

INNOVATIVE REFURBISHMENT STRATEGIES FOR POORLY PERFORMING HOUSING STOCK IN SCOTLAND, UK

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Abstract *Scotland is currently increasing its housing stock at a rate of less than 1% per year. With 174,000 households registered on local authority waiting lists for new or improved housing, the energy-efficient retrofit of derelict and dilapidated housing stock is seen as a key strategy in meeting this demand.*

The traditional “4-in a block” archetype is seen to characterise the housing stock of many low-income communities across Scotland. Such homes were constructed using masonry cavity walls and other experimental techniques which complicate the refurbishment process in meeting current, low-carbon standards.

This paper presents the results from a building performance and retrofit strategy evaluation on two, 4-in-a-block dwellings. One block was purposely built in the Building Research Establishment (BRE) Innovation Park in Motherwell, Scotland whilst the other block forms part of a wider urban regeneration scheme in the region of Fife, Scotland.

In-situ thermal testing and subsequent analysis of each building block showed that significant improvements in meeting modern low-carbon standards and acceptable health conditions can be achieved. The outcomes demonstrated that the rehabilitation of such house types can make a significant contribution to the built environment with improvement to: 1. The provision of housing 2. Reducing the demand for new build housing, 3. Protecting development on green belts and 4. The vitality of existing communities. The findings from this research have been used to direct future dwelling refurbishment strategies, steer innovation in archetype regeneration, generate new knowledge on social housing issues and improve knowledge on methods to meet housing demand.

1. INTRODUCTION

Recent Scottish Government housing statistics report that 150,000 households are on local authority waiting lists across Scotland, with a further 23,600 on transfer list [1]. Social housing completions have fallen by 44% from 2010 to 2014 to just over 3,200 with schemes like ‘Right-to-Buy’ and demolitions adding to the deficit [2]. Additionally, there are 27,000 private sector homes in Scotland that are unoccupied; abandoned, derelict or in a dilapidated state requiring upgrading and refurbishment [3]. In Scotland, the “4-in-a-block” archetype is prevalent in many low-income communities. Built between 1919 and 1965, there are approximately 239,000 in Scotland and were the first to be built using masonry cavity wall and other experimental techniques [4].

The improvement of existing buildings was first highlighted by Sir John Egan in the Construction Task Force report of 1998 [5]. The report highlighted that tackling existing buildings would reduce running-costs. Furthermore, the Sullivan Report in 2007 and its recast in 2013 [6] recognised that in order to meet housing needs it is important to improve existing domestic buildings in reducing their operational carbon emissions. The UK is currently replacing the housing stock at a rate of less than 1% per year and it is therefore imperative that we improve the performance of existing homes [7]. It is expected that emissions from existing homes in 2015 will account for 94% of the total emissions whereas recently built housing (<3 years old) will only contribute 6% [7]. At the current rate of stock turnover, two thirds of our building stock will still be in operation by 2050 [8]. Therefore, for the UK to meet its carbon emission targets of 80% by 2050 (against the 1990 baseline) it will require a robust direction and investment from government [9].

The aim of this paper is to present the results from thermal considerations proposed to retrofit two 4-in-a-block buildings. One was purposely built as a retrofit test laboratory in the Building Research Establishment (BRE) Innovation Park in Motherwell, Scotland and the other forms part of a wider development by local authorities and housing providers in Lochore, Fife, Scotland. The objectives differ in that one will inform future refurbishments considering occupant issues and retrofit innovation and the second provides housing to residents of the region by implementing innovative techniques and testing their effectiveness while occupied. This approach in both case studies makes this research significant. Both blocks underwent building performance evaluations (BPE) which will be discussed in this paper.

2. BACKGROUND

The Scottish Housing Condition Survey (SHCS) [4], classifies 4-in-a-block properties as flats in a common block, where each flat has its own separate access i.e. not through a common stair or entrance and also where no common access or entrance is present. This archetype originated from the UK Governments Housing Acts of 1919 to 1930 that required local authorities to survey housing needs and implement slum clearance. Housing shortage and poor living conditions were abundant in Britain during post-war periods making local authority house building a priority [2]. To this effect, 1.5 million public homes were built by 1951. Such house types, built at a fast rate with reduced budgets produced poorly constructed homes with thermal and acoustic problems that would later exacerbate rates of

fuel poverty [10].

