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Performance Analysis of a Zero Carbon Housing Development

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Abstract
This paper presents a post occupational analysis of a zero carbon housing development in respect to energy use for hot water and space heating. The study found that the dwellings maintained a comfortable environment throughout the year however showed that there was a significant performance gap between predicted energy use from SAP 2009 and measured energy use. The gap was however the inverse of a traditional performance gap where the actual dwellings outperformed the predicted. This "negative performance gap" was shown to be as much as half of the predicted energy use. As post occupational analysis of housing is rare in the UK and rarer for low energy housing, this could point towards low energy dwellings being over designed due to significant carbon emissions in the calculations relating to an energy use that doesn't exist. These findings pose significant questions on the ability of the current form of SAP to accurately model low energy dwellings.

Keywords: Post occupational analysis, performance gap, energy use, comfort

1 Introduction
In May 2011 the Minister of State for Housing and Local Government reaffirmed the UK Government's commitment to zero carbon homes from 2016 namely that all new build properties will be built to zero carbon, stating that 'the carbon footprint of new homes cannot be allowed to add to our overall carbon reduction targets. This needs to be done in ways which are cost effective and which protects the viability of house building' (The Rt Hon Grant Shapps, 2011). There are many ways in which zero carbon can be interpreted in respect to building homes. Does zero carbon include regulated energy? Unregulated energy? Embodied carbon? Net on site zero emissions? Allowable solutions off site? In the UK, it has been the principle objective of the Zero Carbon Hub to define what zero carbon homes are. The current definition uses the zero carbon hierarchy: A minimum standard in fabric energy efficiency must be met, a minimum standard in carbon emissions must be met, and then allowable solutions can be employed in order to bring net carbon emissions down to below zero. This definition relies on computational methods in order to evaluate the performance of the dwelling, the current accepted methodology being the Standard Assessment Procedure (SAP).

The actual performance of dwellings and the calculated performance are often not aligned. This is referred to as the performance gap. Unfortunately because zero carbon homes are rare in the UK and even fewer are subject of Post Occupational Evaluation the actual performance of these 'new' types of dwelling is not known. The Building Use Study supports this and states that benchmarking these types of buildings could take 3-5 years to populate (BUS, 2012)

It is the act of monitoring, learning and re-implementing in new buildings that is key to improving the way in which houses are designed and built. A concerted effort needs to be made in order to learn from zero carbon houses for the future of the building industry, and to ease the UK's transition into a low carbon society.

It is the ultimate aim of this research to compare the design and calculated performance for a zero carbon development against the measured performance in a dwelling that remains in a comfortable condition to occupants. The research focuses on comparing real data gathered from a zero carbon development case study with calculated data using industry standard calculation tools, with the key objective of identifying to what extent a performance gap exists.

2 Case Study

The development utilized as a case study for this research is a development of 10 homes located in Chelmsford, Essex and is one of the first developments in the UK to achieve Code for Sustainable Homes Level 6. Completing in July 2010, it was subject to the Government's old definition of zero carbon homes which at the time was Code for Sustainable Homes Level 6. The strategy to meet zero carbon and the Code for Sustainable Homes was to build to very good fabric insulation values, meet the heating and hot water demand using communal biomass boilers and meet additional electrical demand using Photovoltaic panels. The 2 dwellings to be monitored as part of this research are Unit 5 and Unit 7 of the case study, these are a 3 bed and 2 bed house respectively.

3 Data Gathering Procedures

The research consists of 3 areas; temperature monitoring, energy monitoring using heat meter readings from the dwellings and SAP calculation outputs for the 2 dwellings.

The temperature monitoring was conducted using calibrated iButton monitors that took half hourly readings over the course of a year. An external temperature reading was taken simultaneously to allow comparison between internal and external environmental conditions.

The case study included remotely read heat interface units which served the communal heat network for the development. This provided hourly data for the use of heat energy within the dwellings.

Finally, the dwellings were modelled in accordance with SAP 2009 methodology using approved software. This provides the calculated values on which the performance gap was measured.

4 Analysis of Results

4.1 Energy Use

The space heating requirement for Unit 5 was found to be 19.8 kWh/m2/yr and Unit 7 is 26.0 kWh/m2/yr. It can be seen that the units are still some way off complying with the Passivhaus's space heating requirement of 15 kWh/m2/yr. The measured data however tells a different story with the annual space heating load calculated as 462 and 955 kWh/yr which equates to 5.42 and 13.54 kWh/m2/yr. Using actual performance data it is clear that the dwellings do actually comply with the passivhaus criteria in practice.

