Scenario Testing Of The Energy And Environmental Performance Of The 'Glasgow House'

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ABSTRACT: This paper describes the results from a 12-month study of a prototype low energy dwelling built for Glasgow Housing Association. The dwelling is intended for mainstream and social housing within Glasgow and includes a range of energy reducing features including a thermally heavy clay block wall, sunspaces, MVHR, solar thermal system and low energy lighting. The dwellings have been subject to an innovative monitoring strategy by MEARU, whereby test occupants (students recruited from the School of Architecture) have been asked to inhabit the buildings for six two-week periods using occupancy 'scripts' that determine their internal behaviour. The scenarios thus simulate varying patterns of occupancy in both houses simultaneously and the performance of the houses can then been compared. Indications are that although the clay block house had a poorer thermal performance, it did have other qualitative advantages. The performance of the active systems, including the MVHR system was found to be problematic, and specific scenarios were undertaken to explore the implications of this

Keywords: performance, energy, ventilation

INTRODUCTION

It seems extraordinary given the level of investment in housing and its importance, not only to contemporary objectives of climate change and sustainability, but also the everyday lives of people who live in them in terms of comfort, health and satisfaction, that their performance is hardly ever evaluated. Of even greater concern is that when such evaluation is undertaken it is becoming increasingly apparent that a performance gap exists between predicted and actual domestic energy use [1], [2], [3], [4]. In housing, energy use can vary by up to 5 times predictions [5]. This gap could preclude achieving the carbon reduction milestones and timelines set forth by public policy [6] as buildings' operational energy demands account for nearly half of carbon emissions in the UK [7].

Furthermore, questions are arising about the environmental performance of housing, for example research has highlighted concerns about the possible consequences on indoor air quality of greater airtightness [8], [9]. As health and well-being are likely to remain as significant agendas for building occupants and landlords, there is a significant risk for the energy reduction agenda if low energy homes become associated with problems of discomfort or health.

There are also ethical dimensions that are rarely considered. Discussion of poor energy performance frequently refers to effects of occupancy, sometimes characterised as 'bad' behaviour. However, a converse view is that people live in buildings, which are in effect experiments, and so are, in effect, the subjects of these trials. The resulting question is: what are the effects of buildings on occupants? There is clearly a moral, ethical and ultimately a professional responsibility to those who produce these buildings, as clients, designers and contractors to ensure that they function well and that there are no unintended negative consequences.

Figure 1: The Glasgow House – Plot 1 (right), Plot 3 (left)

DESCRIPTION

Monitoring of occupied houses can be problematic in terms of access and confounding occupancy variables. This paper describes the results of a study undertaken on the 'Glasgow House', funded under the UK Technology Strategy Board (TSB) Building Performance Evaluation (BPE) programme, which used test occupants to examine the performance of these houses. The 'Glasgow House' is a prototype reduced energy dwelling developed by Glasgow Housing Association (GHA) one of the largest landlords in Europe. It is an attempt to develop a new model of low energy, flexible, affordable housing that would be a solution for both social and private rented sectors, and housing for sale.

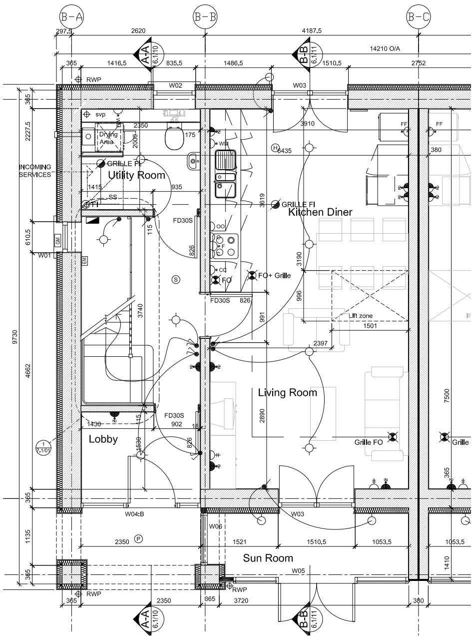

Figure 2: Plot 1 ground floor plan

The design is for a 4 bedroom, 3-storey semi-detached dwelling which included a number of energy reducing strategies, including high insulation levels, sun-spaces, solar hot water heating, efficient heating systems and MVHR.

