Review of actual energy demand and envelope performance of the Housing Innovation Showcase 2012

Post Occupancy & Building Performance Evaluation results 2017

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1. EXECUTIVE SUMMARY

This document presents a review of four years of delivered energy demand of selected dwellings at the Housing Innovation Showcase (HIS) developed by Kingdom Housing Association (KHA). It also includes results of the building performance bi-annual monitoring, used for comparing against design aspirational energy demand calculations.

The results show that throughout the years of occupation, a pattern of consumption has emerged, which distinctly divides early occupation and the latter years after this period of adjustment.

The study has benefited from a low occupant changeover, meaning most of the families that occupied the dwellings at the start of the study in 2012 have remained in their home until the end of the monitoring in January 2017. Only two dwellings have experienced a changeover of occupants which can be unusual in social rented accommodation. This consistent dwelling demographic, benefits the study as it helps to understand the household energy consumption without drastic changes to the occupant type and size, which often can influence longitudinal delivered energy demand studies.

Likewise there are differences in envelope performance. Thirteen of the homes in this 27 plot development underwent wall in-situ U-value evaluation and air permeability testing over the period of pre and post occupation. Results demonstrate a decline in performance, albeit small in these early years of occupation, but concerning if analysed over the life time of the dwellings.

Although this study includes a small sample size, it has demonstrated that compliance models used at the design stage aren't suitable for estimating dwellings with highly specified heating and ventilation technology or renewable sources of energy. The energy demand of these dwellings differs highly to the predictions made at the design stage, whereas the more traditional dwellings with simplified technology for heating purposes and without renewable fuel sources differed less so to the estimations.

2. METHODOLOGY

The work shown in this report has adopted the same methodology stated in previous documents related to this study. The properties have been monitored for a longer period, following the same guidelines and standards as in the initial work. This applies to the data retrieval, and various building performance tests. As a priority, this study kept the placement of monitoring equipment and periods of data retrieval consistent throughout the years, providing a linear comparison that clearly demonstrated trends in performance.

The post occupancy energy consumption study has retrieved hourly energy figures from the in-home display (IHD's) monitors installed before occupation and in operation in most of the analysed dwellings. This was corroborated with yearly energy meter readings of fuel consumption over the study periods.

This study has focused on the delivered heat energy demand and its correlation with the envelope performance. For this report, the use of electricity has been omitted as it is strongly related to the occupants plugged appliances and their efficiencies and hours of use. Total heat energy by space and water heating have been analysed separately, comparing results with as-designed calculations. Water heating was recalculated with actual occupant data obtained from surveys which was then subtracted from the total delivered heat energy to provide total space heating for the dwellings. The use of renewable energy contributing to the demand of h energy was considered particularly in dwellings where it contributed to space heating.

For methodologies concerning the in-situ U-value and air permeability testing it is advised that early reports, particularly the consultancy document by Jack et al., (2013), Bros-Williamson et al., (2014) & Bros-Williamson & Currie, (2015) should be revised.

3. THE PROJECT TIME LINE – WHEN THE TESTS TOOK PLACE

The post occupancy (POE) and building performance evaluation (BPE) of the dwellings at the Housing Innovation Showcase took place over a four year period with key outputs throughout that time line. The following infographic explains the different test periods and milestones in the project.

2012 MAY

HOUSING INNOVATION SHOWCASE 2012
affordable ^ sustainable ^ construction

- Completion of construction stages
- Initial building performance work
- HIS expo
- Final commissioning & completion
- Air tightness testing. n=27

2012 JUNE/ JULY

- Handover to residents
- Start of early occupation study (POE)
- In-house display (IHD) monitors installed

2012 WINTER

- 1st BPE study – U-value tests, Thermography survey. n=24 dwellings
- Meter readings and IHD deployment
- End of early occupation study (POE)
- Occupancy surveys

2013 WINTER

- First year of occupation energy use
- IHD & Meter readings
- Occupant surveys

2014 WINTER

- 2nd BPE study – U-value tests, Air-tightness testing. n=13 dwellings
- Second year of occupation energy use
- IHD & Meter readings
- Temperature °C & Humidity RH% loggers installed
- Weather station deployed
- Occupancy surveys

2015 WINTER

- Third year of occupation energy use
- IHD & Meter readings
- Weather station first year data
- Download & re-deploy °C & RH%
- Occupant surveys

2016 WINTER

- 3rd BPE study – U-value tests, Air-tightness testing. n=13 dwellings
- Fourth year of occupation energy use
- IHD & Meter readings
- Download °C & RH%
- Weather station second year data
- Occupancy surveys

4. DEMOGRAPHICS AND HOUSE TYPE

The POE and BPE began by monitoring and testing as many participant households as possible. During the early occupation 24 of the 27 dwellings were monitored and assessed giving an 88% participation, deemed to be representative given the small sample size. The study was then reduced to 13 dwellings, monitoring one dwelling of each block with the exception of two blocks where all dwellings were analysed (Blocks 6 & 7). This further study tried to focus on monitoring fabric performance and energy demand over longer periods of occupation. The selected represented all archetypes in the development, including flats, bungalows and semi-detached dwellings. See Appendix A for dwelling codes and their description.

13

dwellings analysed in detail

Archetypes include: 3 flats, 2 bungalows & 8 semi-detached dwellings

Occupant retention since first handover

Average number of occupants:

Assumed at design: **2.5** occupants

Actual family size: **2.9** occupants

The study was subject to a low family turnover where 85% of families remained in the dwellings for the duration of the study. At design stage an average figure of 2.5 people in homes was used whereas the actual household size was of 2.9 people which impacted on hot water use, internal temperatures and energy demand.

