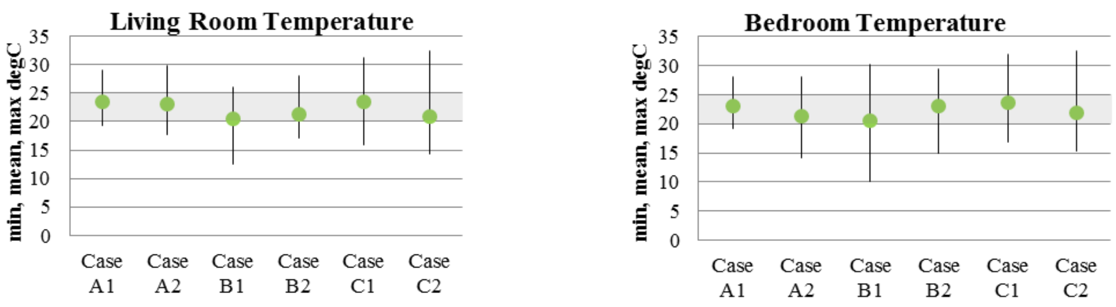
failed to understand the purpose and operation of the low carbon systems or have forgotten the information that was provided to them initially. Lack of occupant understanding is one of the reasons leading to higher energy use and poor performance of systems. This raises questions about the quality of the handover and the need for retraining the occupants.

Occupant expectations and satisfaction

Occupant behaviour and expectations. Internal temperature data (January – December 2013) reveal that demand temperatures in the houses are high as shown in Figure 3. This is closely related to occupants' high expectations of comfort. Overall temperatures are high with five out of six houses having mean living room temperatures above 21°C and three out of six houses having a mean above 23°C. Peak temperatures above 27°C were also observed in the majority of the houses (five out of six). Bedroom temperatures present a similar trend with five out of six houses having mean bedroom temperatures above 21°C. Cases A1 and C1 have the highest mean temperatures as the occupants use a lot of heating energy by keeping their thermostats around 25-27°C throughout the day. In Case C2 occupants also keep their thermostat very high throughout the day (30°C) but mean temperatures are around 21°C because occupants keep their windows open for many hours during the day (Figure 4), thus leading to the high gas consumption shown in Figure 1. This level of demand is leading to a gap between design prediction and actual consumption in terms of both energy use and environmental conditions.



a) b)

Figure 3 Mean, minimum and maximum temperatures in (a) living rooms and (b) bedrooms (January – December 2013).

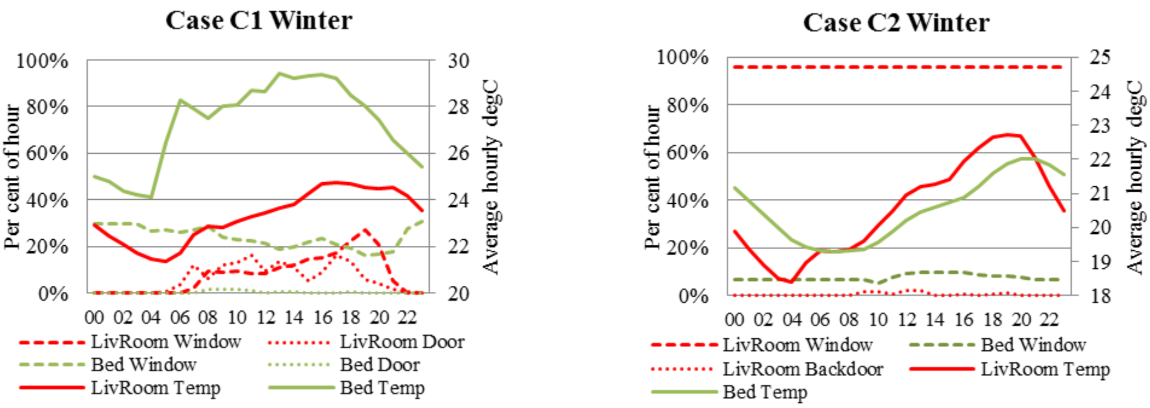


Figure 4 Hourly average temperatures and hourly percentage of window opening across a day (November – April) in Case C1 and Case C2.

Occupant surveys, interviews and walkthroughs. Occupant satisfaction surveys were carried out in all three developments using standardized occupant satisfaction questionnaires (BUS). Additionally, semi-structured interviews and walkthroughs were carried out with the occupants of the six case studies using the same templates. Table 5 summarizes the positive and negative occupant feedback from the survey and occupant interviews related to contols, comfort and satisfaction with space.

