Housing Innovation Showcase 2012 Post Occupancy Evaluation

Phase 1 – Part 2

Energy Demand - First Year of Occupation

Summary document

kingdom housing association

HOUSING INNOVATION SHOWCASE 2012
affordable ^ sustainable ^ construction

Prof John I Currie
Julio Bros-Williamson
Jon Stinson

Edinburgh Napier University, Institute for Sustainable Construction, Scottish Energy Centre

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Edinburgh Napier UNIVERSITY

Institute for Sustainable Construction
Construction technologies for tomorrow's communities

EXECUTIVE SUMMARY

The Housing Innovation Showcase (HIS), developed by Kingdom Housing Association (KHA) comprised of twenty seven dwellings of varying size and form, using ten different construction techniques; twelve flats with communal gardens, and eleven terraced houses and four bungalows, all with private gardens.

The evaluation of the HIS properties was split into two phases comprising two distinct parts; the first phase, part one, formed a pre and post-handover early occupation Building Performance Evaluation (Jack, Currie, Bros-Williamson, et al. 2013).This report, which forms the second part of phase one, focuses on an initial twelve months of occupation following handover, comparing actual energy consumption against predicted energy consumption This analysis was performed by logging consumption data using an In-home Display Monitor (IHD) correlated by meter readings; which permitted a direct comparison with predicted consumption.

The report analyses energy use derived from a combination of heat and electricity consumption and comparing it with typical household figures and average regional figures whilst observing total carbon and cost comparisons across the development.

Despite the best efforts from KHA and stakeholders in designing and building quality homes to meet specific targets, the results of energy for space and water heating consumption were substantially higher than the predicted. This gap in performance ranged from properties being 5% to 350% higher than design values. This gap in energy consumption also produced disparities in total dwelling heating costs with a £175 increase between the mean predicted and the mean delivered. In comparison, the HIS development was £254 below the typical Scottish mean expenditure (£537/yr).

This performance gap is a result of: construction type discrepancies, for example some ground floor concrete slabs not being level creating problems in the timber frame erection, varying occupant comfort and behaviour patterns; creating different heating patterns thus consuming unusual amounts of energy, and the result of using different building services where controls weren't adequately operated, deemed to be complicated or not operating as expected.

The study will continue into the next monitoring phase; focussing on testing a smaller representative sample of dwellings which includes a long term analysis of energy consumption, re-evaluating the properties thermal envelope and monitoring the correlation between indoor air-quality (IAQ) and dwelling ventilation systems. It is hoped that such results can deliver a greater understanding of environmental performance; going beyond the work of most other studies to-date.

Figure 1: Design stage 3D render of the HIS site. Source: Oliver Robb Architects 2012.

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INTRODUCTION

Phase one, part one of this study analysed the impact that the building envelope, services, and residents had on the dwellings energy performance at an early stage of occupancy. This second part of the study focuses on analysing energy consumption over a full year of occupation, together with any energy inputs generated by low carbon technologies installed in the dwelling. The aim was to compare actual energy consumption figures against those predicted from calculations during the design stage where the Standard Assessment Procedure (SAP) was used.

There is little published work on the subject of household energy consumption following a Post Occupancy Evaluation (POE) when compared to other building types, e.g. offices, commercial and industrial properties (Stevenson and Leaman, 2010). This study seeks to explore energy consumption of 3 different dwelling types (flats, bungalows and terraced homes) across the 10 blocks and system providers, amounting to 25 homes in total.

One of the main objectives of this study was to create a profile of energy consumption and production that will correspond to the occupancy and dwelling type under the benefits and constrains that the method of construction delivers. This information will present an interesting dialogue between architects and system providers on how predicted energy differs from actual energy usage and provide evidence to regulatory authorities on the shortcomings of some of the proscribed methods, together with the effect on carbon reduction targets.

Although difficult to separate, occupancy patterns of use are naturally embedded into the energy consumption totals and are analysed concurrently with the numbers of occupants, hours of use and weekly activities.

In-House Display (IHD)

IHD's were fitted into each property providing a direct feedback to the dwelling occupants of real-time energy use. This embedded technology allowed the BPE Study Team to download hourly energy consumption data which could later be analysed to provide daily, weekly, monthly and yearly energy demand profiles. This information was validated and verified against utility meter readings. Most IHD devices installed in the properties were configured to log total electricity and gas consumption allowing a third channel to log, for instance, electricity produced from a Solar PV array. Separate heat metering was used to log solar thermal and air source heat pump (ASHP) delivered energy.
The IHD device connected via a pulse output to the electricity meters by using a current transformer and gas via a pulse block installed on the meter (EWGECO, 2011). These connected to a transmitter which can be connected wirelessly via Zigbee 2.4GHz communication to a traffic light display unit revealing energy consumption.

Figure 2: Example of the IHD display unit

Properties that were able to connect their transmitters to a wireless internet device, stored and displayed their consumption in a web portal service called "My EWGECO". Only 40% of the homes signed-up to this service meaning physical downloads were performed which required access to the property.

Demographic study & sample size

An attempt was made to collect data from all 27 dwellings as part of this study. Whilst some residents were available at all times, others were difficult to contact or were simply not interested in taking part in the study. The success rate of data retrieval was considered to be positive with questionnaires and full twelve month data retrieved from 25 out of the 27 properties.

In order to perform a representative analysis it was essential to understand the influence that the number of residents and their occupancy patterns have on the energy consumption. To obtain this, a house survey and face-to-face interviews were conducted in order to assess how the properties were used and provide an insight into the intensity of energy use. The majority of residents were unemployed or retired which indicates longer period dwelling occupancy hours. Properties that had at least one working adult had either a second unemployed adult, or one to three children living intermittently in the dwelling. From the occupant questionnaire, it was understood that over the weekend, 11 out of the 25 homes were mostly occupied, whereas 12 out of 25 residents indicated that they remained out most of the day during the weekends. These occupation patterns were also dependant on the weather patterns and time of the year.