5. SPACE HEATING

A variety of technologies were trialled at the HIS, however the study concentrated on monitoring the delivered (demand) heat energy. Comparisons were done of individual dwellings between the design assumptions and the actual energy use over four years of occupancy. Energy was split between fuel for hot water use and space heating. The space heating demand was related to the envelope performance and set temperatures from the occupants.

An interesting trend appeared in most of the dwellings over the four year period, observed in Figure 1 below where an average consumption per analysed year is shown. Space heating during the first year of occupation was at its highest, subsequently year two reduces by 600kWh, followed by a stabilisation in years three and four around the 4,700kWh consumption mark. This demonstrates how the first year can be an adjustment year by the occupants in a new home, followed by year two, with a slump in energy use reacting to high energy use in year one and a stable period and possibly a more realistic account for energy use in years after. On average, over a four year period the dwellings consumed nearly 3,000kWh more than the assumed energy calculations for space heating at the design stage.

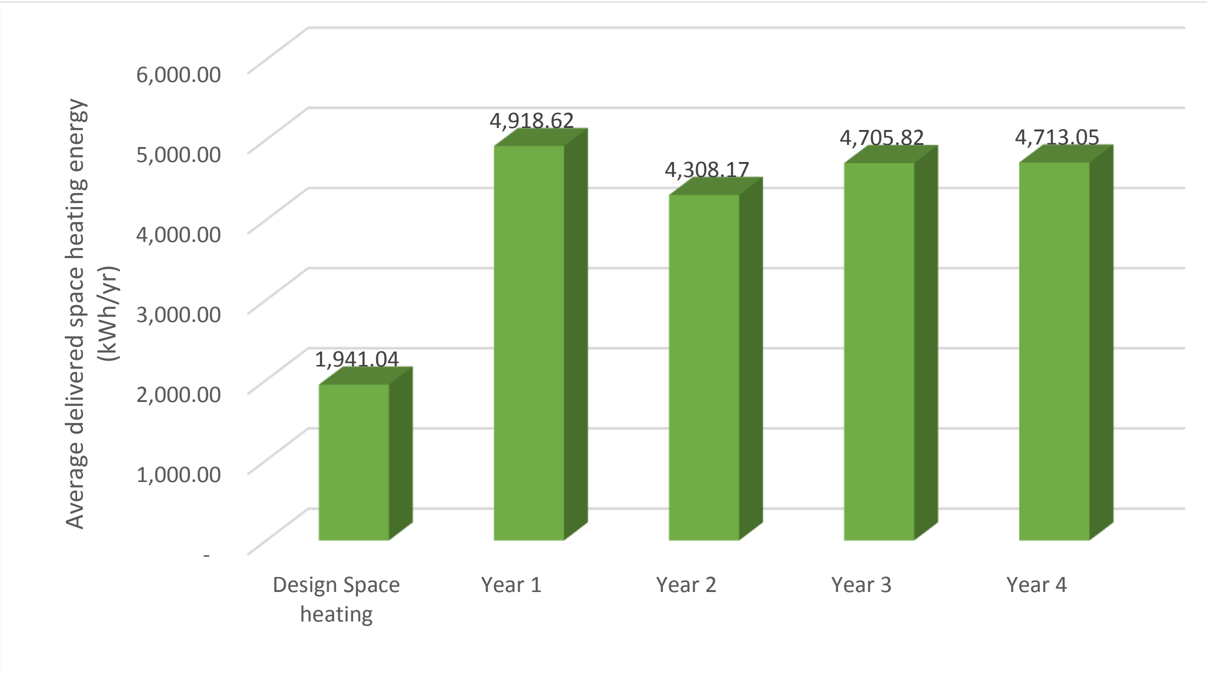

Figure 1: Average delivered space heat energy against design calculations (n=12).

Figure 2 below shows the normalised delivered energy for space heating by floor area during the years of monitoring. As a means of interpreting the results, an appropriate comparison would be against the Sustainability Section 7 Scottish Building Standards Technical Handbook which states a maximum annual demand for useful energy for space heating; Gold level, 30 kWh/m^2 for houses, 20 kWh/m^2 for flats and Silver level, 40kWh/m^2, 30kWh/m^2 respectively. Observing the results in clusters of energy use over the four years of occupation and its proximity to the design expectations (SAP), Figure 2 produces some clarity on the energy efficiency of the dwellings. Dwellings that have demonstrated this efficiency include F.3.12, SD.6.18, T.7.19, T.7.20 and to some extent SD.6.17, all present a very similar consumption over the years and aren't highly displaced from SAP estimates. These dwellings also fall within the maximum demand stated in Section 7 between the 20 and 40 kWh/m^2/yr. Other dwellings, although showing a consistent demand over the years of occupation, are highly disproportionate from the SAP expectations.

