently an appropriate proportion subtracted for the weather correction factor. This approach has its own limitations, such as the difficulty of separating water heating energy from space heating. The proportion of energy from boilers that is used for water heating, as opposed to space heating, is variable and difficult to determine. However, based on discussions with experts at NEF, and on information from other reports, this proportion is estimated to be 23% for water heating and 77% for operating central heating systems for space heating⁵. Using these estimates we recalculated the NPIs for the sample and compared them with the original data. This gave results which were on average 2.7% lower than our original results. See Table 2. This suggests that our overall findings would have been similar using either method.

⁵ For more information, see <u>www.decc.gov.uk/en/content/cms/statistics/publications/ecuk/ecuk.aspx</u>).

SuperHome Number	Method 1 (kWh/m ²)	Method 2 (kWh/m ²)	M1-M2			
82	79	77	2.6			
87	90	88	2.2			
109	68	67	1.2			
111	130	130	-0.2			
119	105	103	2.2			
134	50	53	-4.5			
137	25	23	10.2			
145	98	94	3.4			
148	88	87	1.6			
151	133	125	6.1			
153	62	60	3.5			
155	115	113	2.1			
166	135	136	-0.5			
170	34	31	9.1			
178	94	91	3.9			
180	160	158	1.3			
183	190	184	3.0			
184	134	132	1.3			
186	133	133	0.6			
191	81	81	0.3			
192	114	104	8.8			
196	130	128	1.5			
Mean % difference 2.7						
Mean % difference (absolute) 3.2						
Source: Generated by author, 2015						

The next section presents the results from the survey and the variables of interest for comparison with average UK homes, as represented in the National Energy Efficiency Data-Framework (NEED)⁷ database.

4. Findings

This section of the report presents the results of the data collection and benchmarking calculation exercise. The main characteristics of the sample in terms of the age of the properties and the floor area are described. Subsequently, a presentation of total energy per annum and per square metre is made according to the type, age and size of the property. This is followed by a discussion of carbon emissions for the SuperHomes compared with the 2012 NEED Framework.

4.1 Characteristics of Sampled SuperHomes

As noted in section 3, 28 SuperHomes supplied information which we considered suitable for the benchmarking exercise. They were distributed quite evenly in terms of size and age, as can be seen in Table 3.

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⁶ SuperHomes which have no entries in this table are those for which it was impractical to isolate energy sources for space heating ⁷ The National Energy Efficiency Data-Framework (NEED) was set up by DECC to provide a better understanding of energy use and energy efficiency in domestic and non-domestic buildings in Great Britain



Floor area (m ²⁾ -		Total			
	Pre-war	Inter-war	Post-war	Modern	Total
51 to 100	2	2	2	2	8
101 to 150	2	0	2	4	8
151 to 200	2	2	1	1	6
over 200	2	1	1	2	6
Total	8	5	6	9	28

Table 3: Floor	area and vintage	groupings of	sampled Su	perHomes
		3 3		

The average SuperHome in our eventual sample was 71 years old, with the newest being 25 years old and the oldest being 145. In terms of floor area, the average SuperHome in the sample was $149m^2$. The range was from $61m^2$ to $260m^2$. Full size and age data can be found in Appendix C

4.2 Energy Consumption and Normalised Performance Index (NPI)

4.2.1 Age of building and energy efficiency performance

As building regulations develop, more recently-built properties should be more energy-efficient than older ones. Although older than most UK homes, the average SuperHome consumes only 14722kWh of energy per annum, compared with an average consumption by households in the NEED sample of 18100kWh. This means that the average SuperHome consumes about 19% less energy than the average UK home, despite their age and larger than average floor areas.

SuperHomes do vary around that 14722kWh average, in some cases quite widely. SuperHome 137, for example, consumed the least energy of all SuperHomes in the sample: a little below 4,400 kWh in the year 2014. This is a clear indication that measures installed by this home are contributing positively towards energy use efficiency. Roof, floor and external wall insulation, along with draught-proofing and low-energy lighting and appliances, all contributed to this low figure.