42 ADULTS >16yr OF AGE

1.7 ADULTS PER HOUSEHOLD

21 CHILDREN <16yr OF AGE

1.3 AVERAGE TOTAL OCCUPANTS PER HOUSEHOLD

METHODOLOGY

The study focused on obtaining consumption data during the first year of occupation from hand-over date. Collecting information from these dwellings was dependant on occupant availability and co-ordination in gaining access to the dwellings preferably in clustered time periods. Where possible, data was also collected using the IHD reporting and data storage portal where real-time data is uploaded on an hourly basis. This service was only available to occupants that had their IHD connected to the internet and agreed to have their information uploaded for the study.

Primary data was obtained from the installed IHD located, typically, in the entrance hall of each property. To correlate and validate this data, utility meter readings were obtained from handover to its anniversary of occupation as this was the simplest approach to determining annual billed consumption (EST, 2008).

Data acquired from the properties was analysed to obtain total monthly consumption figures in kilowatt per hour (kWh) for both electricity and gas consumption as well as the heat generated by an ASHP (kWh) or electricity production from a solar PV array. The monitoring and calculation procedure was undertaken using the CIBSE TM22 methodology (Field and Davies, 2006). Comparison with predicted energy figures was focused on space and water heating demand as characterised the efficiency of the envelope and building services. Electricity, unless used for heating purposes (ASHP) lighting, controls and use of pumps in the dwellings, was analysed separately. As this included un-regulated electricity which is occupant-led primarily by appliances. For this reason, space and water heating delivered by the different system technologies in the properties were analysed **closely** and compared with reference values.

Results were presented as annual energy consumption figures for heating with the cost of energy and the environmental impact in carbon emissions (kg of CO_2). In order to compare dwellings in the same block against a typical Kingdom HA home (Control dwelling), normalisation of energy use was made by floor area (m^2).

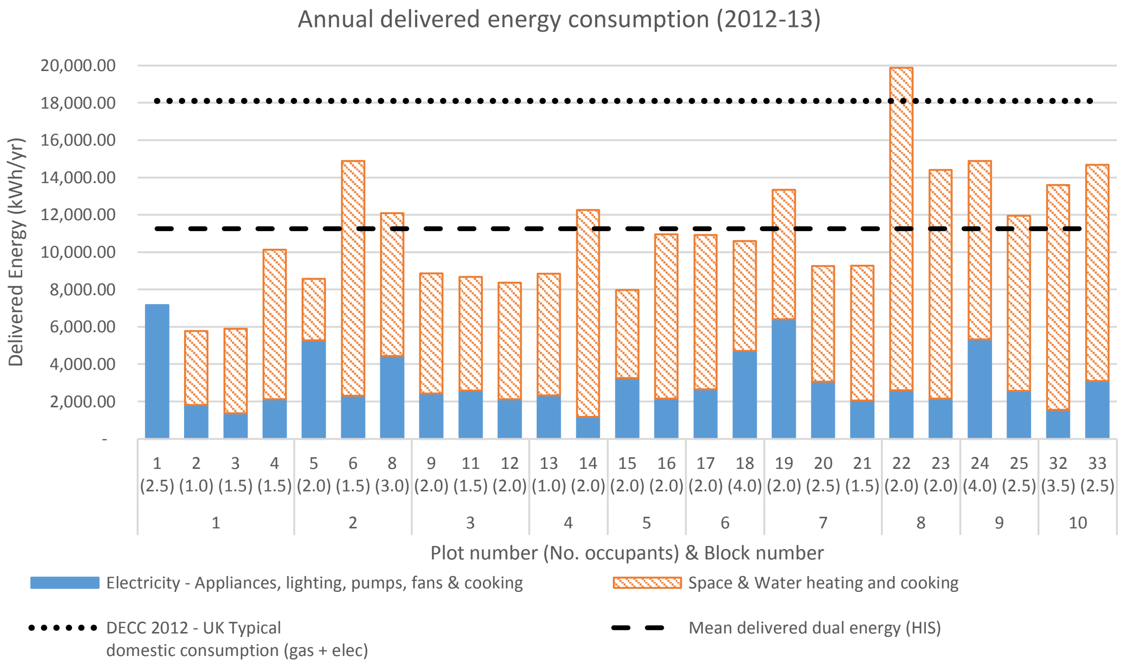
Figure 3: (left) Diversity of heating technology - ASHP & Solar Thermal

Figure 4: (right) Water cylinder for ASHP

EVALUATION OF RESULTS

This section seeks to provide an overview of the total delivered energy consumption during the first year of occupation. It outlines how this impacts on cost and carbon consumption and provides a comparison to typical energy consumption levels in Scotland and UK. As well as comparison against benchmarks, the results are paired with their relevant design-stage predicted energy consumption values.