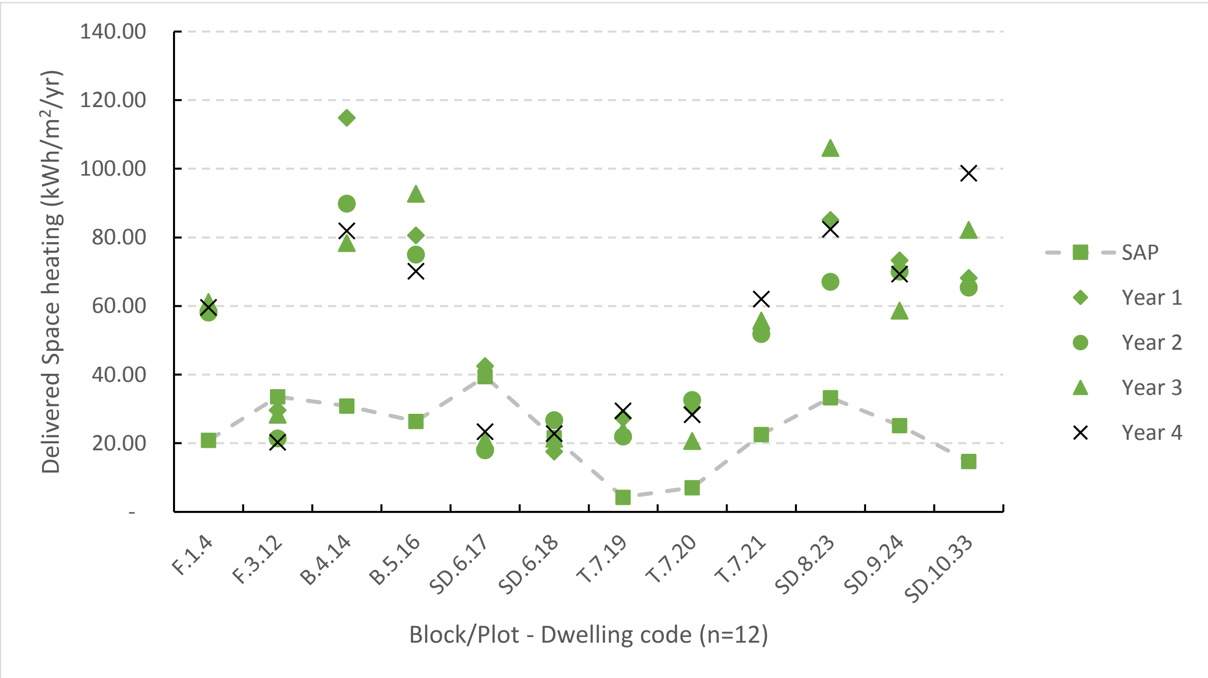

Figure 2: Delivered space heating energy per floor area for the four years of occupation.

Observing the results differently, rather than dwelling-by-dwelling, Figure 3 clusters the dwellings into the construction method employed and their demand of energy through the years of occupation. Although this study shows a small sample size of each, it is evident that the timber closed panel construction has a consistent demand of energy within the Section 7 maximum demand levels. It is followed by the open timber panel and the steel volumetric solutions averaging 60 kWh/m^2/yr. Other construction forms show high displacement levels against the SAP estimates and also dependent on occupancy more so than the others. A wider sample size on these forms of construction would confirm the results.

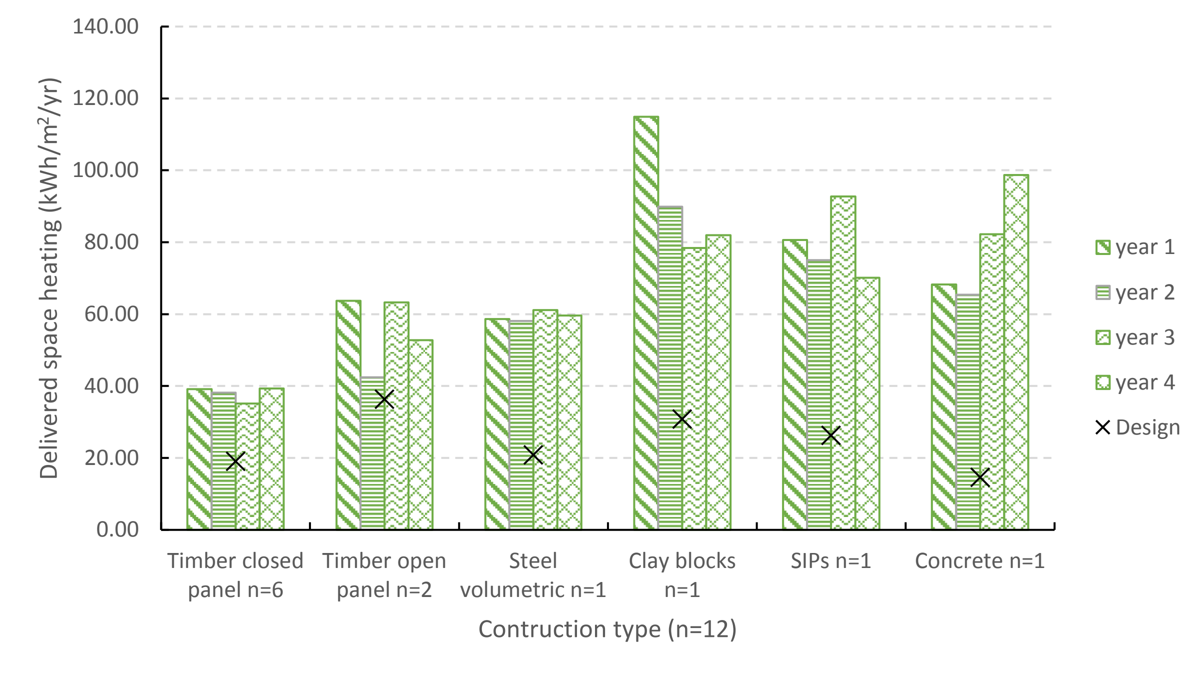

Figure 3: Average space heating energy demand by construction type

Finally, it's useful to measure the difference of energy demand for space heating against the SAP estimates. Figure 4 below indicates the percentage difference above the SAP estimates therefore it is strongly dependent on how close the average consumption over four years is to the SAP calculations.