In contrast, SuperHome 183 consumed the highest amount of energy: nearly 38000 KWh in the year under review. This high consumption could be partially explained by the fact that this home uses relatively large quantities of biomass (wood pellets) to fire its boiler, particularly bearing in mind that this property has no wall or floor insulation in the main building. As we know, wood has a high energy content and so can negatively affect energy use, despite having a positive effect on carbon emission reductions.

The key variable of energy use per square metre (NPI) can be put into context when the average of SuperHomes in this sample is compared with those of the NEED framework. Such a comparison reveals that whilst the average SuperHome consumes about 104kWh/m²/year, the average home in the UK consumes about 177kWh/m²/year. That is, on average, a SuperHome consumes about 41% less energy per square metre than the average UK home.

There are also some variations, in terms of energy benchmarks, when different ages of properties are considered within the sample. Inter-war properties (1919 to 1944) were found to be the most efficient, consuming just 85kWh of energy per square metre per annum. This was followed by pre-war properties (92kWh/m²/year). Modern properties within the sample had an NPI of 119 kWh/m²/year. Table 4 below presents maximum, minimum and mean energy consumption values for each age bracket. Values for each house in the survey are included in Appendix D.

It seems surprising that the more recently built properties in our sample seem to perform poorly in terms of energy used per square metre per annum, when compared with older homes. This does not match the expected trend and requires further investigation before any firm conclusions can be drawn. This is particularly the case in light of our small sample size and the limitations with respect to metering by the



homes in the sample. One possible explanation would be that owners of older homes spend more time and effort retrofitting with the view of catching up with modern homes, which makes them do better in terms of energy use efficiency. A second potential explanation would be that the more modern homes have installed more energy generating capacity and switched to lower carbon fuels which, as we have said before, are not necessarily low in terms of energy. Thus these homes could meet the SuperHomes low carbon benchmark whilst not being excessively energy-efficient. This is an area for further research.

	Table 4: SuperHome energy consumption and NPI, 2014				
Vintage		Normalised energy	NPI (kWh/m²/year)		
		(kWh/year)			
Modern	Max	32357	160		
	Min	4924	81		
	Mean	18139	119		
Post-war	Max	37278	190		
	Min	7505	77		
	Mean	15824	117		
Inter-war	Max	26275	130		
	Min	4390	25		
	Mean	11716	85		
Pre-war	Max	23890	173		
	Min	5869	34		
	Mean	12364	92		
All	Mox				
SuperHomes	IVIAX	37278	190		
	Min	4390	25		
	Mean	14722	104		
Mean NEED					
2012		18100	177		
SH Mean high		16237	114		
SH Mean low		14422	102		
SH Mean, no ST		13385	95		

The table above includes figures for consumption from high and low modelled data, as well as without solar thermal. It will be noticed that the "low" figure is not significantly below the given mean, while the "high" figure is markedly above it. This is because the low figure uses some lower modelled consumption totals but the same degree day figure as the "probable" mean, while the high figure uses higher modelled figures *and* a higher degree day figure (the hypothetical population-weighted national average). If the same degree day figure were used throughout, the high figure would be 107 kWh/m²/year. This narrow range shows that the uncertain modelled data do not make a large contribution to the total, and even using the higher degree day figure SuperHomes do 36% better than the national average.

4.2.2 Size of building and energy efficiency performance

In absolute terms, homes with larger floor area will tend to use more energy than homes with smaller floor area, assuming occupancy and lifestyle are consistent across homes. However, in terms of energy used per square metre, the NEED data shows that homes with larger floor areas tend to use less energy than homes with smaller floor areas. This is attributed to the fact that regardless of the size of a home, there are some standard appliances such as refrigerators and outside lighting which are in use regularly and are somewhat independent of house size. In this sub-section the energy use per unit of floor area is evaluated and we discuss whether our sample conforms to the general rules mentioned above.