This study will analyse the improvement methods of two blocks which have been carefully retrofitted to improve living conditions and provide an alternative to commonly demolished housing stock. The BRE block labelled as the ‘Refurbishment House’ was designed and built using historical design information and traditional methods of construction. Refurbishment options were then integrated into the construction phase of each flat showing materials, technologies and level of intervention. The Lochore block in Fife was selected from an urban re-densification project where five blocks were demolished and new homes built while one was left for refurbishment.

The BRE block has been purposely built as a refurbishment exemplar to inform and guide local authorities and housing developers on different levels of approach and intervention, Figure 1 shows an example. The four different flats were purposely specified and designed in accordance with a common type of occupancy and level of intervention as seen in Table 1. The Lochore block, in Figure 2, was purposely designed to be occupied on its completion as mid-market rent accommodation, see Table 2. Both blocks were intended to comply with Scottish Building Standards (SBS) Section 6 Energy and Section 7 Sustainability labelling system, commonly used for new-build properties, [11].



Figure 1. Example of a 4 in a block similar to BRE block

Figure 2. Derelict block due to be refurbished, Lochore, Fife.

The BRE block imposed restrictions to simulate the occupancy restrictions often encountered during refurbishment. Flat G1 has been designed as an occupied property with minimal disruption where the occupants are unable to vacate the property, i.e. an elderly or disabled resident. Flat G2 was able to be vacated for a short time and interventions are sensitive to the historical heritage of the property. Flat F1 was also occupied with minimal disruption but has undergone a full heating replacement. Flat F2 underwent a full refurbishment requiring occupants to fully vacate the property for a longer period as major work would be done to the interior of the dwelling. These distinctions are important because they present a realistic scenario in the refurbishment of property, often dependant on the type of occupants and the tenure (social & private).

The Lochore block undertook a different approach. The objective behind the retrofit was to implement (as closely as possible) the SBS Section 7 criteria and experiment with the distribution of commercially available products that can be used for retrofit purposes. Similarly

to the BRE block, many materials, technology and methods were adopted and subsequently evaluated at pre and post occupation periods.

Table 1. BRE block, retrofit improvements and restrictions.

	Flat G1	Flat F1	Flat G2	Flat F2
Description	Ground floor (left)	First floor (left)	Ground floor (right)	First floor (right)
Imposed restrictions	Occupied (minimal disruption)	Occupied (minimal disruption)	Decant/ void	Decant/ void
Approach	Cavity & External insulation & basic heating upgrade	Cavity & External insulation & full heating upgrade	Cavity & Internal insulation	Cavity & Internal insulation
Fenestration	Double Glazing, uPVC	Double Glazing, uPVC	Double Glazing, timber sash & case	Triple Glazing, uPVC
Space & water heating	Gas Combi boiler with flue saving	Gas System boiler	Electric Combi boiler	Air source heat pump
Ventilation	Natural & extract fans	Positive input ventilation (PIV)	Intermittent & heat recovery	MVHR
Renewables	-	4m ² Solar thermal, 210 Lt cylinder	0.5 kWp Solar PV	-

Table 2. Lochore block, retrofit improvements and restrictions.

	Flat G1	Flat F1	Flat G2	Flat F2
Description	Ground floor (left)	First floor (left)	Ground floor (right)	First floor (right)
Approach	Cavity & internal insulation	Cavity, internal & external insulation	Cavity & internal insulation	Cavity, internal & external insulation
Fenestration	Triple Glazing, uPVC	Double Glazing, uPVC	Double Glazing, uPVC	Triple Glazing, uPVC
Space & water heating	Combi boiler	System boiler & 165 Lt cylinder	System boiler & 165 Lt cylinder	Combi boiler
Ventilation	Natural & Fan extractors	Natural & Fan extractors	MVHR	Natural & Fan extractors
Renewables	1.05 kWp Solar PV panel	4.5m ² Solar thermal panel	6.8m ² Solar thermal panel	0.9 kWp Solar PV panel

3. METHODS

3.1. Building envelope monitoring

The air permeability of properties was assessed by pressurisation and depressurisation using Blower Door and fan test equipment. Accuracy of the tests results is based on BS EN Standard 13829:2001 [12] criteria. Air tightness tests identify air leakage where uncontrolled air flow appears through the envelope. [13].

In-situ U-value tests were conducted during a heating period using Grant Squirrel data loggers ($\pm 0.1\%$) with Hukseflux HFP01 thermopile-based heat flux transducers ($\pm 3\%$) and four K-type thermocouples, deployed at five minute intervals for a period of 14 days. Additional Gemini data loggers, model Tiny Tag TGU-4500 ($\pm 0.5^\circ\text{C}$) recorded temperature and humidity to validate thermocouples. Figure 3 shows where equipment was mounted. The testing complied with BS ISO 9869:2014 guidelines and calculations [14] as seen in Figure 4. Reliable results are obtained with a temperature differential (ΔT) of $>10^\circ\text{C}$ across the building element.