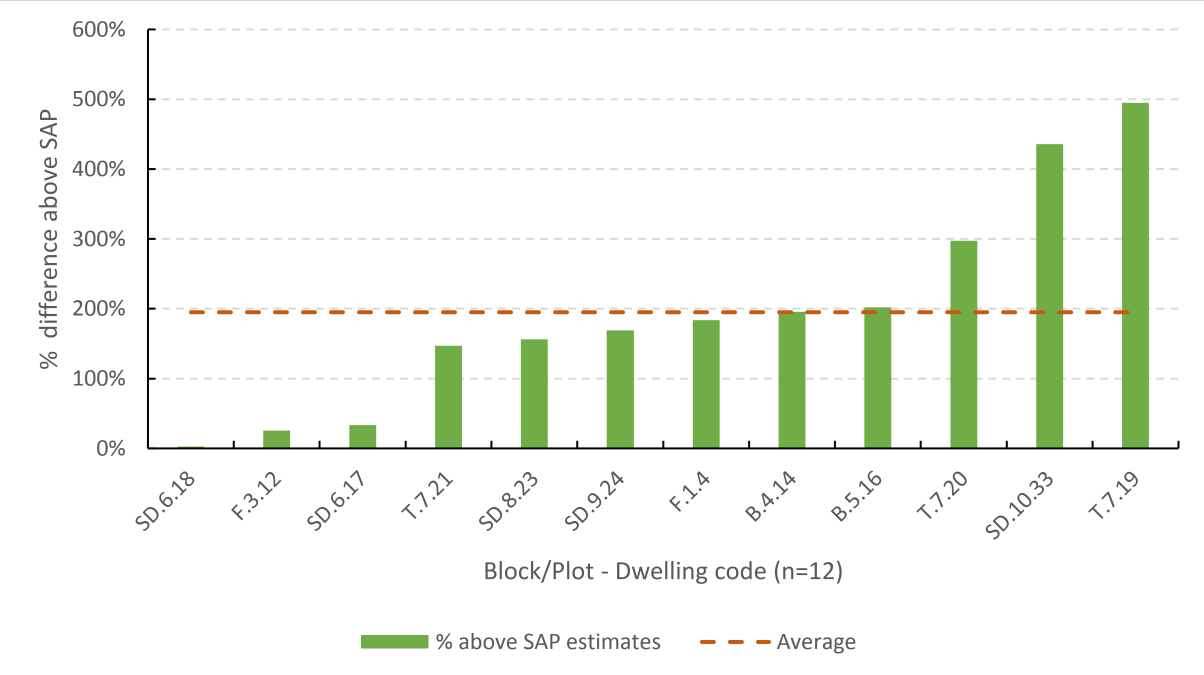

Figure 4: Percentage difference between delivered and SAP calculations

Dwellings F.3.12, SD.6.17 and SD.6.18 are very close to the SAP estimates whereas T.7.19 and SD.10.33 are highly displaced from SAP. Dwelling T.7.19 is particularly interesting as it has the highest percentage difference, despite its electricity produced by its larger array of photovoltaic panels (PV). This dwelling, although consumed low amounts of energy over the four years of monitoring, its initial design predictions were very low, thus reflecting a high displacement. Nine out of the twelve dwellings are below the average of 200% difference which reflects the developments level of performance.

Space heating demand plays a big part in defining energy efficiency as it is strongly related to the envelope and construction efficiency of the analysed dwellings. Although occupant behaviour can influence the results, by separating water heating from the total energy demand, a more transparent dwelling performance emerges.

6. WATER HEATING

For this study, it was important to re-consider the demand for water heating by using the same calculation methodology employed by SAP. These calculations were done to obtain the actual consumption by the actual occupants of each dwelling over the four years of occupation.

All analysed dwellings underwent yearly occupant surveys focusing on thermal comfort and occupancy patterns. This information was processed to consider water demand for showers, baths and cooking/ other but using the same water heating technology efficiency and system losses to produce a more refined water heating demand, true to the actual occupation.

Figure 5 is a clear example of the percentage difference between the calculations by SAP, based on assumed occupancy against an actual occupation averaged over the four years. The most precise calculations were those of T.7.19 and T.7.21 who were below the 5% difference. The rest of the dwellings were occupied by more people than the assumed in the calculations therefore experienced larger amounts of water heating demand. An average difference from the SAP estimation of 24% resulted across the 12 dwellings however the majority of dwellings experienced a demand difference between 25% and 35%.

