Upgrading Glasgow's High-rise Building Stock – A Case Study

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Abstract

The city of Glasgow contains the highest concentration of social housing tower blocks in the UK – however a quarter of Glasgow's high-rises have been demolished in less than 10 years and many more are assigned for demolition as part of the city's plans for regeneration. However, this is an intrinsically expensive route to achieving the required number of affordable, energy-efficient housing units and instead many of the surviving tower blocks have been subject to a programme of retrofit to improve energy efficiency and thermal performance for residents. This paper looks at the four existing building typologies and their energy performance before the programme of external insulation and installation of a community CHP system providing residents with new efficient heating systems. Thermal energy data recorded and predicted from the 'as existing' scenarios are compared against the dataset of measured thermal energy consumption from 970 homes across all house-types from the first 12 months following retrofit. The data compares not only the actual thermal energy savings but also illustrates the cost saving to the resident and discusses methods of sharing the cost of communal standing charges equitably among residents taking cognizance of house-type size, number of occupants and their type of tenure.

Keywords: *energy-efficient upgrades; retrofit; high density housing; community heating*

Introduction

The European Performance of Buildings Directive (1) indicates that 40% of carbon dioxide emissions are attributed to buildings and sets out the legislative framework for EU member states to meet energy and carbon dioxide reductions in buildings in line with Kyoto protocol commitments. The Energy Efficiency Standard for Social Housing (2) aims to improve the energy efficiency of social housing in Scotland. It will help to reduce energy consumption, fuel poverty and the emission of greenhouse gases. The standard also contributes to reducing carbon emissions by 42% by 2020, and 80% by 2050, in line with the requirements set out in the Climate Change (Scotland) Act 2009 (3). In the built environment in Scotland, the carbon emission reduction commitment is legislated through the Building Regulations (Scotland), which has increasing requirements to reduce energy use through fabric and technical measures (4).

This paper focusses not only on the reduction in energy consumption but assess the impact that has on fuel costs for residents in existing social housing stock. Recent Scottish fuel poverty statistics indicate that 34.9% or around 845,000 households were living in fuel poverty and the number of households in extreme fuel poverty are 8.3% or 203, 000 (5). A household is in fuel poverty if, in order to maintain a satisfactory heating regime, it would be required to spend more than 10% of its income on all household fuel use. If over 20% of income is required, then this is termed as being in extreme fuel poverty (6).

Background

In 2008 The Mackintosh Environmental Architecture Research Unit (MEARU) undertook a feasibility study for a Glasgow based Housing Association which investigated upgrade options for their high density housing stock estate that would improve thermal efficiency and reduce energy consumption. As well as improvements in insulation levels, the recommendations also included the installation of a district heating system. In the study MEARU took 4 typical house types from the estate and calculated theoretical energy consumption figures for the existing blocks and proposed upgrades with predicted energy loads.

A comprehensive programme of improvements was completed by mid 2015 and an evaluation of the impact of the retrofit upgrade and district heating system on energy use and affordability was undertaken. This includes an analysis of recent fuel consumption data obtained from the energy provider- who manage the district heating system, to assess the impact of the upgrades on the resident's fuel bills. This paper reports the initial evaluation of heat energy consumption and highlights the improved energy performance by comparing the 'before refurbishment' theoretical energy consumption value with the recorded data provided by the utility company. The report also compares the cost per kWh from the 'before refurbishment' scenario with the 'after' scenario to quantify the resident's cost savings.

The initial energy feasibility study explored practical and economic means of upgrading the residential housing stock within estate. It provided retrofit scenarios to enhance thermal performance meeting particular minimum standards such as the Scottish Quality Housing Standard (SHQS) and the Energy Savings Trust (EST) Best Practice Refurbishment; and, where practical, moving towards German 'Passivhaus' compliance. The report identified a series of upgrades including recommendations for affordably improving the thermal envelope as well as providing new heating systems and enhanced means of ventilation.