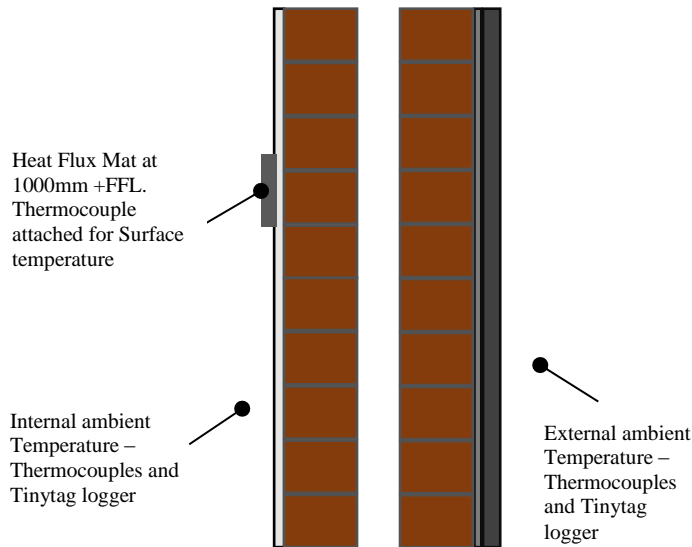


Figure 3. Cross section of installed equipment

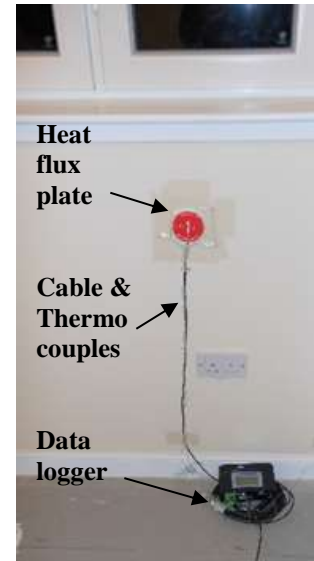


Figure 4. Photo-diagram of typical installation

Infra-red thermography surveys were conducted during the first heating period. It included an internal and external survey of building elevations. Infra-red thermography is a non-destructive qualitative test in accordance with BS EN 13187: 1999 [15]. It is a tool that establishes surface temperature variations caused by building defects.

3.2. Compliance modelling – energy consumption

Under the Energy Performance of Buildings Directive (EPBD) 2002/91/EC and its recast 2010/31/EC [16] each Member State is required to evaluate and certify their buildings. In the UK the National Calculation Methodology (NCM) created the Standard Assessment Procedure (SAP) generating Energy Performance Certificates (EPC). Calculations have become the commercial and analytical method of understanding building performance of dwellings in the UK.

For the purposes of this paper, a simple evaluation of the compliance SAP results at the design stage were compared against the results at the As-built stage. As-designed envelope U-values were substituted with the in-situ monitoring U-values. Similarly, the same methodology was adopted with the air permeability results. Once results at both stages were generated, energy for space and water heating and controlled electrical ancillary energy use

were compared against each other, highlighting the differences and their environmental impact.

4. RESULTS

4.1. Building envelope monitoring

4.1.1 Air permeability

The tests were conducted whilst the properties were partially furnished and unoccupied. The test results, presented as As-built q50 are constantly higher for every property than the As-designed specified values, this difference was seen as high as 90%. The difference in test and design results are systematically much higher in the Lochore block. These results suggest that each property potentially had much more heat escaping through undesired ventilation than expected. During the testing researchers detected apertures around service penetrations and gaps between junctions causing undesirable air infiltration. Many of the apertures could have been sealed if specific workmanship checks were conducted on these service penetration areas. The results for the BRE block are shown in Figure 5 and for the Lochore block in Figure 6.