First, let us consider the relationship between floor area and total energy consumed, as shown in Figure 1. We can see that, as one would expect, total annual energy consumption increases with floor area. We can also see that all except one are below the UK average for their size according to the NEED data, as shown by the green trend line, and that most are well below it. The average difference is shown by the distance between the green and red trend lines (NEED and SuperHomes, respectively). The grey trend line shows the average using the higher modelled figures and higher, hypothetical degree day average. This line is also significantly below the red NEED trend line. Also included are trend lines using low modelled data (orange) and leaving out solar thermal (blue). These show the total possible range, although it should be noted that the green trend line represents significantly the most probable outcome.

It will be observed from the spread of green data points that there are significant deviations from the trend line within the SuperHomes data set. There are three possible explanations for this.

One is that these deviations could reflect inaccuracies: energy sources not captured through our survey, for example, or data that was derived from poor instrumentation or imperfect modelling. This may account for some of the data points, but given the cautious selection process and rejection of unverifiable data it cannot account for many.

The second is that there may be differences in the original characteristics of the houses, e.g. heat retention or amount of natural light, or in the lifestyles of the occupants. Again, this may account for some of the variation, but it seems unlikely that these two factors can account for the order-of-magnitude differences that we see between houses of similar sizes.

This leaves a third explanation: that while all SuperHomes have significantly improved carbon performance, and the vast majority are more energy-efficient than the average UK home even before taking into account renewable generation, some SuperHomers have focused more on one or other of these aspects. That is, some have installed more energy use reduction systems, such as insulation and low energy appliances, reducing their energy use and carbon emissions equally, while others have installed more renewable energy generation technologies such as solar thermal and biomass boilers, reducing their carbon emissions very greatly but not impacting their energy use as significantly. A large house with extensive energy saving installations could thus use less energy than a small house whose owner has focused on generating clean energy rather than on saving energy per se. For example, the orange data point far below the red trend line in Figure 1 represents SuperHome number 153, with a floor area of 157m² and total energy consumption of 9772kWh/yr, which is very low for the 150m²-200m² size bracket. This SuperHome installed a wide range of energy-saving technologies: Double glazed argon gas-filled window units to replace all existing windows, mineral wool cavity insulation in an extension, 50mm plaster-covered polystyrene internal wall insulation on existing walls, 75mm mineral wool roof insulation, 75mm of polystyrene foam floor insulation, a gas condensing boiler with timer controls, a wireless room thermostat, all low-energy lighting, and AA or A+ rated washing machine, refrigerator and freezer. They have not focused particularly on energy generation, only installing photovoltaic panels with 1.25KWp, but have vastly reduced their energy consumption.

Nonetheless, because most of that energy comes from the grid, they have final CO_2 emissions of 1.6 tonnes/person/year, which is very low nationally but slightly high for a SuperHome. SuperHome number 180 meanwhile, represented by the purple data point somewhat above the red trend line, installed relatively few energy saving measures (some new double glazing and insulation), but these were coupled with a 1.71kWp solar PV system, solar thermal for water heating, and a wood burning stove. These brought their CO_2 /person/year down to 0.9 tonnes, but will have had little impact on their energy consumption, which explains why they are the highest energy consumers in their size bracket.

This correlates with other findings, as detailed in section 4.2.4.ii. Further exploration of exactly how and why some homes consume so much less overall energy than others of a similar or larger size will provide material for future research, and may well give insights into how to achieve such energy savings more widely.





Figure 1: Floor area and total energy consumption

In Figure 2, total energy consumed is plotted against floor area groupings for both SuperHomes and the NEED database. We observe that for both groups, as floor area increases the total energy consumed per annum also rises. It is important to note that in all floor area categories, SuperHomes use significantly less energy per annum than the NEED sample.





Figure 2: Comparing mean energy consumption of SuperHomes (2014) with NEED Framework (2012) To evaluate the extent to which the total energy consumed by SuperHomes is less than that consumed by households in the NEED sample, the difference between the two categories for each floor area grouping is shown as a percentage. Properties within the 151 to 200m² range are the highest performers among SuperHomes in our sample, using 46% less energy than the NEED average, but all categories show savings of 30% or more. The fact that overall the total energy use is only 19% lower is explained by the high representation in our survey of homes at the larger end of the size spectrum. This will change when we take into account floor area in the next section.