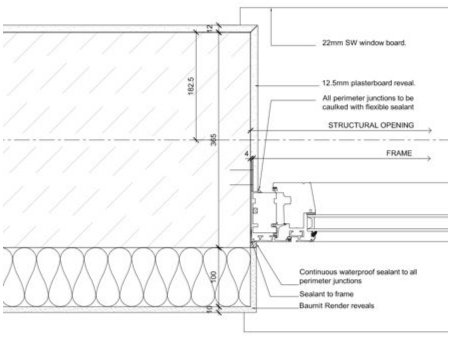

Figure 3: Plot 1 construction detail

The original proposal included an externally insulated clay block construction system that provided thermal mass. As some of these technologies represented a departure from conventional forms of construction, GHA took the unusual, but very progressive step, of constructing a prototype house at the City Building Skills Academy. Two versions were built, one using the clay block system (Plot 1), and the other using a more conventional offsite timber frame system (Plot 3).

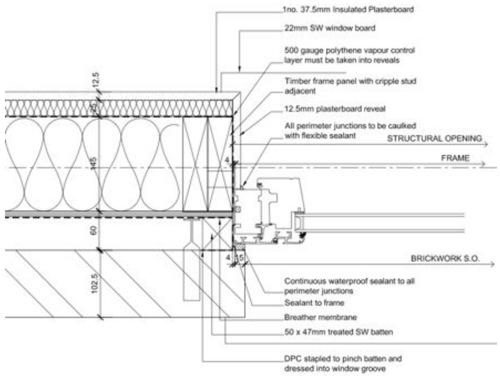

Figure 4: Plot 3 construction detail

As the buildings were not available for sale or tenure they provide a unique opportunity to make a side-by-side comparison of two alternative forms of construction in otherwise identical designs, and to undertake a study of their relative performance under a range of controlled occupancy conditions. So rather than examining similar houses under varying occupancies, which is normally the case, this study examines different houses under identical controlled occupancies. The study undertook a standard TSB BPE Phase 1 analysis for both houses which includes: Airtightness Testing; Co-heating test; U-value testing; Thermography; MVHR testing. This was followed by a series of six early occupancy studies that use varying occupancy regimes that tested the environmental performance of the houses and users perceptions of comfort and environmental quality. The project was conducted between January 2011 and March 2012.

SCENARIO TESTING

The scenarios were two-week periods of occupancy during which both houses were inhabited by volunteer residents (n=4 in each house) recruited from students at the MSA who lived in both houses using identical regimes. The occupants were given an occupancy script that determined their general activity and use of the house. Care was taken to ensure comparative occupancy in both houses. Information was collected through ticksheets and diaries about their detailed activity, such as cooking, window opening, frequency of shower use, etc. Qualitative assessment was undertaken during the occupancy scenarios, including surveys, interviews and comfort polling which was used to assess thermal comfort and air quality on a 7 point scale with 4 being neutral.

Monitoring of the temperature, relative humidity and carbon dioxide in all spaces was undertaken using Eltek

GD-47 transmitters recorded at 5-minute intervals. Daily meter readings were taken for gas and electricity.

These regimes were based on monitored occupancy profiles derived from other monitoring projects undertaken by MEARU, common to housing stock owned by GHA, but also investigated some issues that arose during the project, for example the impacts of the MVHR system.

SC1 A standard occupancy based on SAP assumptions
SC2 Standard occupancy, with variation in the use of the MVHR system
SC3 Continuous daytime occupancy
SC4 Originally summer, revised to unoccupied testing looking at sunspace and thermal mass
SC5 Examination of continuous vs intermittent heating regime
SC5 Comparison of natural vs mechanical ventilation regimes

A large amount of data was produced during the project and this paper describes some of the key findings from the study.

ENERGY CONSUMPTION

The original target figure for energy for space and water heating was 23 kWh/m2. Annual measured consumption was 69.9 kWh/m2 for Plot 1 and 62.4 kWh/m2 for Plot 3, however these figures do not account for uncontrolled occupancy or other differences, for example the failure of the Solar Thermal system in Plot 1.

The Scenarios provided a much more accurate comparison. In energy terms Plot 3 consumed less energy than Plot 1 during all the scenarios except SC5. In the base case SC1 which follow the standard SAP regime, this was 5.43 kWh/m2 in Plot 1 and 4.06 kWh/m2 in Plot 3. This relative performance in terms of fabric was confirmed in a whole house fabric heat loss (co-heating) test conducted on both houses simultaneously, which gave Plot 1: 1.53 kWh/m2 and Plot 3 1.26 kWh/m2. Given that the tested airtightness is reasonably close (Plot 1: 3.93 m3/h/m2 and Plot 3 4.06 m3/h/m2), there is identical roof and floor construction; the differences are likely to be primarily due to varying fabric performance. It is noted that there has been a decrease in airtightness performance since the houses were constructed. Original values were 3.02 m3/h/m2 for Plot 1 and 3.47 m3/h/m2 for Plot 3.