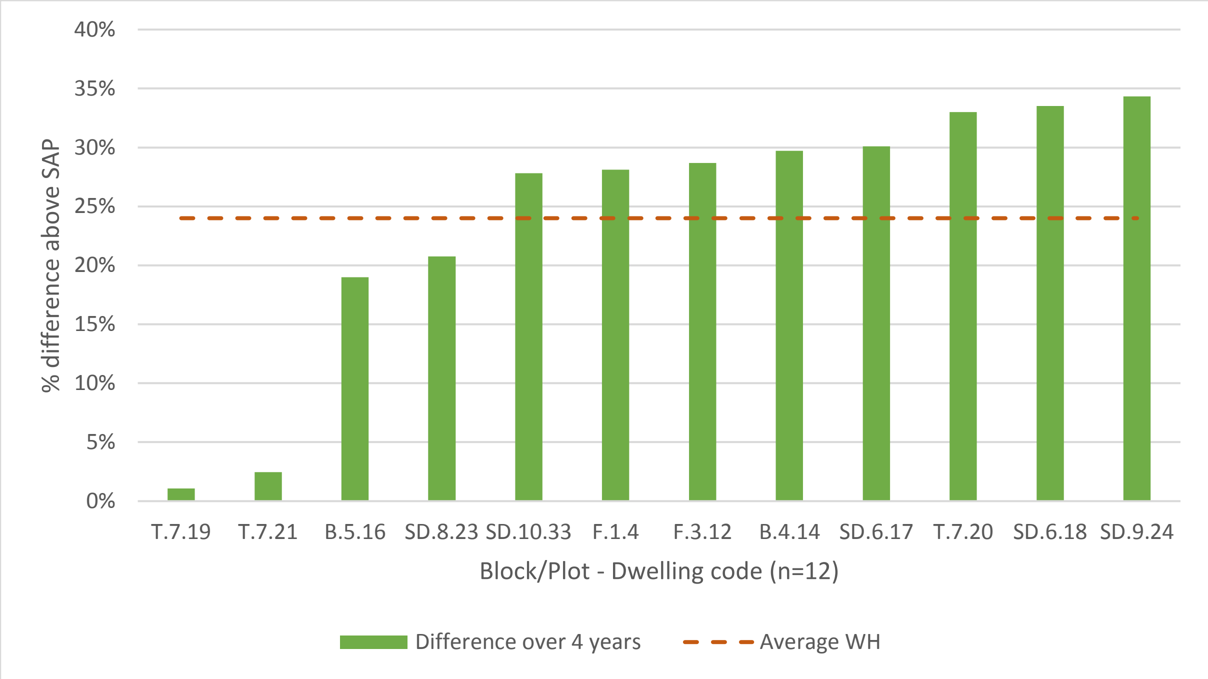

Figure 5: Percentage difference of water heating from the calculated in SAP

7. ENEVELOPE PERFORMANCE

7.1 Wall U-value

The measurement of thermal transmittance (U-value) of walls was conducted during set periods of the dwellings post occupation. The tests focused on the walls U-value as this was the differentiating element among the 13 dwellings across the 10 blocks.

The first tests were conducted during the winter months of 2012/13, 2014/15 and 2016/17, measuring the same walls, with the same orientation and positioning of equipment. Each test included the deployment of two heat flux pads on the same wall at different heights, attached for a duration of 15 days, measuring at 5 minute intervals. Also part for the calculation procedure was the measurement of internal ambient and surface temperatures as well as localised external temperatures. Typical margin of error considerations from results are in the region of less than ±10% which for example means that a result of 0.20 W/m^{2}K will have an absolute value between 0.18 and 0.22 W/m^{2}K. All the measurements were conducted in accordance with current British Standards, particularly BS ISO 9869.

Results are presented in comparison with the predicted at the design stage as shown in Figure 6 with a cross mark. Individually, each dwelling presents various results over the three BPE stages with a downward or increasing trend.

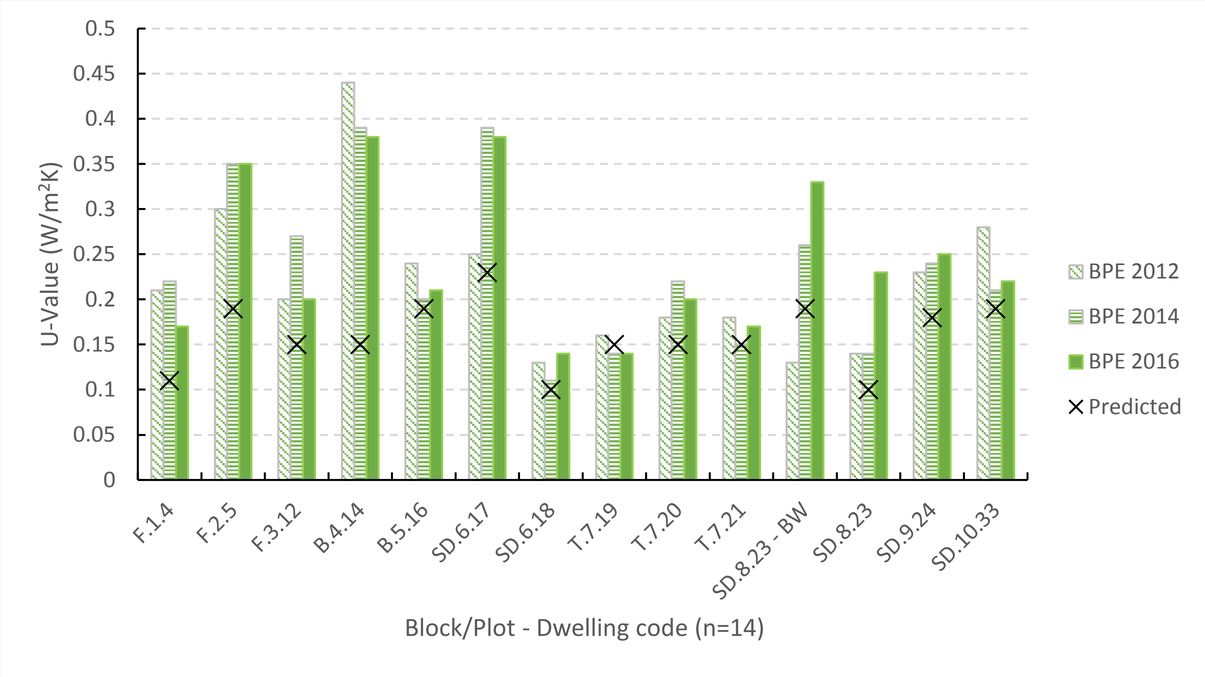

Figure 6: Wall U-value across the analysed dwellings compared with predicted values

Important to highlight is the percentage difference from the predicted as shown in Figure 7. This highlights the percentage difference above the cero axis; the closer to the cero the closer it was to the predicted.