Let us now turn our attention to establishing whether our data set confirms the assertion that energy use per square metre declines as floor area increases, as suggested by the NEED database. Figure 3 is a scatter plot of NPI against floor area for all the SuperHomes in the sample. The trend line on the scatter plot seems to suggest an inverse relation between the two variables, but it is important to note that the correlation is very weak, with an R² value of 0.0024. This implies that total floor area is not a strong predictor of energy consumption per m² in SuperHomes, and that other factors must be involved. Those factors, which allow a home of 61m² to consume only 82kWh/year while one of 197m² consumes 190kWh/m², are presumably related to the three factors mentioned above in our discussion of Figure 2, but further research is required to clarify this.



Figure 3: Relationship between floor area and energy consumed per square metre

Figure 4 compares the NPI/m² of SuperHomes with those of the NEED database in each floor area band. We observe NPI/m² declining as we move from smaller floor area bands to bigger ones. SuperHome NPI performance was better than that of the average UK home in all floor area bands: the energy consumed per square metre by SuperHomes in our sample was two-fifths less, on average, than the average home in the UK as reported by the NEED database. That is, for every unit of energy used per square metre by a SuperHome, an average UK home will require 1.8 units of energy to provide the same comfort for the occupants (see Figure 7 below).





Figure 4: Energy use efficiency by floor area groupings

4.2.3 CO₂ emissions

One way of tracking the effect of energy use on the environment is to assess the CO_2 released into the atmosphere as a result of energy consumed. In this section we compare the modelled CO_2 of SuperHomes with the national picture in the UK, per property and per occupant.

It was found that the average SuperHome was occupied by 2.8 people, compared with a national average of 2.36. The average number of occupants initially increases in step with floor area, to a maximum of 3.7 in the 151-200 band. The over-200 band is anomalous, showing a decrease in number of occupants compared to the 151-200 band.

Before retrofitting, properties in the larger floor area bands emitted significantly higher levels of CO_2 than smaller ones, as would be expected. SuperHomes in our sample within the 51 to $100m^2$ floor area band emitted an average of 7 tonnes of carbon per annum before retrofitting, compared with 16 tonnes for the over-200 band. Proportionally, these differences between different floor area categories do not change significantly after retrofitting. That is, similar savings are made in all bands. Within each bands, there are significant CO_2 emissions reductions. After retrofitting the SuperHomes have average carbon emissions of 3 tonnes, compared with 11 tonnes before retrofitting and 4.6 tonnes for the average UK home. See Table 5.

This indicates a very significant difference between the national average and that of SuperHomes. For every tonne of carbon per person emitted by the average SuperHome, the average UK home emits 1.6 tonnes. This represents a carbon efficiency advantage of 38% for SuperHomers.



	2					Tonnes of
Floor area bands (m ²)	m²	Occupancy	CO ₂ _before	CO ₂ _after	Saving	CO ₂ /person
51-100						
	61	1	5.4	1.8	67%	1.8
	74	1	6.0	2.4	61%	2.4
	76	2	4.8	1.8	62%	0.9
	80	2	8.7	2.4	72%	1.1
	82	4	6.5	2.2	67%	0.5
	89	3	11.6	3.0	74%	1.2
	94	3	7.4	2.8	62%	0.9
	98	2	7.3	2.7	62%	1.4
Mean	82	2.3	7.2	2.4	66%	1.3
101 to 150						
	103	2	8.7	2.6	70%	1.3
	120	2	7.8	2.0	74%	1.0
	123	3	7.6	2.7	65%	0.9
	126	4	11.0	1.7	85%	0.4
	138	3	13.2	4.7	65%	1.6
	140	4	14.0	4.1	71%	1.0
	140	2	5.9	1.8	69%	0.9
	140	2	8.9	1.9	79%	0.9
	129	2.8	9.6	2.7	72%	1.0
Mean	103	2	8.7	2.6	70%	1.3
151 to 200						
	157	3	11.9	4.8	60%	1.6
	166	4	17.2	3.9	78%	1.0
	174	6	14.7	2.8	81%	0.5
	180	4	12.9	5.1	60%	1.3
	192	3	10.0	1.6	84%	0.5
	197	2	28.1	4.4	84%	2.2
Mean	178	3.7	15.8	3.8	75%	1.2
over 200						
	208	2	14.5	5.7	61%	2.9
	228	2	15.7	4.3	72%	2.2
	240	2	10.0	-0.8	108%	-0.4
	240	3	18.1	5.8	68%	2.3
	250	2	12.5	4.5	64%	2.2
Mean	260	5	23.0	1.8	92%	0.4
Mean SuperHomes: UK Housing Fact File	149	2.78	11.5	3.0	72%	1.2
2013 average:		2.36	N/A	4.6	N/A	1.9