Annual energy consumption

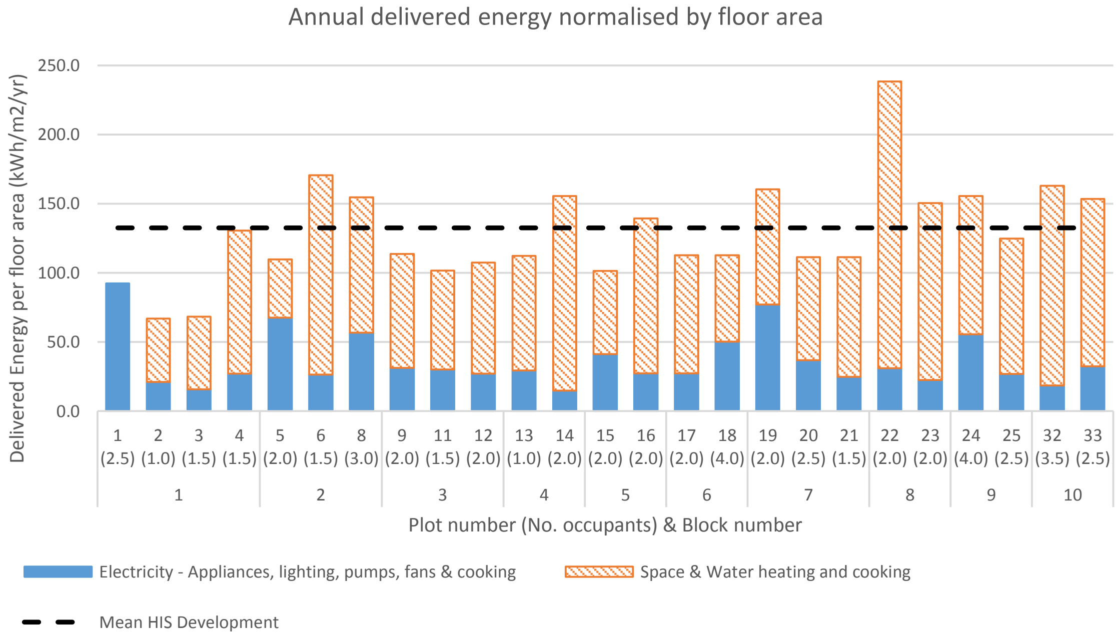


Graph 1: Annual delivered energy consumption over the first year of occupation: 2012-13

Annual delivered (metered) energy consumption for the homes is presented in Graph 1. In order to provide a comparative benchmark the graph also shows the most recent UK Sub-National Energy Consumption Statistics for gas and electricity at 18,094kWh/yr (DECC, 2012). Additionally they are compared with the average delivered energy of the whole development which stands at 11,200kWh/yr.

- 24 of the 25 dwellings performed better than the UK Sub-National Energy Consumption benchmarks (DECC, 2012)
- Ten of the dwellings consume more energy than the development energy consumption mean with some peak values approaching 20,000kWh/yr
- The impact of electrical energy was smaller than that of energy for heat, however electricity has a larger environmental impact than gas used typically to heat the properties
- Properties with high electricity consumption are due to a higher number of occupants or higher quantities of electricity used to provide heating (e.g. ASHP, plots 5 & 19) or may have experienced a fault with their controls.

Normalised energy consumption comparison



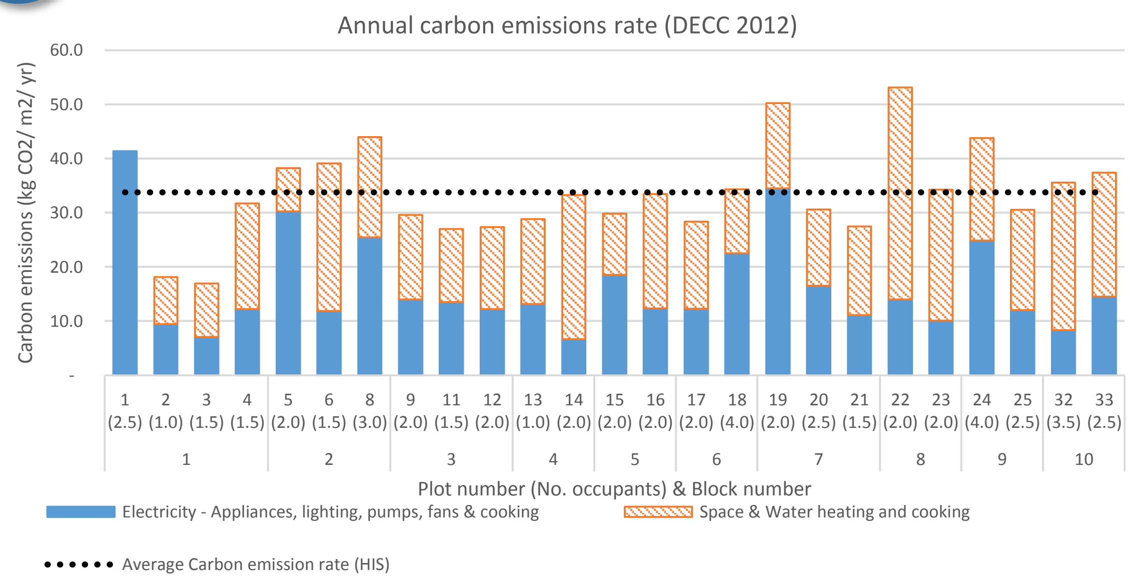
Graph 2: Annual delivered energy normalise by floor area

Normalised energy consumption by floor area for the control dwelling (plot 17) indicates that a quarter of its energy is used for electrical purposes (appliances, lighting & pumps/fans) and the remaining three quarters of energy is required for space heating. In comparison to similar properties, e.g. plot 18 (Passive House), this has a similar energy consumption per floor area; where nearly half of its energy is used as electricity with the other half as heating. This provides an interesting comparison as the Passive House property is heavily insulated with high performing doors and enhanced solar gains while the control house is a standard 2010 Kingdom HA home.

An analysis of plot 14 showed that a 1/8th of its energy consumption came from electricity while the remaining was for space and water heating. This property is occupied by a retired couple who experienced some complications in understanding the heating control system, moreover they seldom leave the property. A similar pattern was experienced in plot 16; occupied by an elderly retired couple who occasionally have grandchildren staying in the home

- Normalised energy use by floor area is useful to facilitate a comparison between properties.
- The highest energy consumer is plot 22 with 2 adults living permanently in the property; consuming 240kWh/m^2/yr.
- The rest of the properties show a consumption range between 100 and 170kWh/m^2/yr.
- High electricity consumers include plots 1, 5 and 19 that utilise ASHP as their main heating source.
- The remaining properties show an average electrical consumption no greater than 25kWh/m^2/yr,
- Plots 8, 18 and 24 are occupied by 3 to 4 residents per household and consume >50kWh/m^2/yr.