Existing energy consumption for the existing scenario of the 4 house types was generated using BREDEM analysis to provide a breakdown of estimated space heating loads and norms for domestic hot water and electricity use (regulated and unregulated). BREDEM (BRE Domestic Energy Model) is the name given to a family of simple but reliable energy calculation procedures for dwellings. It was first developed in the early 1980s and, as a result of continuous testing and development, it has become very widely used. It can be used to estimate energy requirements in different dwelling types. In this paper the existing (before refurbishment) values are compared with the measured data (annual heat energy consumption) supplied by the utility company.

4 house types across the estate as follows:

- House type 1- 26 storey multi storey flats
- House type 2- 15 storey multi storey flats
- House type 3- 8 storey multi storey flats
- House type 4- 4 storey maisonettes

This characterisation of house types by block type is used in this report. However this paper also identifies the variations in flat types by number of bedrooms in order to identify energy consumption differences between 1, 2 and 3 bedroom flats. In addition the analysis identifies variations in charges between rented accommodation and those which are privately owned but are connected to the HA's district heating system.

Housing Stock Upgrades

The HA undertook a programme of upgrades to the building fabric over a 5-year period commencing in 2009. The high rise blocks have undergone a programme of over cladding which includes improving the thermal performance of the external envelope with 100mm of rigid insulation faced with coloured render. High performance double glazed windows (and balcony doors) with a U-value of 1.8 W/m^2K have also been installed on all high-rise blocks. These improvements will substantially reduce heat losses and reduce air permeability to which high rise blocks can be particularly susceptible.

In addition to the fabric upgrades the HA installed a 1.2 MW CHP heating system. The original electric night storage heating in the multi-storey and low rise housing was very expensive and uncontrollable and during the late 2012 and early 2013, this was replaced by a district heating system which provides heating and hot water. The plant is a gas-fired Combined Heat and Power generator located on the estate, which distributes heat via hot water pipes across the scheme and heat is delivered to the dwellings via a wall mounted heat exchanger which in turn supplies modern slim line radiators with thermostatic radiator valves (TRV's) as part of a wet central heating system. These allow the resident greater control of temperatures in each room together with a central timer to allow regular heating patterns to be set to suit the occupants. Radiators have been installed in all rooms (except kitchens). Overall the new heating and hot water system allows the resident greater control over their heating and gives more instantaneous heat than the previous storage heater system. The old heating system used electric heating, based on 'on peak' and 'off peak' tariffs. Many residents were previously dissatisfied with the electric heating, which was perceived as ineffective and expensive.

All of the properties within the estate owned by the HA have been connected to the district heating system and 266 privately owned houses (mainly in the maisonettes) also took up the offer of free connection to the new district heating system; assisted by grant funding secured through support from the Scottish Government and Glasgow City Council. The network is supplied by a 1.2MW gas CHP engine with three 4.5MW backup/peaking gas boilers, and a thermal store (120,000 litres). Electricity from the CHP is not supplied specifically to the estate but is exported via the public network. The utility provider operates and maintains the heating system, and provides metering and billing services, under a long term contract with the HA.

Some households have a credit meter and either pay by direct debit or periodic billing (such as quarterly). Others have a system similar to a prepayment meter in that they charge up their meter using a 'key' at a local shop. Initially this rate was based on the utility companies estimate of annual consumption for different types of home, and it is revised periodically to reflect actual consumption patterns.

Methodology

Annual energy consumption (heating and hot water) data was provided by the utility company – energy data from 1,690 properties in total. The data was provided in postcode/ house code format rather than by house address in accordance with Data Protection legislation. The data provided by the utility company was from January 2014 until March 2015. These were then cross referenced with the HA database of house types and averaged on a block-by-block basis.

This data has been sorted into individual blocks to allow the HA to assess the different energy demands in each flat type within each block. The data has been recorded from heat meters within each individual flat - these record the energy supplied to the dwelling for the wet central heating system and the hot water, but does not differentiate between the two uses. There is no data for electrical energy use as each resident has their own supplier (and private contract with that energy supplier which is subject to data protection).