Tested U-values for the walls were 0.27 W/m2/K for plot 1 and 0.18 W/m2/K for Plot 3 (both 0.15 W/m2/K design vales). Tested U-values for the roof were 0.32 W/m2/K (design value 0.13 W/m2/K). The values for Plot 1 walls are surprisingly high. Possible explanations for this could include test error, effects at block edges, filling of end joints (noted in the adjacent Plot 2), dynamic effects due to the mass or as the test site is close to a window opening, or possible moisture absorption in the external insulation, and are subject to on-going investigation. It is noted that previous whole wall tests on similar construction have produced comparable results [10].

Nevertheless overall thermal integrity was good in both houses. Thermographic imaging revealed some weakness, particularly at windows and window openings and doors, particularly seals.

Figure 5: Thermal weaknesses at window openings

The possibility of exploiting the thermal mass of Plot 1 was examined in SC5, which tested different heating regimes. In this scenario a 2-period heating regime with higher thermostat settings (07:00 – 09:00 and 17:00 – 23:00, TRV's 4, 20ºC thermostat) in week 1 was compared to a 1-period heating regime with lower settings (07:00 – 23:00, TRV's 2 20ºC thermostat) in week 2.

Table 1: Energy consumption Co-heating and SC5 week 1 and week 2

	Ext Temp	Plot 1 kWh/m^2	Plot 3 kWh/m^2	P1:P3
Co-heating Test	7.0 °C	1.54	1.26	1.22
Scenario 5 Week 1	8.6 °C	0.31	0.22	1.45
Scenario 5 Week 2	6.8 °C	0.29	0.28	1.05

This appeared to be beneficial in the case of the more thermally massive construction of Plot 1 – i.e. the dwelling could be heated at low level during the day with the heating being absorbed by thermal mass and then being released back to the space during the periods of occupation. In this case consumption was closer to that of Plot 3, and less than in the previous week, despite lower external temperatures. In SC5 comfort polling indicated that although both dwellings performed well, Plot 1 had a marginally improved performance, and this is underpinned findings from other scenarios, which tended to rate Plot 1 as being more comfortable and less prone to overheating.

Table 2: Mean comfort levels SC5 week 1 and week 2

Mean thermal comfort (std. dev)		
	Plot 1	Plot 3
Week 1	4.48 (0.60)	4.61 (0.35)
Week 2	4.18 (0.48)	4.45 (0.47)

ENVIRONMENTAL PERFORMANCE

A particular area of investigation concerned indoor air quality. In a pilot study conducted in 2011 a number of defects were identified in the MVHR system, included crushed and split ducts, and the system had been re-commissioned prior to SC1, but inherent limitations of the system continue to compromise its performance.

Table 3: Measured MVHR airflow rates

	Plot 1		Plot 3	
Extract Positions	High Rate l/s)	Low Rate l/s)	High Rate l/s)	Low Rate l/s)
Utility/ WC	7.23	5.49	9.23	5.64
Kitchen	9.81	6.81	12.11	8
Bathroom	9.3	6.3	8.26	5.35
Total	**26.34**	**18.6**	**29.6**	**18.99**
Supply Positions	High Rate l/s)	Low Rate l/s)	High Rate l/s)	Low Rate l/s)
Living Room	5.64	4.51	7.27	7.34
Bedroom 1	9.31	7.45	8.69	8.64
Bedroom 2	8.13	6.23	6.53	6.9
Bedroom 3	7.8	5.96	3.88	4.26
Attic Room	8.42	6.69	7.27	7.48
Total	**39.3**	**30.84**	**33.64**	**34.62**

Ductwork is complex and restricted, with 100mm flexible ducting widely used and remains unbalanced, as some ducts cannot be accessed to check for leaks or obstructions. As the system only provides a background level of ventilation, its ability to respond to peak loads is limited. There is no means of enabling airflow through the building when bedroom or bathroom doors are closed. The location of the unit in the loft will compromise regular and effective filter cleaning and maintenance. Of note are the values for individual rooms compared with a desired ventilation rate of 8 l/s per person. Given that most rooms could reasonably be expected to have multiple occupancy this is a cause for concern. There is no other provision for background ventilation in the dwelling, so concerns were raised about the dwelling performance should the MVHR system fail or be disabled. It was also found that the filters quickly became dirty between scenarios. The effects of this were investigated in SC2, when the system was first occluded (simulating filter blockage) in week 1, and then turned off in week 2. Occupants were asked not to open windows during this period.