Annual Carbon Emissions



Graph 3: Total first year carbon footprint and carbon emissions rate using DECC 2012 factors

Carbon emissions (heating and electricity demand) for households in the HIS development range from:

- flatted dwellings 17 to 44 kg/CO_2/m^2/yr,
- semi-detached bungalows from 30 to 33 kg/CO_2/m^2/yr,
- terraced homes from 28 to 53 kg/CO_2/m^2/yr.

Differences are mainly identified with occupancy profile or because of high electrical use for appliances and heating devices (ASHP).

The impact on carbon emissions is evident when households depend on the use of electricity for their heating, i.e. plots 1, 5 and 19 which are equipped with ASHP's. Plot 5 shows lower than average carbon emissions from electricity primarily due to its low occupancy. In comparison, plot 1 emits above 40 kg/CO_2/m^2/yr just on the electricity carbon impact alone, much higher than many other plots with combined carbon impacts. On other plots, the carbon impact of heating exceeds the average combined carbon emissions; as the case with plots 6, 14, 22, 23, 32 & 33, where heat outstrips electrical carbon impact. The remaining properties have a balanced effect of heat and electricity on its carbon footprint. Comparing results with the control house (plot 17), 10 out of 25 properties have performed similarly. Two plots (2 & 3) underperform the control house in carbon emissions, but are homes with low occupancy numbers and intermittent occupation.

34

Kg CO_2/m^2/yr

Mean Carbon Emissions in HIS

17

Kg CO_2/m^2/yr

Lowest Carbon Emitting property (1 adult + 1 <16 yr old & intermittent occupancy)

53

Kg CO_2/m^2/yr

Highest Carbon Emitting property (2 adults & unemployed during 1st year of occupation)

56% (14 of 25)

Households below mean CO_2 in HIS

Annual energy costs

In developments like the HIS, energy cost is of particular importance to the social landlord as well as to the residents. For the purposes of this analysis, the actual tariffs for delivered energy of heat in a bungalow and flat have been applied to the energy consumption figures in order to make a comparison. The cost structure applied to these calculations is derived from the gas equivalent cost for heating and the electricity cost delivered to the source properties. From the interview survey it was ascertained that some tenants had switched from standard metering to pre-paid meters during the monitoring period which can distort cost calculations. The most striking observation of the results was that electricity is the predominant energy cost compared with costs of heating. This is both due to consumption in some dwellings and also cost per kWh of each fuel.

The average cost for **heating only** was:

- Flats: Between £150 and £480 per year (£2.9 to £9.2 per week),
- Bungalows between £180 and £480 per year (£3.50 and £9.2 per week),
- Terraced homes between £225 and £470 per year (£4.30 and £9.0 per week).
- Properties with an electrical (ASHP) space & water heat source spent more per year.

£1,115/yr

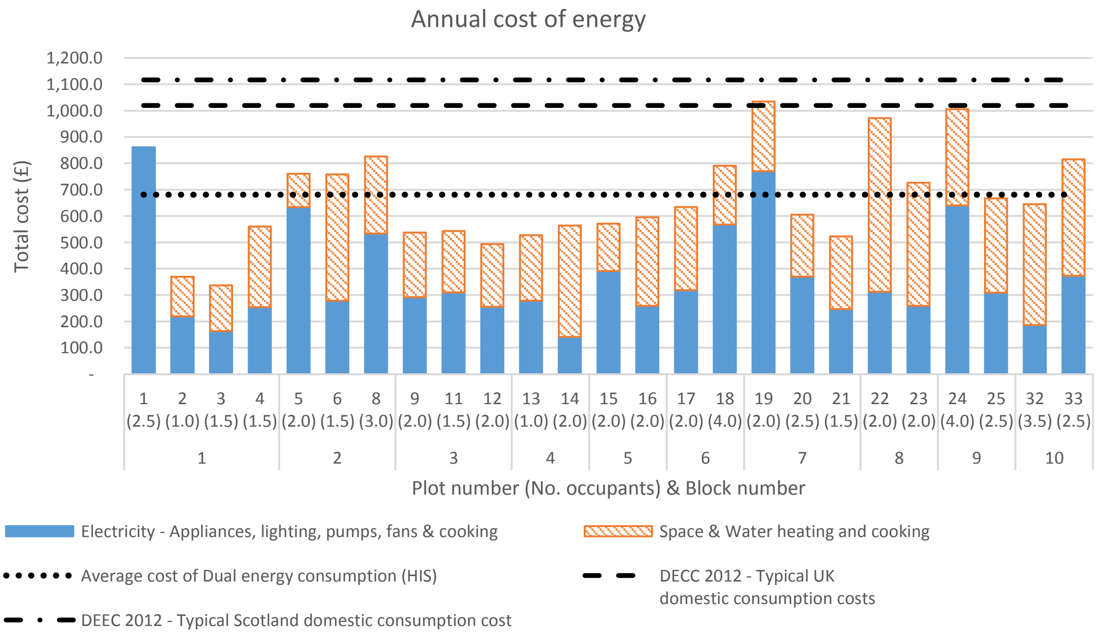
Scotland typical annual domestic **dual** energy expenditure (DECC, 2012)

£1,020/yr

UK typical annual domestic **dual** energy expenditure (DECC, 2012)