Table 5. Common emerging issues highlighted by occupant survey and interviews.

	Development A	Development B	Development C
Positive feedback			
Satisfaction with space and layout	×	×	×
Satisfaction with design and appearance	×	×	×
Satisfaction with light levels (natural, artificial)	×		×
Temperatures good overall	×	×	×
Negative feedback			
Poor control over heating	×	×	
Lack of understanding of heating system	×	×	
Lack of knowledge about MVHR	×	×	×
Poor control over ventilation		×	
Hot during summer		×	
Home User Guide considered complicated.	×	×	
Energy bills considered high	×	×	×

In all developments occupants are fairly satisfied with the appearance, design, layout and space of the houses. Also, daylight levels are appreciated in most cases. Most negative feedback involves the operation and control of the heating and MVHR system. Control over heating is considered problematic in Developments A and B that feature heat pumps and underfloor heating as occupants are not well familiar with such technologies and find the Home User Guide confusing. Control over ventilation is also considered problematic in most cases due to occupant confusion about the operation of the MVHR system. Moreover, energy bills are high in all houses althought all three developments designed to reduce energy use. Occupants in Developments A and B are very unhappy with their electricity bills which they attribute to the poor performance of the heating system. In Table 6 actual electricity and gas bills are between 3 to 20 times higher than the SAP estimated energy costs.. The combination of many new technologies, unfamiliar to both the occupants and the developers and owners, led to confusion and dissatisfaction in most cases.

Energy use in houses depends heavily on the occupants' perception of comfort and their attempts to attain comfortable conditions. Thermal comfort satisfaction is closely linked to the level of understanding and control over the heating and ventilation system. Resolving the issue of comfort and control effectively and understanding occupant expectations through follow-ups and training are essential for closing the performance gap and achieving better environmental conditions.

Table 6. Comparison of actual bills with SAP estimated costs and UK typical domestic energy bills

Cost (£)	A1	A2	B1	B2	C1	C2	UK typical [2]
Predicted (SAP) cost	70	70	330	336	259	315	
Electricity bills	1,440	1,200	1,300	1,100	700	960	424
Gas bills	-	-	-	-	720	1,500	608
Actual total cost	1,440	1,200	1,300	1,100	1,420	2,460	1,032

CONCLUSION

Using a mixed-methods socio-technical BPE approach, this study has identified the reasons for underperformance of 'close to zero' carbon new dwellings. The study has revealed that the actual energy use in the case study houses exceeds design predictions by a factor up to 3. Furthermore, actual energy use across the six case study houses varies by a factor 1.6, despite all the developments being designed to CSH Level 4 or 5 and having similar occupancy profiles. Fabric performance, commissioning of systems, usability of controls and occupant understanding and expectations increase the gap between actual and design performance. Discrepancies in fabric and system performance may result from difficulty of communicating design intentions and expectations, specification error or omissions and construction errors. Such issues could be avoided through rapid diagnostics onsite and better

[2] Typical UK domestic energy bills and consumption figures based on average household bills (Ofgem, 2011)

communication between all stakeholders. Installation and commissioning is clearly an area where increased training and awareness and checks will have a large impact on improving the performance of dwellings. In order to improve commissioning and maintenance developers and constructors need to ensure that their technicians receive adequate training. Seasonal commissioning also needs to be encouraged for houses with technologies such as heat pumps and MVHR systems.

The study also highlights the need for a detailed and coordinated services layout plan showing location of systems and controls that will help to solve issues of accessibility and will provide the basis for a clear strategy that the occupants need to follow. Combination of clear design intentions, intuitive and responsive control mechanisms and good occupant guidance and training will ensure better use of systems and increase the potential for energy reductions and improvement of environmental conditions. Findings indicate the need for graduated handover that involves hands on application by occupants, supplemented by visual home user guides offering clear guidance on the daily and seasonal operation of systems and controls. Guidance must be customized according to residents' background and abilities.

Learning from real-world case studies is an insightful way for understanding the reasons behind the energy performance gap in order to achieve low carbon housing in practice. This requires a formalized briefing, commissioning and feedback protocol, such as 'Soft Landings' (BSRIA, 2009), that has started to be used in domestic projects. This will help to ensure that these lessons are captured and fed back to the developers, constructors and designers. Otherwise there is a risk that UK Government's zero carbon housing policy may get undermined.

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