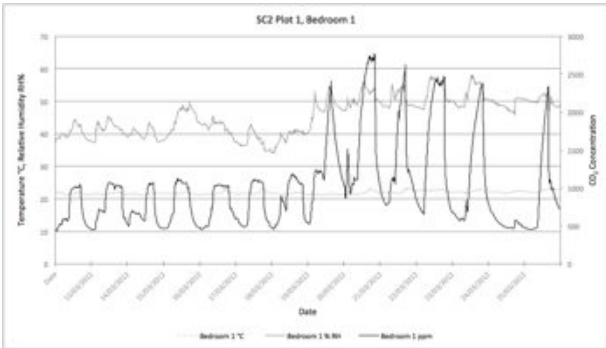

Figure 6: CO_2 levels SC2, Plot 1, Bedroom 1

During the first week of occupation the same diurnal relationship of CO_2 concentration and RH is evident through all apartments. In general the peaks in CO_2 concentration are comparable to those seen in SC1 and indicate that the impact on performance of the 50% occlusion is limited. Measured airflow in this period was similar to the un-occluded period, suggesting that fan speed is increased (with a consequent energy penalty). In week 2 when the system was disabled the impact on IAQ is far more pronounced. The peaks in CO_2 concentration reach levels, particularly in bedrooms, that are indicative of very poor air quality. This increase in pollution levels also extends to include water vapour as RH levels are seen to incrementally increase independent of the internal temperature.

Table 4: Mean CO_2 Concentration SC6

	Mean CO_2 Concentration	
Period	Plot 1	Plot 3
Week 1	822.6 ppm	939.0 ppm
Week 2	1422.2 ppm	1371.6 ppm

In SC6 this problem was revisited, with more detailed investigation of effects on user comfort and perception, and comparing MVHR use with natural ventilation. In week 1 the dwellings were reliant on the MVHR system and in week 2 the system was again disabled, but window opening was allowed.

It is apparent that there is a marked deterioration in mean CO_2 levels in the dwellings between the two weeks. Occupant perception of air quality in both dwellings and over both weeks is perceived as being generally good by the residents with values close to '4' with low standard deviation consistently achieved. Between the two weeks there is very little change in perception of IAQ in Plot 3 while in Plot 1 the IAQ is seen to be less stuffy.

Table 5: Mean Internal Air Quality Perception SC6

	Mean Internal Air Quality Perception (std. dev)	
Period	Plot 1	Plot 3
Week 1	4.38 (0.14)	4.75 (0.32)
Week 2	3.78 (0.22)	4.79 (0.33)

In comparing the living room conditions over the two-week period, the difference is not significant. Peaks of CO_2 are experienced during periods of high occupancy, but window opening mitigates these.

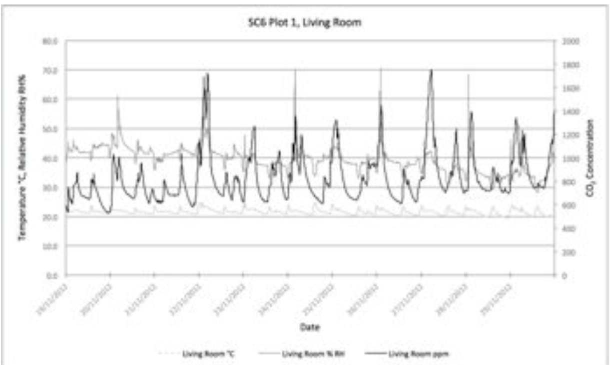

Figure 7: CO_2 levels SC6, Plot 1, Living room

In the bedrooms an identical pattern to SC2 was observed, with very high CO_2 levels recorded overnight. From the monitored data it is clear that the actual IAQ was markedly worse during the second week therefore it is worth considering why this would not be perceived by the residents.

The obvious explanation is the model of adaptive comfort; having the opportunity to ventilate directly made the occupants feel more in control and capable of altering the environment as they require. However it is clear that this model does not apply to bedrooms overnight. Windows are not opened to ameliorate air quality – as might be expected, people who are asleep do not perceive and therefore act to change their environment. This is significant as not only are conditions very poor, but the occupants are exposed to them for long periods of time.