The data set was reviewed to identify any outliers - the studio flats are regularly available for let and are therefore often empty for short periods of time. Therefore, any data which has 2 consecutive zero readings during the heating season (Sept to May) are excluded from this dataset to account for void or partially void flats. An average value for each house type (including variations in flat size) has been calculated and compared against the estimated annual energy consumption figure for the 'before refurbishment' scenario prepared by MEARU in 2008. A percentage improvement figure is highlighted in the table of results.

The annual heat energy costs for each house type have been calculated using the utility company standard tariffs and the standing charge rates applicable for both rented and owner occupied homes. The costs have been calculated based on the current tariff unit rate of 5.22 p/kWh and fixed charges at 41.3323p/day (as of June 2015).

A tariff to reflect the previous electricity rate (for the storage heaters) has been applied to the theoretical energy consumption figures for the 'before refurbishment' scenario to calculate an indicative 'before' cost. This is then compared with the current annual energy cost and a percentage improvement figure is generated. This paper concludes with explanations of the resultant energy consumption and cost figures and makes suggestions for future in depth study to identify causes of trends.

Energy Analysis by House type

House type 1 - 26 Storey Blocks (4 number blocks, Total - 600 flats)

Figure 1- 26 Storey block, before and after refurbishment.

March 2008- 26 storey block prior to refurbishment	May 2015- 26 storey block after refurbishment

In the 26-storey block there are 6 flats on each landing; four 1-bedroom flats, and two studio flats. The studio flats are regularly available for short-term lets and therefore have a high turnover of occupants and are often empty for short periods of time. This has been accounted for in the energy calculations to ensure that the average consumptions are not lower than expected.

These blocks have undergone thermal upgrading works including improving the performance of the external envelope with 100mm of rigid insulation (Rockwool – Eco Rock) faced with coloured render. High performance double glazed windows (and balcony doors) with a U-value of 1.8 W/m^2K have also been added. The original electric storage heaters have been replaced by modern slim line radiators with thermostatic radiator valves (TRV's) and programmable domestic system controls, as part of a wet central heating system. These allow the resident greater control of temperatures in each room together with a central timer to allow regular heating patterns to be set to suit the occupants.

Energy Consumption (for heating and hot water).

The following data has been provided by the utility company and represents a typical year (12 month period from Jan-Dec 2014) for 596 dwellings. N= 416 dwellings.

Table 1- Energy consumption (heat) average per flat type (average across all 26 storey blocks).

House type **26 storey block**	**Before refurbishment** Theoretical annual energy (heat) consumption (kWh)[1.]	**After refurbishment** Recorded annual energy (heat) consumption (kWh)[2.]	**After refurbishment** Average monthly energy (heat) consumption	**Percentage improvement** Heat energy consumption
1 bed flat($45.2m^2$) *297 dwellings*	9,536 kWh ($211kWh/m^2$)	5,392 kWh ($119kWh/m^2$)	449 kWh	44%

1. *Theoretical figure calculated by MEARU in 2008 using BREDEM calculation.*
2. *Figures taken from data provided by utility company for Jan- Dec 2014.*

Using BREDEM methodology the 'before refurbishment' theoretical energy consumption figure was calculated on the 1-bedroom flat type. The actual heat energy consumption recorded for the 1-bedroom flat is a 44% improvement on the theoretical value calculated 'before refurbishment'. This new average annual heat energy consumption after refurbishment indicates a significant decrease.

Energy Costs

Table 2- 26 storey block, energy cost comparison, January - December 2014.

House type **26 storey block**	**Before refurbishment** Theoretical annual energy (heat) cost[1]	**After refurbishment** Recorded annual heating cost [2]	**Theoretical Annual Cost Saving**	**Percentage improvement in cost**
1 bed flat (rented)	£654.08	£432.30	£221.78	34%
1 bed flat (privately owned)	£654.08	£521.65[3]	£132.43	20%

1. Based on the previous tariff of 6.17p/kWh and 18p standing charge per day. However, this tariff would have varied depending on the energy supplier and method of payment.