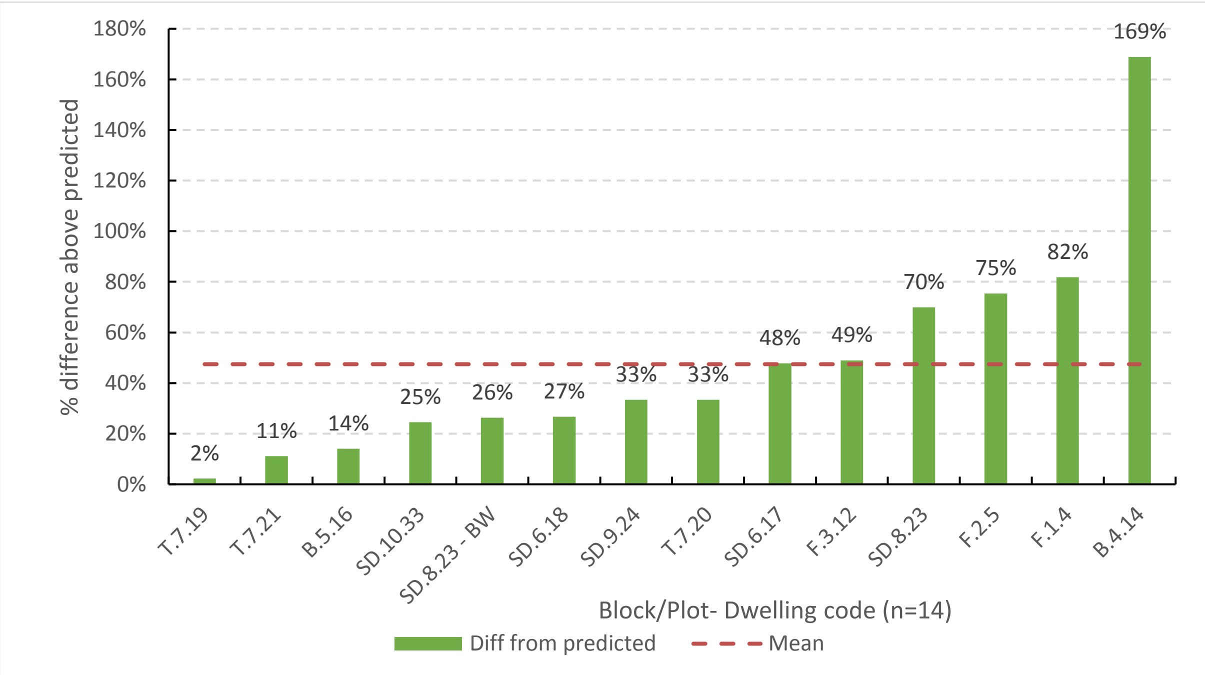

Figure 7: Wall U-value percentage difference from the predicted at design stage

As observed, most dwellings outperform the predicted values which will have a negative impact on the dwelling fabric performance and energy use for space heating. Dwelling B.4.14 is 170% above the U-value calculated and used in the SAP calculations. Also interesting to observe is the parity of the average U-value results aligned to the construction type employed in the dwelling. Figure 8 below shows two fundamental indicators of performance. The first the proximity to the predicted U-values and the second how clustered the results are over the years of monitoring. A set of results clustered together confirms a trend of its U-value and one that spreads may indicate that the wall is diminishing its thermal performance over time, within the accuracy of the monitoring.

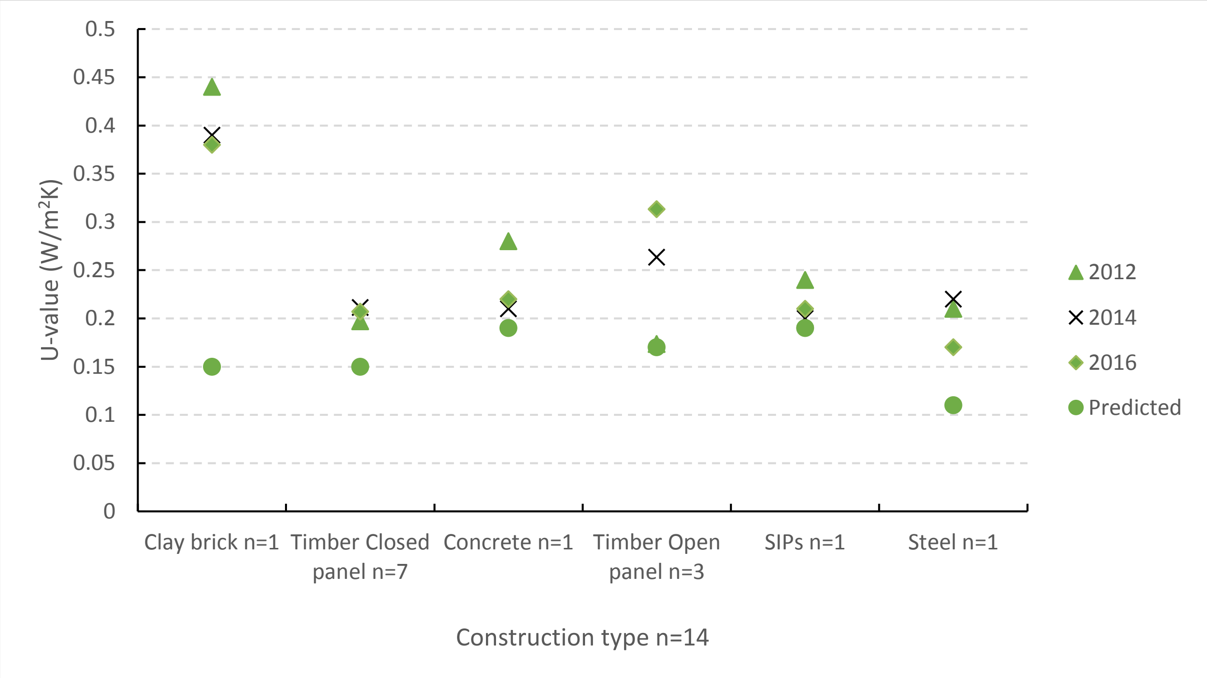

Figure 8: Average wall U-value results according to the construction method

The results have shown that some dwellings differ largely from the predicted at the design stage, confirmed through the percentage difference from the predicted and also individually over the years of monitoring. The results in most dwellings have confirmed the actual U-value of the walls, beneficial for future reference. Rather than compare dwelling and system provider, this research has compared the construction method employed. The results show that timber closed panel construction and the SIP's method are closer to the predicted and most consistent throughout the years of monitoring. A more comprehensive and definitive conclusion of construction method performance should be done with a larger sample size to confirm the results, particularly with those that have presented a high percentage difference to the predicted.