 Table 5: Floor area band, occupancy and carbon emissions before and after retrofits



In terms of carbon emissions for the entire SuperHome and per person, the values increase with building age. This suggests that people occupying older homes need more energy to maintain a comfortable living environment than those occupying newer builds. Columns 4 and 6 in Table 6 show how average carbon emissions increase with building age. All values are mean values for the age group. Figures for each SuperHome can be found in Appendix E.

Table	6: Age of propert	y, occupancy and	d carbon emis	sions befor	e and after retrofits
Age groups	Occupancy	CO ₂ _before	CO₂_after	Saving	Tonnes of CO₂
					per person
Modern	2.3	9.1	2.2	76%	1.0
Post-war	2.4	11.8	2.5	79%	1.2
Inter-war	3.5	11.5	3.3	71%	1.2
Pre-war	3.2	12.3	3.9	68%	1.5

4.2.4 Exploring some energy efficiency questions of interest

As noted in Section 3, there are still some unanswered questions about renewable energy, the relationship between energy efficiency and carbon reduction, and the effect that the type of property might have on the NPI. This section explores these issues.

i. Renewable energy in the energy consumption mix

Considering all sources of energy used by SuperHomes in the sample, the average benchmarked energy use per square metre is 104kWh per annum. However, if we exclude energy used by the SuperHomes from renewable sources, this figure declines by 42% to around 60kWh per square metre per annum on average⁸. There were some SuperHomes within the sample which did not derive a significant proportion of their energy from renewable sources, while others did so extensively. In some cases, renewable sources accounted for as much as 91% of the total household energy use.

Figure 5 shows the total energy consumption (in red), the consumption of energy from non-renewable sources (in green), the consumption excluding solar thermal (in purple), and the area (in blue) of each house in our survey. The distance between the red and green lines shows how much energy is being derived from renewable sources. This figure reflects the diversity of approaches employed by SuperHomes, with some homes getting almost all of their energy from renewable sources and others only a small proportion. The second group will have focused on energy saving. This wide range of highly effective techniques to reduce both energy use and emissions suggests that, with further efforts, more homes in the UK could reduce their energy consumption from the national grid considerably and contribute to carbon emission reductions. We consider this issue in the next sub-section.

⁸ This figure is approximate because individual energy figures for different fuels were not adjusted to account for weather and exposure. Rather, those adjustments were applied to the totals. The true, unadjusted figure for average consumption from non-renewables is 56kWh/m²/yr, but that figure has been adjusted here by the average increase seen across our data between "raw" and weather-adjusted data.





Figure 5: Proportion of renewable energy in the total energy consumption

ii. Correlation between energy use and carbon emissions

There are strong arguments to suggest that low-carbon emissions do not always imply energy use efficiency. Although all SuperHomes have achieved carbon reductions of over 60%, they could theoretically be using more energy overall, though we have seen that is not, in fact, the case.

As we have seen (from sub-section 4.4.2.i above) the importance of renewable energy sources in the energy mix of SuperHomes is significant, and varied. This is particularly relevant here because in our calculations we took biomass energy generation to be carbon-neutral. If it were assigned a different value, the relationship between energy use and carbon emissions might look quite different. Nevertheless, our earlier discussions in this report suggest that this would not change the overall picture. By simply comparing the energy use efficiency of SuperHomes with UK averages, we find the SuperHomes to be superior in all instances.