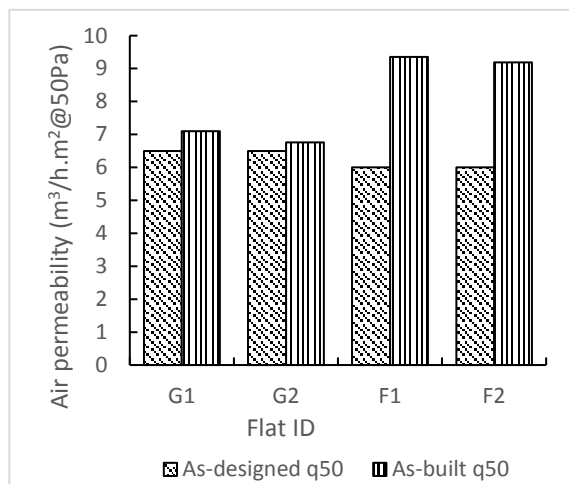


Figure 5. Air permeability results – BRE block

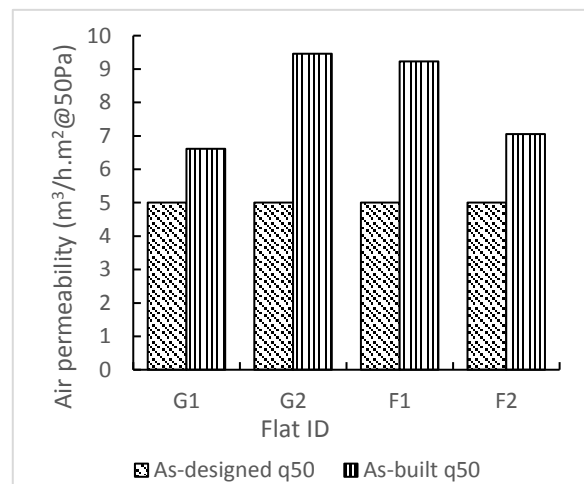


Figure 6. Air permeability results – Lochore block

4.1.2 In situ U-value

The measured values for each component analysed in the two blocks can be seen in Tables 3 and 4. Both blocks were designed to 2010 Scottish Building Standards with U-values calculated at design stage to be below 0.21 W/m²K. Neither block had overly stringent U-values than the other. Test results show that the U-value for all but 2 components in each block were higher than designed, meaning the flats would experience more fabric heat loss than designed.

On average the ceiling U-value results were close to or fell within the 10% logger error of

the designed values (<+/-18%). This was expected as cold-roof ceiling insulating methods are relatively simpler and easier to check and correct. The U-value test results for BRE G1 and Lochore F2 walls show that the As-built values are 120% higher than the As-designed, however the BRE G2, F2 and Lochore G1 walls are between 30% and 45% lower than designed. There was no significance in the percentage difference U-value result and the placement of insulation i.e. cavity, internal etc. Each flat had different insulation methods in order to fulfil the expected performance. However, the quality of workmanship and the attention to detail during construction could have altered the performance of the components, hence the observed changes. Significant increases in measured U-value may be the result of air infiltration around the insulation, unprotected and therefore damp insulation installed and still drying out, and differences in insulation thickness with repeated and linear thermal bridges.

Table 3. BRE block, As-designed and As-built results

U-value (W/m ² K)						
	Wall		Ceiling/roof		Floor	
	As-designed	As-built	As-designed	As-built	As-designed	As-built
G1	0.15	0.33	-	-	0.17	0.21
G2	0.21	0.12	-	-	0.17	0.21
F1	0.15	0.28	0.11	0.13	-	-
F2	0.19	0.12	0.11	0.13	-	-

Table 4. Lochore block, as-designed and as-built results

U-value (W/m ² K)						
	Wall		Ceiling/roof		Floor	
	As-designed	As-built	As-designed	As-built	As-designed	As-built
G1	0.17	0.12	-	-	0.14	0.27
G2	0.18	0.26	-	-	0.19	0.25
F1	0.13	0.17	0.13	0.11	-	-
F2	0.12	0.26	0.13	0.14	-	-

4.1.3 Infra-red thermography

Infrared thermography surveys were carried out by the research team with a FLIR B335 - 320 x 240 pixel resolution thermal imaging camera. In both blocks there were distinctive differences between the walls that were externally and internally insulated showing thermal bridging and heat loss. The research team also spotted several deficiencies internally, particularly at ceiling level in the first floor flats in both blocks. Considerable thermal irregularities were detected between the wall and ceiling junction where misplaced insulation and inadequate sealing around roof ventilation vents created air leakage, this correlates with the ceiling U-value in Lochore G1 where the measured U-value was 93% higher than designed. In ground floors, some thermal bridging occurred at the walls and the skirting boards coupled with missing insulation and thermal bridging between and on floor joists. Additionally, in both blocks heat loss appeared around sockets where gaps were not

insulated appropriately. These findings correlate with the recorded higher than designed air permeability values.