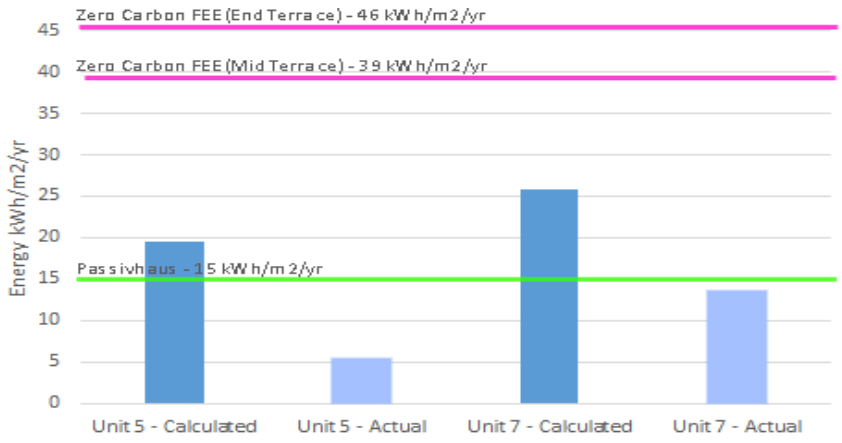

Figure 1 – Performance Data vs Calculated for Space Heating Demand

The performance data in Figure 1 shows an 72.6% and 47.9% reduction in the energy loss of the dwellings, this is clearly a significant overestimation by SAP that has more the doubled the actual heating load of the dwellings and in the case of Unit 5, nearly tripled it. The sample size of this research obviously does play a part in the interpretation of these results because the use of a dwelling can fluctuate up to 300% depending on the occupier (Gram-Hanssen, 2010). The analysis does however support that these dwellings were being used in a "normal" fashion, with Unit 5 having a thermostat setpoint of between 22 and 23^0C and Unit 7 having a setpoint of 24^0C. This is a higher internal temperature then the SAP allows for in the calculations (being 18^0C for habitable areas and 21^0C for living rooms), this shows that the occupants enjoy internal temperatures that actually exceed that used in the SAP calculation, this should mean that the energy use of the dwellings will be higher than that in SAP. This in turn supports the argument that SAP has highly overestimated the energy use of the dwelling.

This could provide issues in the dwellings if any design work was based upon the SAP data such as radiator design. Having the calculated heat load at double the requirement will lead the space heating designer to over-spec the system. The most severe effect of this could be overheating, where a small amount of heating is required and only large amounts can be produced. This however could be mitigated in part by the effective use of controls. It was observed that overheating according to CIBSE criteria does occur in Unit 7. It was however considered that this occurred during the summer months when heating was not required, there was no evidence that overheating has occurred during winter periods.

It is possible that the SAP hasn't been accurately modelled, although the modelling has been in accordance with the SAP methodology there are elements such as thermal bridging; that may distort the figures and cause of the overestimation of the heating demand. Default psi values were taken for most of the thermal bridges that in reality were designed to provide a high degree of resistance to heat losses through thermal bridging. Although this is a perfectly acceptable method of inputting the data where psi value data is not available, this may have contributed to the overestimation. This has been tested through a SAP modelled using a Y-Value of 0 (ie zero heat loss through thermal bridging), this is not realistic however gives a view of the extent to which the thermal bridging data can affect the calculations. The adjusted SAP for Unit 5 gives a space heating demand of 16.1 kWh/m2/yr which is a decrease of 20% over the actual SAP. This shows that even if the thermal bridging were modelled in full, this would not make up the extent to which the gap exists between the modelled and actual

performance and would still show a significant overestimation of the actual space heating load.

4.2 Hot Water Heating

The actual hot water use for the case study dwellings has been calculated using the metered data for the summer period, the average daily usage for a period of 3 months in the summer was taken and assumed to remain consistent throughout the year. Assuming that the average hot water usage extends throughout the year the annual consumption is 1,529 and 1,412 kWh/yr for Unit 5 and 7 respectively. This is approximately 50% less than the calculated value from SAP which can be seen in Figure 2.