To see what relationship exists between energy use and carbon emissions, the correlation coefficient of the two variables must be explored (Figure 6). Our sample size is too small to draw firm conclusions, but we can see that, perhaps unexpectedly, there is negligible correlation between energy use and carbon emissions within our sample (R^2 =0.0039). At first glance the trend line suggests a negative correlation, but the data points are too broadly spread for this to be significant.

It is instructive to recall that this is a sample of homes, some of which have focused on reducing energy consumption and some of which have focused on renewable energy generation, as discussed above in section 4.2.2. For instance, SuperHome 196, represented by the data point below the x axis in Figure 6 (highlighted in green) reduced carbon emissions by installing a biomass log boiler and solar thermal, generating 91% of its energy from renewable sources, but this will not have had a noticeable effect on total energy consumption. Although this home also reduced its energy consumption through the use of new double glazing and LED lights, it clearly has very low carbon emissions but only average energy usage compared to the other SuperHomes. The opposite is true of SuperHome 170, represented by the yellow data point in Figure 6: these SuperHomers focused predominantly on saving energy. They did this by installing double glazing, 100mm internal wall insulation, roof insulation, draught proof membranes, 150mm underfloor insulation, wall joint insulation, heat recovery fans, a more efficient condensing boiler, and LED lighting. Thus, their energy consumption has been reduced considerably, and by consequence also their CO₂ emissions, but only 19% of that energy is generated renewably, by a small solar thermal installation. This means that despite their low carbon emissions by national standards, those emissions are at the top end of the range for SuperHomes because many others in the sample are generating much more energy renewably. Thus, SH137 has very low emissions and average - low energy consumption, while SH170 has very low consumption but only average - low emissions.



This suggests that, while energy use and CO₂ emissions are generally correlated, and while all SuperHomes have reduced both, the choice of the homeowner as to whether to focus on energy reduction or carbon reduction has such a large effect that it can mask that correlation in the case of an extensive retrofit. To conclusively confirm this hypothesis, or provide an alternative explanation, will require further investigation.



Figure 6: Relationship between energy consumption and carbon emissions

iii. Effect of property type on energy use efficiency and carbon emissions

The significance of space heating energy with regards to the total energy consumption of homes in the UK is crucial. As far as space heating energy loss is concerned, exposed buildings are more susceptible than those which are not exposed. Assuming similar levels of wall insulation, it is expected that detached houses would lose more space heating energy than mid-terrace homes in the same area. In calculating NPI this is accounted for with the use of an exposure factor, as detailed in our methodology section.

To further examine the relationship between house type and energy use efficiency, the average NPI was calculated for four groups of properties in our sample (Table 7): detached/bungalow, semi-detached, endterrace, and mid-terrace. Semi-detached SuperHomes were found to be the most energy efficient on average - a finding which might run against general expectation. Equally, end-terrace homes were found to be no more efficient than detached homes. This might be as homes with larger heat loss areas are able to show greater improvements from similar measures as a larger area is treated. However, the limitation imposed by the relatively small sample size does not allow us to extrapolate from this result. Additionally, there seems to be no clear trend when comparing CO₂ emissions with the relative exposure for the four types of property. It might be that, when dealing with retrofitted properties, the nature and extent of the retrofit are of more consequence than the exposure of the building.



			CO ₂ emissic		
Type of property	Frequency in sample	kWh per m ²	Before retrofit	After retrofit	CO₂ per person
Detached/Bungalow	12	117	11.7	2.4	1.0
Semi-detached	6	79	13.7	4.8	1.7
End Terrace	6	118	9	2.9	1.2
Mid terrace	4	80	8	2.6	1.4
All	28	104	11	3	1.2

Table 7: Relationship between house type, energy consumption and carbon emissions

5. Conclusions

This report has presented the results from an energy efficiency benchmarks study of SuperHomes. Using the NPI approach, the study finds that the vast majority of SuperHomes are considerably more energy-efficient than the average UK home, despite having been noticeably less efficient before their retrofits. It also confirms that SuperHomes have very significantly lower CO_2 emissions.