2.Tariff- Unit Rate of 5.22 p/kWh for all properties plus a Fixed Charge of 41.3323 p/day.

3. Tariff for privately owned properties as above but also includes their contribution to the Capital Replacement Fund: 24.4800 p/day.

Table 3- 26 storey block, energy cost per tenure type, January – December 2014 (after refurbishment).

House type **26 storey block**	**Annual energy (heat) cost for rented property**	**Annual energy (heat) cost for private property**	**Average monthly energy cost**	**Energy cost for winter month (January).**
Studio	£410.00 (8.223p/kWh)	£499.35 (10.015p/kWh)	£34.20 (or £41.61- private property)	£45.53
1 bed flat	£432.30 (8.020p/kWh)	£521.65 (9.670p/kWh)	£36.00 (or £43.47- private property)	£57.64

From the data provided, the annual energy cost for residents in a 1-bedroom flat in the 26 storey block is £432.30. This is an average of £36.00 a month (a typical winter month may be as high as £57.64). The tariff unit rate of 5.22 p/kWh for all properties is a relatively low rate (although it is difficult to make comparisons with other energy companies due to their complex charging structures and variations in rates). However, the fixed charge of 41.3323p/day is relatively high (this includes a 24 Hour call out service and all repair and maintenance to the Heat Interface Unit and Meter along with the metering standing charge).

House type 2-14 storey blocks (5 no blocks, Total - 279 flats)

Image 2- 15 storey block, before and after refurbishment.

March 2008- 15 storey block prior to refurbishment	**May 2015- 15 storey block after refurbishment**

These five blocks are situated at the entrance of the estate. There are four flats on each landing, all 2 bedroom flats and each flat is double-glazed and has its own veranda. These blocks were upgraded with cavity wall insulation (70 mm Knauf Crown Supafil loose fill) which was then further enhanced by the programme of over cladding. During the over cladding the thermal performance of the external envelope was improved by the addition of 100mm of rigid insulation (Rockwool – Eco Rock) product faced with coloured render. High performance double glazed windows (and balcony doors) with a U value of 1.8 W/m^2K have also been added. The original electric storage heaters have been replaced by modern slim line radiators with thermostatic radiator valves (TRV’s) as part of a wet central heating system.

Energy Consumption (for heating and hot water).

The following data has been provided by the utility company and represents a typical year (12 month period from Jan-Dec 2014). n= 241 dwellings.

Table 5- 15 storey block, average energy consumption (heat) per block, January - December 2014 (after refurbishment).

Table 4- Energy consumption (heat) per 2 bed flat, (average across all 15 storey blocks).

House type **15 storey block**	**Before refurbishment** Theoretical annual energy (heat) consumption (kWh)[1.]	**After Refurbishment** Recorded annual energy (heat) consumption (kWh)[2.]	**After refurbishment** Average monthly energy (heat) consumption	**Percentage improvement** Heat energy consumption
2 bed ($64m^2$) 241 dwellings	9,180 kwh 143kWh/m^2	4,922kWh 77kWh/m^2	410kW	46%

1. *Theoretical figure calculated by MEARU in 2008 using BREDEM calculation.*
2. *Figures taken from data provided by utility company for Jan- Dec 2014.*

The existing annual energy consumption figure (before refurbishment) is 9,180kWh and the recorded energy consumption after refurbishment is now reduced to 4,922kWh representing a 46% improvement in energy efficiency.

Energy Costs

Table 5- 15 storey block, Cost of Energy Consumption (heat) per flat type, January - December 2014.

House type **15 storey block** (rented accommodation)	**Before Refurbishment** Theoretical Annual energy (heat) cost [1]	**After Refurbishment** Recorded Annual energy heating cost[2]	**Theoretical Annual Cost Saving**	**Percentage improvement in cost**
2 bed(rented)	£632.11	£407.78	£224.33	35%
2 bed (privately owned)	£632.11	£496.35[3]	£135.76	21%

1. Based on the previous tariff of 6.17p/kWh and 18p standing charge per day. However, this tariff would have varied depending on the energy supplier and method of payment.