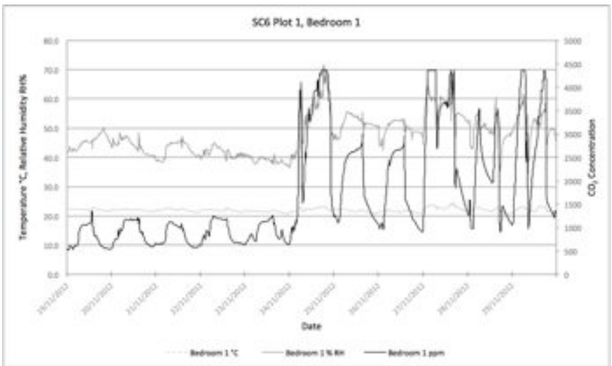

Figure 8: CO_2 levels SC6, Plot 1, Bedroom 1

TEMPERATURE

Temperatures were controlled during the scenarios, with boiler, programmer and TRV's set by the researchers. Some issues were identified that would contribute to inefficient performance. In a pilot study, setting TRV's at 4 resulted in unacceptably high temperatures, even during very cold periods, and it is apparent that the heating system is over-sized for such a thermally efficient dwelling. A radiator is provided in the thermally weak draught lobby. The other key problem was overheating due to un-insulated pipework from the hot water and solar thermal system. The solar thermal store is located in a top floor plant space and temperatures here were seen to be remaining between 25ºC and 30ºC. Thermographic imaging revealed the impact of this on adjacent spaces, particularly the attic bedroom, which tended to experience higher average temperatures.

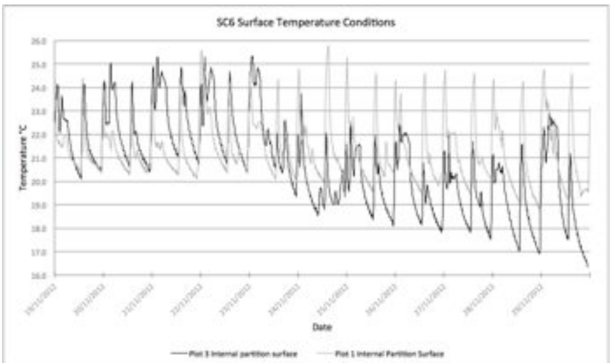

Figure 9: Internal partition surface temperatures SC6 Plot 1 and 2

The other issue of note was observed in SC6. In this scenario internal surface temperatures in the living room were recorded (Figure 9). It is apparent that the fabric in Plot 1 retains its temperature with a more liberal window-opening regime. This would have important implications for comfort and energy consumption, particularly in conjunction with a low level continuous heating regime.

CONCLUSIONS

Actual energy consumption for space and water heating are around 3x the predicted value. Although some elements of occupancy contribute to this, sub-optimal performance of the fabric and active systems was identified. Although in pure energy terms Plot 3 outperformed Plot 1, the latter scored better in qualitative terms and scenario testing identified several instances where the mass would have beneficial effects in terms of both energy use and comfort.

Overall consumption is estimated to be in the order of £390 - £490 per year for Plot 1 and £350 - £370 for Plot 3 for space and water heating, within limits of affordability for the size and type of house. However this could be reduced with fabric improvements, optimization of the solar thermal and MVHR systems, and a more closely sized and better-controlled heating system. The sunspaces (not discussed in this paper) could be used to reduce heat loss, assist with ventilation and removal of moisture from key activities such as clothes drying.

The inclusion of active systems needs careful consideration in terms of matching design intention with actual performance, which, in these houses was problematic. This raises questions for the client about how such systems can be included in an affordable and beneficial way. Performance requirements, maintenance costs and user interaction are key variables.

Whilst there are potential beneficial effects in terms of reducing ventilation losses and maintaining indoor air quality through the use of MVHR systems, it is clear that these rely on careful design, procurement, installation, maintenance and user interaction. Loss of air-tightness over time will also undermine its effectiveness. The implications of system failure are significant, and can present a real risk to the quality of internal environments and, over time, to the health of residents as well as increasing energy consumption.

This project is a clear demonstration of the benefits of undertaking a process of building performance evaluation, and strongly supports the decision to undertake construction of these prototypes and the lessons learned are being fed into future projects Scenario testing developed insights and although not widely applicable, provided a methodologically sound approach to the examination of key issues

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