£680/yr

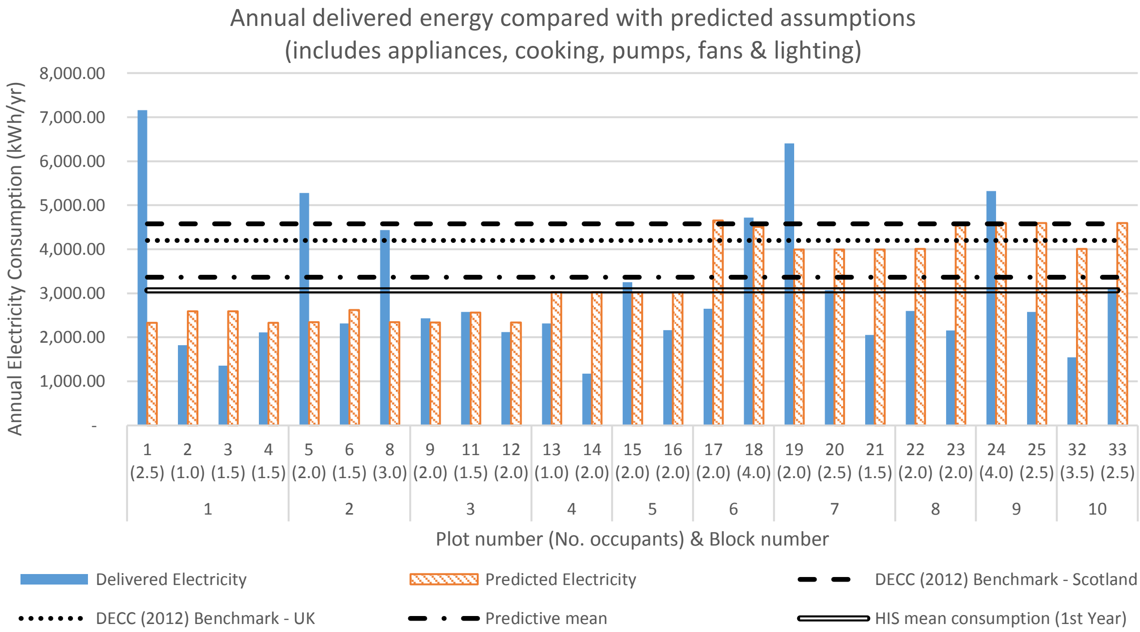
Mean **dual** energy consumption in HIS



Graph 4: Total cost to deliver both electrical and gas (heat) energy to the properties

Consumption - Electricity

In a scheme such as the HIS, electrical energy consumption can vary enormously between household given the diversity of technology installed, the occupancy and the house type.



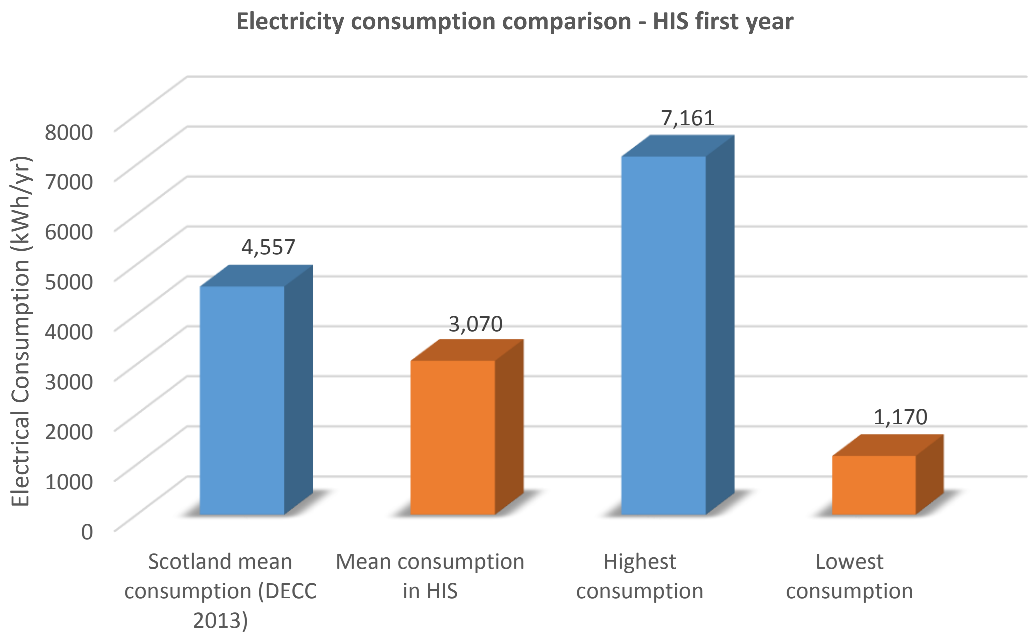
Graph 5: Annual delivered electrical energy compared with predicted assumptions.

Graph 5 shows how the delivered (metered) energy consumed over twelve months compares against predicted calculations of assumed performance. Estimating electrical consumption in a dwelling depends on many parameters where occupant's behaviour plays a big part in the total energy use (Firth et al., 2008). Reduction in electricity demand through occupant behaviour changes can be between 10-30% (Palmborg, 1986) primarily through social habits. Prediction tools used in the built environment for compliance purposes do not consider any un-controlled electrical energy use but do include consumption for lighting; in relation with the number of assumed occupants, floor area, percentage of low emission fixed lighting outlets (BRE & DECC, 2011) and daylighting in accordance to factors applied to the month of the year. It also accounts to electricity used for pumps and fans consumed by ventilation and heating technology (Yohanis, 2012).

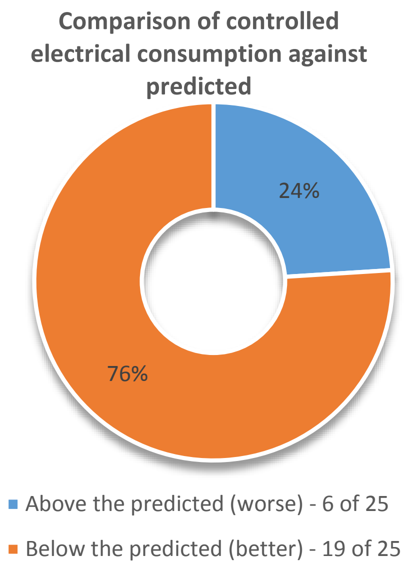
For the purposes of this project, and to produce a comparison base between the actual energy consumed, real-life energy consumption benchmarks have been used as well as average household energy statistical data (DECC, 2013).