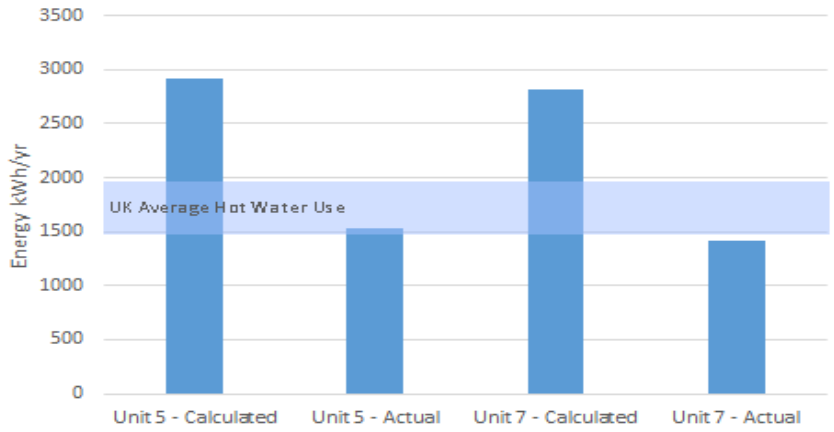

Figure 2 – Performance Data vs Calculated for Hot Water Demand

It can be seen clearly in Figure 1 that the SAP calculated data shows usage well above the UK average data (Energy Savings Trust, 2008) whereas the case study dwellings perform at or below the lower end of the scale. It would be expected that the SAP data would be in the range of the average rather than exceeding it by some way, this again shows that the SAP grossly overestimated the energy usage of the dwellings. The actual energy used for hot water is very low when compared with the UK average. The dwellings were fitted with low flow fittings in order to reduce the water use to below 80 L/person/day in order to meet mandatory requirement of the CfSH, it is expected that these low flow fittings have contributed to the decreased level of hot water demand in the dwellings and hence it is considered that these results can be relied upon.

4.3 Implications of the Performance Gap

It can be seen that in respect to hot water and space heating there is a clear performance gap between calculated energy use and actual energy use, it has been shown that actual energy use is realistic in the context of the case study dwellings which may actually show abnormally high usage. The performance gap is not as expected though in that the dwellings outperform the calculated data, this is contrary to what a performance gap normally is where the dwelling uses more energy then was predicted. The research therefore shows a “negative performance gap”.

Given that this may be indicative for low energy dwellings, this could provide an issue with future design of buildings as they are expected to achieve a performance closer to that demonstrated by the case study. If the performance gap is as extreme as that shown then it is very possible that low energy buildings are being overdesigned. For Unit 5 the total calculated energy use for space and hot water heating is 4,612 kWh/yr yet the actual energy use is closer to 1,991 kWh/yr, this represents an overestimation of 56.7% which also means that the carbon associated with the overestimated energy need not have been offset by using zero carbon renewable technologies. Unit 7 shows a similar story with an overestimation of 2,281 kWh/yr or 49%.

For the case study this impact on carbon will not be as severe because the source of heating is biomass which has a low fuel carbon factor however were the case study supplied by gas this would equate to an overestimation of 450kgCO2/yr. This is equivalent to approx. 870 kWh of electricity (or ~1 kWp of photovoltaic panels) which could represent a significant cost savings on the cost of the development of a zero carbon dwelling.

5 Conclusions

The output from SAP 2009 is used as the calculated compliance method for new build dwellings, these outputs were compared with measured data in respect to energy use. In respect to space heating demand it was determined that the case study dwellings outperformed the SAP calculations by 47.9% and 72.6%. Given that the internal environment remain comfortable throughout the year and that the dwellings in both cases were heated to temperature exceeding SAP assumptions, it was considered that the results were dependable. The robustness of the SAP calculation was also tested by rerunning the calculation with thermal bridging reduced to zero, it was found that the calculation performance improved by 20% however was still exceeded by the actual performance data.

The hot water energy use showed similar results with both of the case study dwellings outperforming the predicted energy use from the SAP. The calculations were mapped against the UK average from the Energy Savings Trust and were shown to be in excess by approx. 30%. Given the assumption that there is reduced level of water in low energy dwellings enabled through the CfSH, it is likely that all dwellings meeting higher levels of water efficiency will outperform the hot water energy use determined by SAP.

It is the conclusion of this research that performance gap for the case study is actually negative, i.e. it outperforms the calculated performance. This is contrary to the indications of the industry which shows that dwellings do not perform as well as indicated in calculations. The built environment is looking at the effects of the performance gap and looking for reasons and solutions for its existence. The regulations are pushing towards low energy, zero carbon dwellings.

On the basis of this research the performance gap for low energy buildings could be negative with dwellings outperforming calculations and this is likely to lead to the overdesign of future dwellings unless the performance gap for low energy dwellings is fully researched and realised.

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