7.2 Air tightness

The measurement of the selected dwellings air permeability was performed during three set periods. The first at the construction completed stages at the pre-occupation period and the second and third tests after two and four years of occupation (2014/15 and 2016/17). Tests were conducted on the 13 selected dwellings which were representative of the 10 blocks and the variety of system providers used.

Typical margin of error considerations from results are in the region of less than ±5% given by test procedure, equipment and meteorological conditions. All the measurements were conducted to meet British and Industry Standards (BS EN, 2001 & ATTMA, 2010).

The dwellings were tested under depressurisation and pressurisation methods reaching 50 Pascal pressures. The results from both tests were averaged to obtain the final air permeability results. Tests were performed under calm and appropriate meteorological conditions as stated in the regulatory literature.

The common trend with the results over the monitoring periods is that most dwellings air permeability increased with the exception of plot SD.6.17 which was always lower than predicted and even improved in the last tests after some remedial work on defected fenestration and gable wall. See Figure 9 below.

Figure 9: Dwelling air permeability over the three testes at pre and post occupation stages

Figure 10 shows the percentage difference from the predicted values used for SAP calculations at the design stage. The results show that seven out of the thirteen dwellings performed bellow the mean results of 51%, whilst the rest of the dwellings performed above this mean. A high percentage was obtained in dwelling SD.6.18 as its predicted figure was very low and the two post-occupied measurements show a twofold difference. Dwelling SD.6.17 outperformed its predicted figures by 27% which will benefit on the reduction of energy demand.

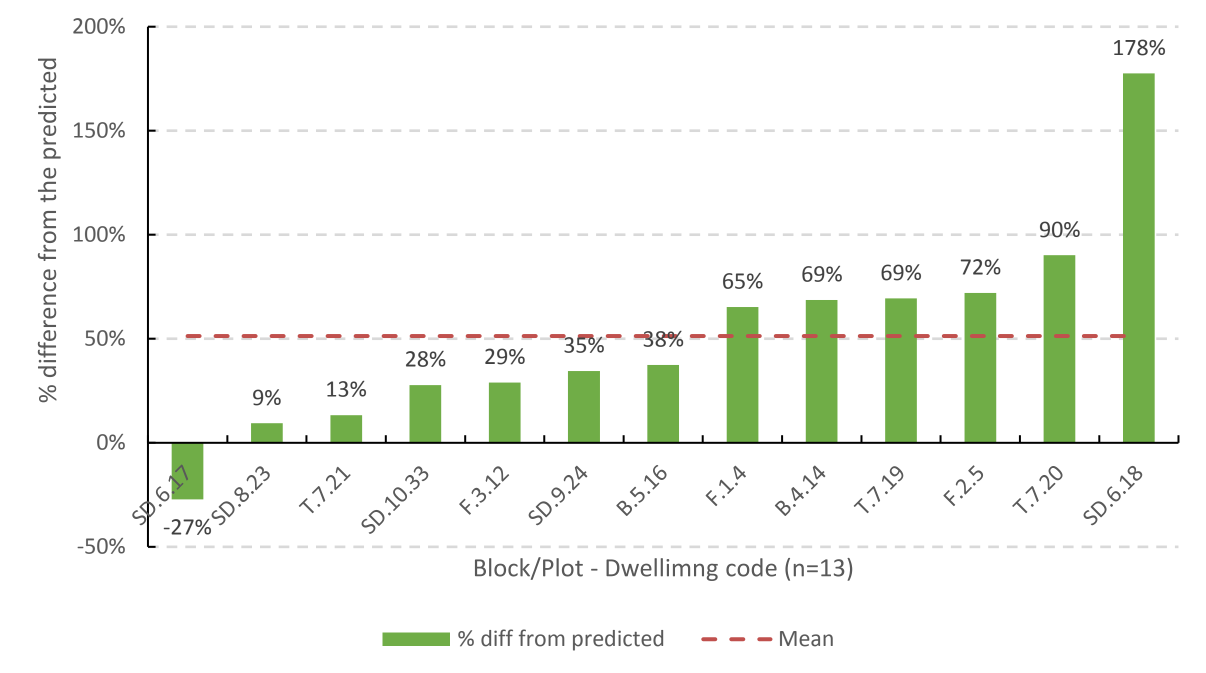

Figure 10: Percentage difference from the SAP prediction values

Analysing the results by method of construction, it is clear that there are distinct differences between them. In Figure 11 the more air tight dwellings over the monitored period were the timber open panel wall types, outperforming the predictions at design stage.