Floor area benchmarks suggested by Yohanis et al. (2008), have been used to obtain a prediction of controlled and un-controlled energy use.

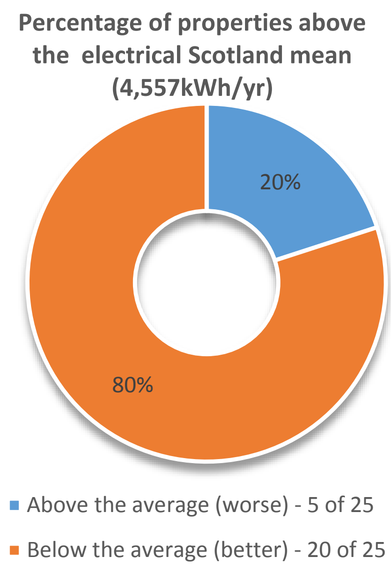
- Results in Graph 5 include consumed energy by lighting, cooking, pumps, fans and appliances.
- Properties that use ASHP are easily identified as high electrical consumers.
- A threefold electrical energy consumption over the predicted has been monitored in Plot 1 (ground floor flat).
- Plot 5 (ground floor flat) with an ASHP presents a twofold consumption from the predicted.
- Plot 19 (terraced dwelling) presents a disparity of 60% with two retired adults and an intermittent occupancy pattern.



Graph 6: Electricity consumption comparison in the first year of occupation



Graph 7: Delivered against the predicted



Graph 8: Properties above/ below UK mean

60%

of properties above the Scotland mean used an ASHP as their main heating

39%

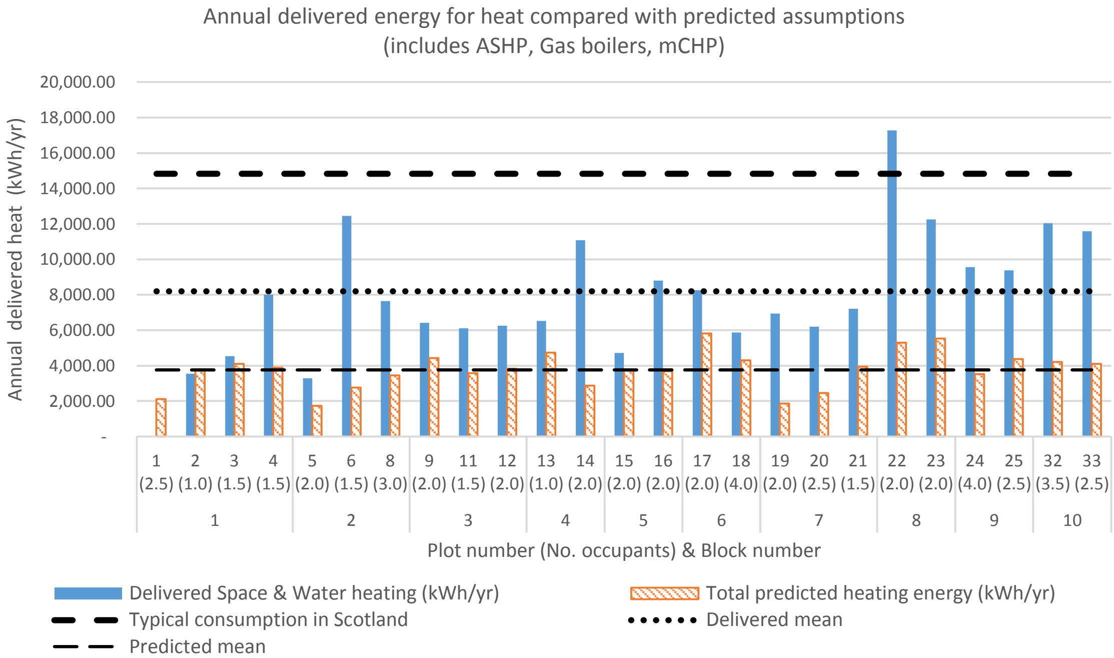
mean electricity demand was met by Solar PV technology

Occupancy profile, Household appliance use, Heating controls, Technology misuse

were the main reasons for high electrical energy demand.

Consumption - Heating

Compliance modelling performed during the design process indicated that the energy efficiency and environmental carbon impact of a building is proportional to the dwellings envelope performance, ventilation performance, and the efficiency of the delivery of heat to the building. Property energy efficiency is calculated with aspirational design specifications and performance features (Kelly et al., 2012) . The quality of the model and how well the design is executed by contractors should deliver a building that performs closely to its predictions, this is seldom experienced, hence a performance gap.



Graph 9: Delivered & predicted heat energy comparison

The delivery of heat to the properties at the HIS came in various forms making it difficult to compare like with like. Instead, 12 month heat consumption by property were compared individually against the reference values obtained at design stage.

The HIS development showed a variety of technologies installed in each block of dwellings. The implementation of domestic building services ranged from heat pump technology using ASHP to micro Combined Heat and Power (mCHP). Some dwellings were fitted with conventional combination boilers and/ or solar hot water. Many properties were also fitted with Mechanical Ventilation with Heat Recovery (MVHR) systems which recover waste heat from wet room extract and supplies it back to living areas.

Graph 9 displays a comparison of delivered heat energy per household against that predicted at design stage.