It has been shown that the extent of these advantages in efficiency is consistent across categories of size, type, age and occupancy. It has also been suggested that, while every SuperHome surveyed had reduced both energy use and CO_2 emissions, homeowners can choose to focus more on one or the other in order to gain still greater increases in efficiency in the area that is most important to them. This appears to be a determining factor in final emissions and energy consumption, rather than size or age of property, which underscores the efficacy and variety of the technologies available.

Despite limitations posed by the data quality and sample size, the results of this survey help to establish empirically that resources being spent by home owners and government agencies on retrofitting old homes are indeed having great success in reducing both energy use and overall carbon dioxide emissions.



6. Appendices

Appendix A: Technologies employed in SuperHomes to achieve energy and emissions reductions

- Overhauling and draught-proofing existing windows
- Fitting new high-performance windows
- Double or triple glazing with vacuum or gas fill
- Internally or externally insulating external walls
- Underfloor insulation
- Installing fill in uninsulated cavity walls
- Reducing ventilation rates by sealing joints
- Replacing heating systems, including upgraded controls
- Fitting a condensing boiler with accurate and responsive controls
- Wood stoves and boilers
- Solar thermal panels for domestic water heating
- Photovoltaic panels for electrical energy generation
- Micro or larger wind turbines for electrical energy generation
- Loft insulation new or top-up
- Low-energy lighting
- Low-energy appliances



Appendix B: Formula for calculating wood energy

- (A) Total Energy=TE
- (B) Total Energy without wood=TE_{nonwood} (known from other collated data)
- (C) Space Heating Energy=SHE_{total}
- (D) Non-Space Heating Energy=nSHE
- (E) SHE that comes from wood=SHE_{wood}
- (F) SHE that doesn't come from wood=SHE_{nonwood}
- (G) SHE_{total}=SHE_{wood}+SHE_{nonwood}
- (H) Proportion of SHE that comes from wood=SHE_{wood}/SHE_{total}=P_{wood} (e.g. 0.1, 0.25) (from SAP)
- (I) SHE_{total}=2/3*TE
- (J) nSHE=1/3*TE
- (K) therefore nSHE=1/2*SHE_{total}
- (L) from (G), SHE_{total}=SHE_{wood}/P_{wood}
- (M) from (K) and (L), nSHE=SHE_{wood}/(2*P_{wood})
- (N) TE=TEnonwood+SHEwood
- (O) TE=nSHE+SHE_{total}
- (P) TE_{nonwood}+SHE_{wood}=nSHE+SHE_{total}
- (Q) Substituting into (P) from (L) and (M), TEnonwood+SHEwood=SHEwood/Pwood+SHEwood/(2*Pwood)
- (R) Taking SHE_{wood} from both sides, TE_{nonwood}=(SHE_{wood}/P_{wood}+SHE_{wood}/(2*P_{wood}))-SHE_{wood}
- (S) Simplifying the right hand side, (3-2*Pwood)/(2*Pwood)*SHEwood=TEnonwood
- (T) Dividing through by the constants, SHE_{wood}=TE_{nonwood}*(2*P_{wood})/(3-2*P_{wood})



Vintage	SuperHome Number	Age	m²
Modern	68	36	140
	71	36	103
	87	29	123
	145	31	140
	166	47	240
	180	46	94
	184	26	192
	191	27	61
	196	25	240
Mean		34	148
Post-war	119	55	76
	150	55	98
	168	55	120
	183	61	197
	192	55	126
Mean		56	123
Inter-war	111	65	80
	137	65	174
	153	77	157
	155	65	228
	178	95	82
Mean		73	144
Pre-war	82	117	74
	109	115	208
	129	105	138
	134	142	250
	148	145	166
	151	115	89
	170	112	180
	199	125	140
	186	205	110
Mean		131	151
Min SuperHomes		25	61
Mean SuperHomes		76	144
Max SuperHomes		205	250