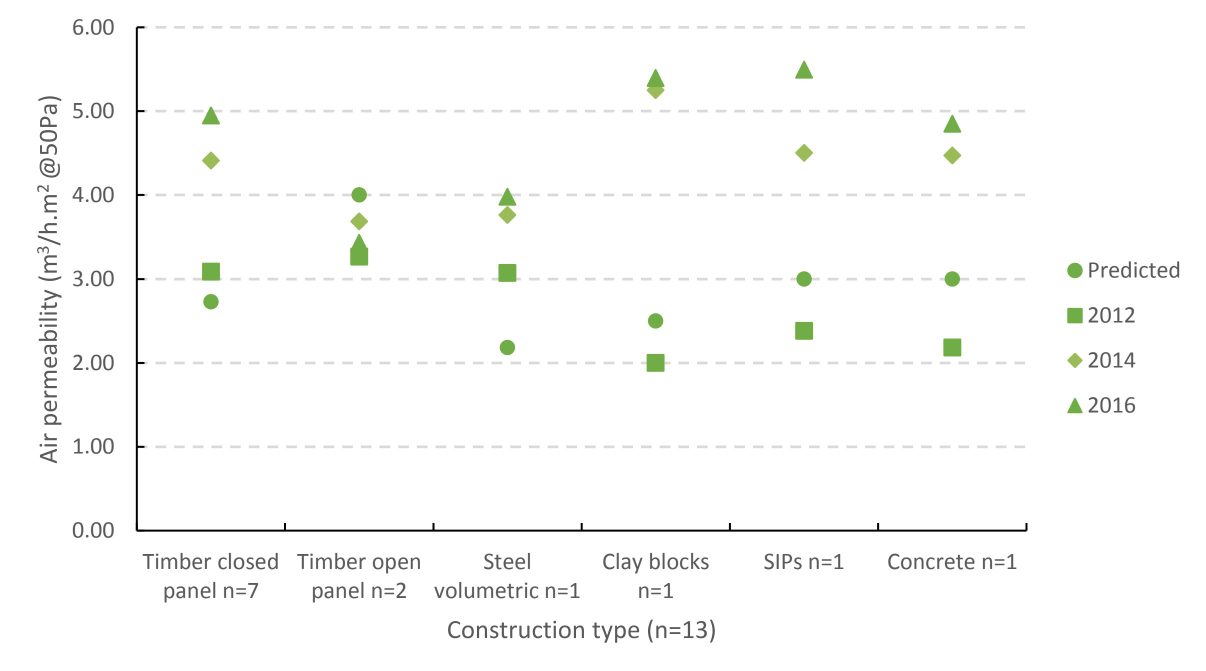

Figure 11: Construction type comparison of air permeability results

Both the timber closed panel and the volumetric steel dwellings gradually got less air tight during the monitoring periods, whilst the clay blocks, SIP's and concrete dwellings at the first tests were more air tight than the predicted but in the latter tests indicated that the envelope deteriorated, impacting on its performance.

8. Conclusions & discussion

The building performance evaluation (BPE) of a sample of the dwellings at the Housing Innovation Showcase has been presented in this document. The development has been a successful showcase of different technologies, house types and construction methods from timber open/ closed panel solutions to modular steel and concrete form methods.

The results have been discussed with a focus on comparing the predicted scores and calculations at the design stage with the monitored results over a longer occupation period of four years. This type of study is unprecedented as most BPE's of buildings are performed only during the post construction stages and early occupation for less than 2 years post-handover.

The actual delivered heat energy demand for the selected dwellings has been carefully split between the energy for water heating and the energy for space heating. This has been useful to be able to benchmark against SBS aspired performance levels for space heating, as stated in the SBS Technical Handbooks, Section 7 Sustainability. Although eight out of the twelve dwellings are out with these space heating benchmarks, the resultant dwellings are close to the predicted SAP calculations and also meet the benchmarks over the four years of monitoring. Useful to understand efficiency and performance are the dwellings percentage difference to SAP calculations, which in its majority are below the average monitored in this development. The totality of the results have shown that early energy demand for space heating during the first two years of occupation can be unpredictable and regarded as an adjustment period. The latter years of this monitoring have shown a more reliable and true energy demand for the sample dwellings.

The fabric performance has been good to gage how close the predicted is with the actual over long periods of occupation. It has shown that some dwellings have outperformed or are very close to the predicted. Some have shown good levels of U-values over the monitored periods, but not necessarily good levels of air tightness, this is the case of the timber open panel systems. The results also show that U-values, although different to the predicted in most cases, do not differ too much over long periods of occupation whereas air tightness does. Dwellings have in most cases had a downwards trend in air permeability figures as most repeated tests show envelopes being less air tight. This may be due to envelope disturbances created by the occupants due to DIY jobs, settlement of structures and also the envelope dilapidation over time creating cracks, apertures and open seals around the envelope.

This study continues into the final stages of a Doctorate Thesis which is due to be finalised in 2018. The research seeks to obtain correlations over longer periods of occupation taking into consideration the dilapidation of the building envelope and the increase of energy for space heating. The use of a reduced sample of dwellings modelled under climate change scenarios and statistical trend analysis will help to progress this research further.

The research team would like to thank Kingdom Housing Association and in particular, Julie Watson and Bill Banks for their patience and consideration while this study has taken place. An acknowledgement also goes to the residents who took part in this study as they opened their homes year-after-year enduring the regimented testing schedules and survey questionnaires.

9. References

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10. Appendices

Appendix A. Block/Plot- Dwelling code description

No.	Dwelling code	Archetype	System Provider/ builder	Construction method	Block	Plot	Postal Address
1	F.1.4	Flat	Powerwall -Enewall	Steel volumetric	1	4	8 Ericht Drive
2	F.2.5	Flat	Scotframe/ Campion	Closed panel	2	5	10 Ericht Drive
3	F.3.12	Flat	Stewart Milne	Closed panel	3	12	24 Ericht Drive
4	B.4.14	Bungalow	Porotherm	Clay block	4	14	28 Ericht Drive
5	B.5.16	Bungalow	Cube RE-treat	SIP's	5	16	32 Ericht Drive
6	SD.6.17	Semi-detached	Control House - Campion	Open panel	6	17	34 Ericht Drive
7	SD.6.18	Semi-detached	Passive House - Campion	Closed panel	6	18	36 Ericht Drive
8	T.7.19	Terrace	Future Affordable 2016	Closed panel	7	19	38 Ericht Drive
9	T.7.20	Terrace	Future Affordable 2013	Closed panel	7	20	40 Ericht Drive
10	T.7.21	Terrace	Future Affordable 2010	Closed panel	7	21	42 Ericht Drive
11a	SD.8.23 - BW	Semi-detached	Lomond - Breathing Wall	Open panel	8	23	46 Ericht Drive
11b	SD.8.23						
12	SD.9.24	Semi-detached	CCG - iQ	Closed panel	9	24	48 Ericht Drive
13	SD.10.33	Semi-detached	BECO	Concrete form	10	33	2 Fyne Brae