3,300kWh/yr
Lowest (best) heat demand

17,300kWh/yr
Highest (worst) heating demand

UK Benchmark – 14,080kWh/yr → 5,800kWh/yr lower

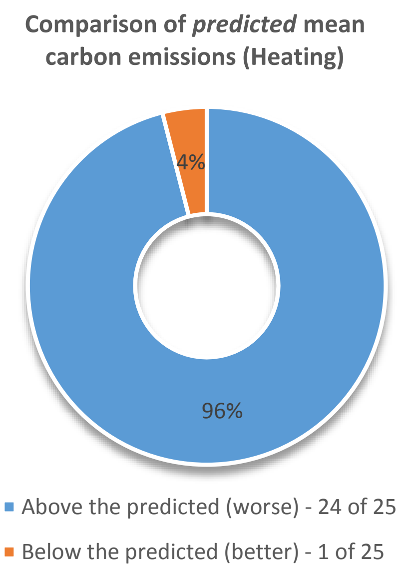
Scotland Benchmark – 14,800kWh/yr → 6,600kWh/yr lower

HIS mean delivered consumption 8,200kWh/yr → 4,400kWh/yr higher

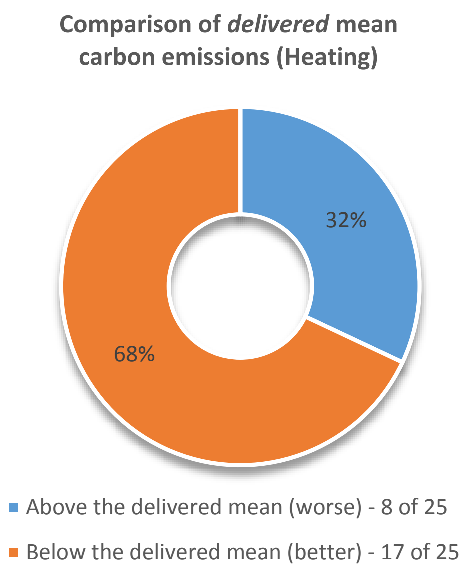
HIS mean predicted consumption 3,800kWh/yr

Carbon emissions comparison - Heating

The impact of carbon emissions from fuel consumed for space and water heating were calculated using the factors quoted by The Department of Energy and Climate Change (DECC) which are updated annually based on changes in generation emission factors (DEFRA & RICARDO-AEA, 2013).



Graph 10: Predicted mean carbon emissions



Graph 11: Delivered mean carbon emissions

9.0

Kg $CO_2/m^2/yr$

Predicted mean carbon emissions of the HIS development

19.5

Kg $CO_2/m^2/yr$

Delivered mean carbon emissions of the HIS development

7.7

Kg $CO_2/m^2/yr$

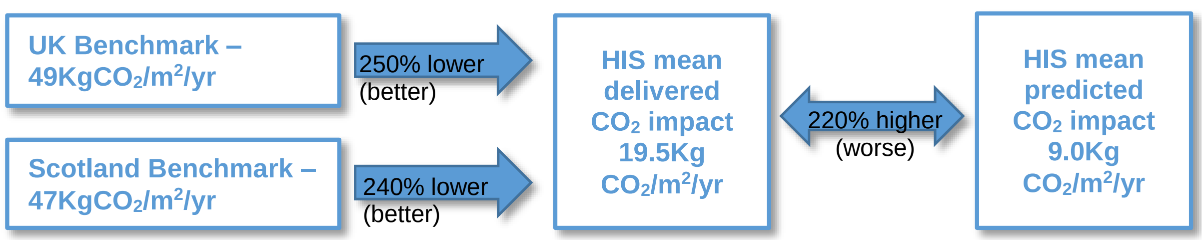
Dwelling with lowest delivered carbon impact

37

Kg $CO_2/m^2/yr$

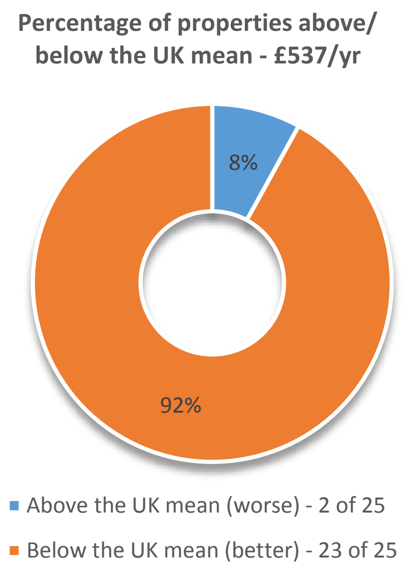
Dwelling with highest delivered carbon impact

A direct comparison can be misleading as the HIS development has mixed occupancy, heating technology and building performance. Properties depending on electrical energy for space and water heating were the higher impact properties. Electricity has a much higher carbon emission factor (0.448kgCO_2/kWh) than gas (0.189 kgCO_2/kWh) providing a higher impact differential between homes.

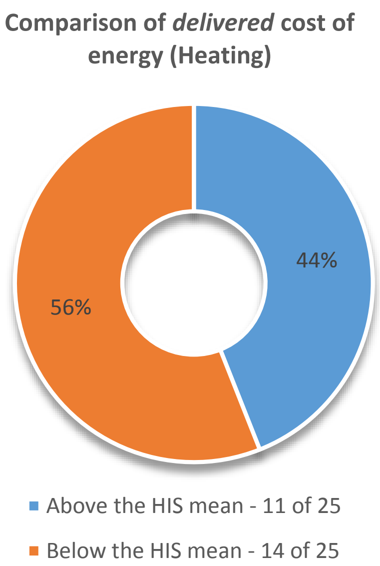


Cost comparison - Heating

It is hoped that sustainable and energy efficient homes like those built in the HIS are healthier, environmentally less of a burden and cheaper to run than the average private or public dwelling under current Building Regulations. However, according to The Scottish Government (2012), there are concerns about the affordability of keeping households warm and comfortable given the sharp increase in energy costs. The average direct debit domestic gas bill in Scotland increased in real terms by approximately 49% over the period 2007 – 2013 (DEEC, 2013).