Appendix C: Size and age of sampled SuperHomes

Source: Generated by author, 2015



		Normalised energy	-
Vintage	SuperHome number	consumption (kWh/year)	kWh/m²/vear
Madara	68	12642	00
Modern	71	12042	90
	87	14/34	144
	145	7950	20
	145	11105	114
	180	27274	114
	184	20059	149
	10 1	20038	104 01
	191	4524	01
Maan	190	20137	109
	110	13429	104
Post-war	119	4807	64 77
	150	7505	// 01
	100	22486	81 165
	103	32480	105
	192	7207	57
	111	12345	89
Inter-war	111	8758	109
	157	2568	15
	155	6249	40
	100	20709	91
	178	//55	95
Mean	00	9208	70
Pre-war	02	4391	59
	109	/545	42
	129	22110.3	167
	134	9903	40
	148	12308	74
	151	11859	133
	170	6062	34
	199	9347	67
	ISO	13704	125
Mean		10803	82
win SuperHomes		2568	15
Iviean SuperHomes		12280	88
Wax SuperHomes		32486	167
UN Mean (NEED 2012)		18100	177

Appendix <u>D: Energy consumption for all individual SuperHomes in the survey</u>



	Occupancy	CO, before	CO, after	CO₂ per person
Modern	2	87	<u>26</u>	13
Modelli	2	7.6	2.0	1.5 N Q
	2	59	1.8	0.0
	2	18.1	5.8	23
	3	74	2.8	0.9
	3	10	1.6	0.5
	1	5.4	1.8	1.8
	2	10	-0.8	-0.4
	2	8.9	1.9	0.9
Mean	2.3	9.1	2.2	1.0
Post-war	2	4.8	1.8	0.9
	2	7.3	2.7	1.4
	2	7.8	2.0	1.0
	2	28.1	4.4	2.2
	4	11	1.7	0.4
Mean	2.4	11.8	2.5	1.2
Inter-war	2	8.7	2.4	1.1
	6	14.7	2.8	0.5
	3	11.9	4.8	1.6
	2	15.7	4.3	2.2
	4	6.5	2.2	0.5
Mean	3.5	11.5	3.3	1.2
Pre-war	1	6	2.4	2.4
	2	14.5	5.7	2.9
	3	13.2	4.7	1.6
	2	12.5	4.5	2.2
	4	17.2	3.9	1.0
	3	11.5	3.0	1.0
	4	12.9	5.1	1.3
	4	14	4.1	1.0
	6	8.8	2.2	0.4
Mean	3.2	12.3	3.9	1.5
Mean SuperHomes	3	11	3	1.2
UK Housing Fact File_2013	2.36	N/A	4.57	1.9

Appendix E: Age of property, occupancy and carbon emissions before and after retrofits



References

ⁱ Liz Waters, Victoria Goodwright and Emily Wilkes, *Energy Consumption in the UK (2015)*, Department of Energy and Climate Change, 2015, p.5.

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/338662/ecuk_chapter_3_domestic_facts heet.pdf

ⁱⁱ Solar PV output figures used in modelling come from CIBSE, <u>http://www.cibse.org/getmedia/0984a488-bbeb-453b-</u> <u>b10c-25abf10ce001/cb5.pdf.aspx</u>

ⁱⁱⁱ 50% PV export figure comes from, among others, Ofgem. <u>https://www.ofgem.gov.uk/ofgem-publications/58855/fit-generator-guidance.pdf</u>

^{iv} Wood energy density figures come from the Biomass Energy Centre, <u>http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,59188&_dad=portal</u>

^v Secondary heating fraction from SAP 2012 version 9.92 (October 2013). <u>https://www.bre.co.uk/filelibrary/SAP/2012/SAP-</u>2012_9-92.pdf p224

^{vi} Solar Thermal energy generation figures come from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/376187/ECA770_Solar_thermal_technology.pdf

http://www.aessolar.co.uk/downloads/AES%20-%20Estimating%20Solar%20Thermal%20Performance.pdf