4.2. Calculated energy consumption

In this section, the results from the air permeability and U-value tests have been used to create a new SAP As-built model to quantify the differences in the flats energy use. At the design stage, many of the envelope performance values were obtained from static calculations and good practice aspired figures in order to pass certain standards and aspirational performance. The results in Figures 7 & 8 show that changes in thermal transmission and air permeability values have impacted on the As-built space heating energy demand. The BRE block presents between 11% and 24% increments in space heating from the designed values, which evidences the lack of intervention and attention to detail. However this block was built from new without the inherent problems of an older property. The Lochore block has shown between 12% and 41% increased space heating energy requirements which are strongly related to its envelope performance.

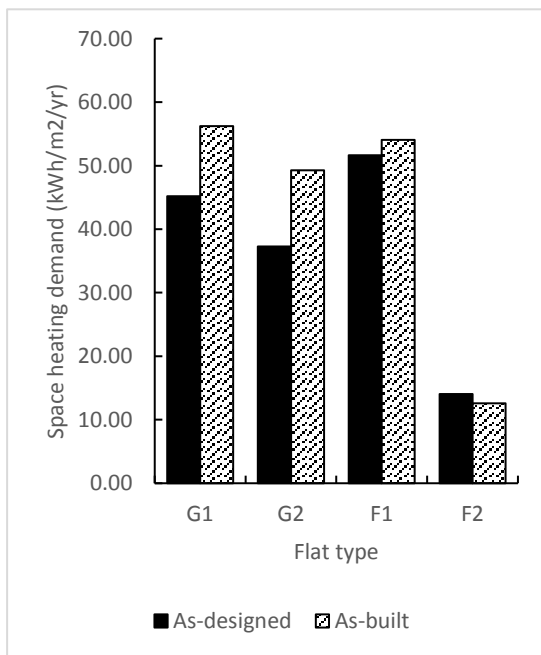


Figure 7. BRE block – As-designed vs As-built demand

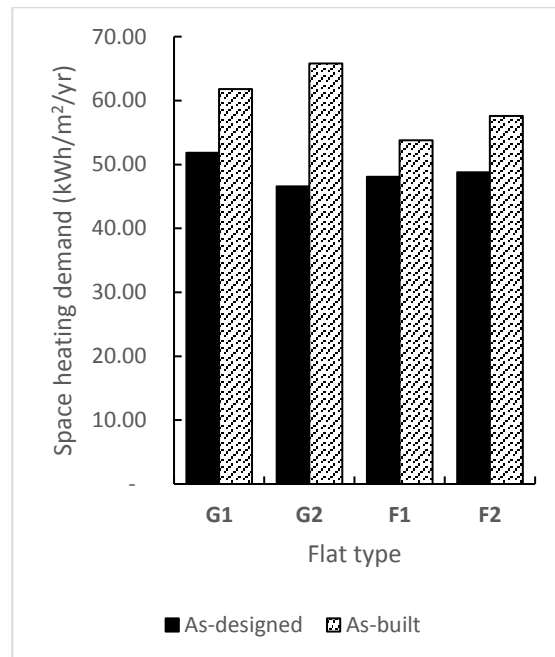


Figure 8. Lochore block – As-designed vs As-built demand

5. CONCLUSIONS

The evaluation of the building elements employed gives an indication of performance backed by thermal testing, including In-situ U-value and air permeability testing. The results of this study underline the importance of monitoring activities in the innovation of retrofit solutions in low performing dwellings. Although some of the results show proximity to the design aspirational calculations, it is the overall building energy performance that will determine how successful each retrofit has been. The BRE block has

shown that according to the interventions made, different performance results are obtained with some improvements from the As-designed aspirations. The level of intervention and their impact on the reduction of energy will inform housing providers on the best approach to take when retrofitting housing stock, alongside allocated budget and occupant type. In the Lochore block, providing high performance housing using existing dwelling stock has been deemed a priority. The retrofit of this block has not only rescued an existing block, but it has explored the technical, economic and performance based approaches to retrofit that are aligned with current building regulations. Further work on these blocks will evaluate how housing providers have implemented the solutions suggested and also compare actual delivered energy use over a twelve month period against As-designed calculations, thus quantifying the energy performance gap between them. The research has shown that ambitious retrofit strategies and specifications are somewhat circumvented by difficulties in the procurement, application, and financing of such work. Finished blocks can be seen in Figures 11 & 12.



Figure 11. BRE block As-built for demonstration purposes.



Figure 12. Lochore block As-built before occupation

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