Graph 12: Properties above/ below UK mean consumption



Graph 13: Properties above/ below HIS mean

£145/yr

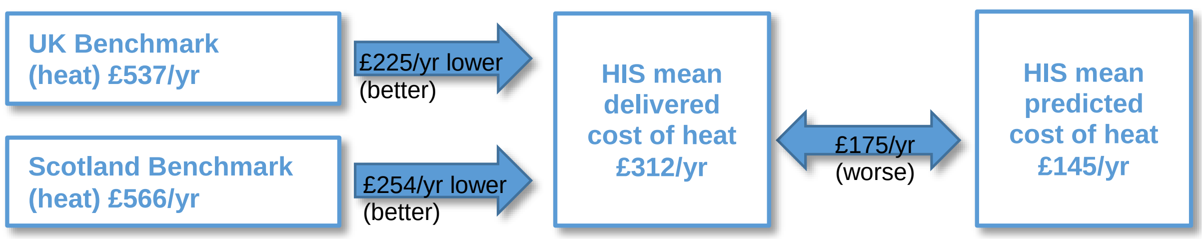
Mean predicted cost of heat in the HIS development

£312/yr

Mean delivered cost of heat in the HIS development

25 of 25 properties

were above the mean predicted cost of the HIS development (£144.50/yr)



CONCLUSIONS

The Housing Innovation Scheme (HIS) was a bold attempt to trial and drive forward innovation in the construction of housing in Scotland. Kingdom Housing Association (KHA) have recognised the varied construction systems that innovate within the industry and have tried to implement them all in one development and learn from the outcomes that each have entailed. KHA were not only interested in the thermal performance of the properties; but were equally interested in build speed, cost and occupant satisfaction. Phase I part I of the Building Performance Evaluation (Jack, Currie, Bros-Williamson et al. 2013) reported on such issues as well as the early occupation building performance which gave the social landlord an indication of construction quality and thermal effectiveness.

This brave attempt to pilot different construction types and processes were additionally intended to test the efficacy of applying various performance standards now becoming a backbone of development, particularly in social housing. Although a relatively small sample size, the inclusion of a Passive House, Scottish Building Standards Section 7 Silver and Gold in the development; signified how the scheme was advancing towards Low and Zero Carbon housing policy, for example the Government's Homes that don't Cost the Earth (The Scottish Government, 2012), Homes Fit for the 21st Century (The Scottish Government, 2011), and the stimulating roadmap set by Lynne Sullivan dubbed "The Sullivan Report" (Sullivan, 2007) which has now reconvened setting out new challenges reviewing targets in a post-economic downturn and beyond (Sullivan, 2013).

The overall results for delivered heat energy demand for the twenty five monitored dwellings were:

- Only one dwelling was <5% above the predicted

- Five dwellings consumed ≤40% above the predicted

- Five dwellings consumed between 60% – 90% more than the predicted

- Thirteen dwellings consumed between 100% and 350% more than it's predicted.

- The mean over-consumption in the HIS development was 122% more than the predicted

Although the energy results demonstrated a significant shortfall against the predicted consumption, it is important to recognise the scheme is a success in the approach and dedication of all the industry partners. The diversity and unification of various partners in one development has been a success which has created new stakeholder partnerships. The results show that an industry led change is required where aspirational performance has to be closely lined up with each other, reducing performance gaps by enhancing communication and site awareness in the execution of energy efficient methods. Each partner has used this project to learn and further fine tune their design.

It is important to point out that the data presented in this report is for the first 12 months of occupation. The first year of occupancy is a period in which residents are still un-familiar with heating controls and the use and benefits of renewable technology are unknown. This period acts as a learning curve for many people where thermostats are not used appropriately and energy is wasted where unfamiliar seasonal conditions combine with highly insulated envelopes. For this reason, the data presented can be somewhat distorted and not truly representative of a typical building performance; rather a behavioural reaction to a new home and an adjustment period. Data retrieved for the second year of occupation should show a more realistic account to the building performance.

Figure 5: Bock 2 – Scotframe flatted accommodation

Complications during study

- **Lack of access:** Twenty five out of the twenty seven dwellings were fully monitored. Access to these properties was sporadic but full data was retrieved when available.
- **Poor IHD installation and commissioning:** Most IHD's were installed by building contractors who had little knowledge of the importance of adequate set-up and commissioning.
- **Gaps in energy logging using IHD:** When downloading consumption data, some gaps appeared caused by IHD's being switched off, interference of data retrieval or occupant tampering. All data was supported by meter readings.
- **Sub-metering of heat and electricity:** IHD's only have the capacity to log total energy consumption; therefore heat and electricity was not segregated by appliance use, water/ space heating and other forms.
- **Lack of energy data recording:** The IHD's predominantly were installed to monitor gas, electricity and heat generated. Not all technology in dwellings was monitored leaving some gaps in energy consumed and generated.


Figure 6: View across the playground of HIS

Figure 7: Block 9 - CCG terraced dwellings

Further Work

Subsequent to this report of the first year of occupation energy consumption evaluation, a more defined and comprehensive study will follow. Representative dwellings from the Housing Innovation Showcase will be selected for long term detailed monitoring which will look at how envelope and whole-house performance can decline over time. The overarching aim of the continued work is to accurately quantify the performance gap that has been observed in this document but also define the effects it will have on the properties life cycle. Field tests will be more defined in order to explore how the building performance affects the buildings environmental impact, occupant's health and comfort whilst also observing how electrical energy is used in a more detailed way.

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Prepared for: **Kingdom Housing Association Limited**

Saltire Centre, Pentland Court,
Glenrothes, Fife KY6 2DA

Phone: 01592 631661
Fax: 01592 631991
e-mail: **kingdom@kingdomhousing.org.uk**
Web: **www.kingdomhousing.org.uk**
Web: **www.housinginnovationshowcase.co.uk**

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Prepared by: - **Scottish Energy Centre, Institute For Sustainable Construction, Edinburgh Napier University**
Email: **j.broswilliamson@napier.ac.uk**
Tel: 0131 455 51 39
Web: **www.napier.ac.uk/sec**

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