2.Tariff- Unit Rate of 5.22 p/kWh for all properties plus a Fixed Charge of 41.3323 p/day

3. Tariff for privately owned properties as above but also includes their contribution to the Capital Replacement Fund: 24.4800 p/day.

Table 6- 15 storey block, Cost of Energy Consumption (heat) per flat type, January - December 2014 (after refurbishment).

House type **15 storey block**	**Annual energy (heat) cost for rented property[1]**	**Annual energy (heat) cost for private property[2]**	**Average monthly energy cost**	**Energy cost for winter month (January).**
2 bed	£407.78 (8.28p/kWh)	£496.35 (10.08p/kWh)	£33.00 (or £41.36- private property)	£56.24

From the data provided the annual energy cost for residents in a 2 bedroom flat in the 15 storey block is £408 - this is an average of £34 a month, or £1.11 per day. Whilst the energy consumption has improved by 46%, the cost saving to the resident in their energy bill will more likely to be 36%. This is in part due to the standing charges for the district heating system (to cover repair and maintenance). The saving might actually be greater for some residents who were on higher electricity tariffs previously and those who paid at higher rates for prepayment meters.

House type 3-8 storey blocks (7 no blocks, Total - 209 flats)

Image 3- 8 storey block, before and after refurbishment

March 2008- 8 storey block prior to refurbishment   May 2015- 8 storey block after refurbishment

These blocks have been referred to as the 'Bison blocks' due to the concrete construction system from the 1960's. A particular feature of this design is that the slab concrete floor construction penetrates through the external fabric, causing a significant thermal bridge; making these properties exceptionally hard to heat. They are 8 storey high and there are four flats on each landing; two 1 bedroom flats and two 2 bedrooms flats. All flats have their own verandas. Similar to the 26 and 15 storey blocks, these have undergone a programme of over cladding which includes improving the thermal performance of the external envelope and resolving the thermal bridging issues; with 100mm of rigid insulation faced with coloured render. The verandas have been enclosed and high performance double glazed windows (and balcony doors) with a U value of 1.8 W/m^2K have also been added. The original electric storage heaters have been replaced by modern slim line radiators with thermostatic radiator valves (TRV's).

Energy Consumption (for heating and hot water).

The following data has been provided by the utility company and represents a typical year (12 month period from Jan-Dec 2014). N= 165 dwellings.

Table 7- 8 storey block, energy consumption (heat) per flat type, January - December 2014.

House type 8 storey block	Before refurbishment Theoretical annual energy (heat) consumption (kWh)[1.]	After refurbishment Recorded annual energy (heat) consumption (kWh)[2.]	After refurbishment Average monthly energy (heat) consumption	Percentage Improvement Heat energy consumption
1 bedroom (48m^2) 84 dwellings	5,873 kWh 122kWh/m^2	3,563 kWh 74kWh/m^2	296kWh	39%

1. *Theoretical figure calculated by MEARU in 2008 using in BREDEM calculation.*
2. *Figures taken from data provided by utility company for Jan- Dec 2014.*

The 2008 report calculated the theoretical energy consumption of the 1 bedroom flat to be 5,873kWh which compared with the measured data provided by the energy company which shows a 39% improvement in energy consumption.

Energy Costs

Table 8- 8 storey block, energy consumption cost per flat type, January - December 2014.

House type 8 storey block	Before refurbishment Annual energy (heat) cost [1]	After refurbishment Recorded Annual energy (heat) cost [2]	Theoretical Annual cost saving	Percentage Improvement in Cost
1 bed flat(rented)	£428	£336	£92	21%
1 bed flat(private)	£428	£425[3]	£3	0.7%

1. Based on the previous tariff of 6.17p/kWh and 18p standing charge per day. However, this tariff would have varied depending on the energy supplier and method of payment.

2.Tariff- Unit Rate of 5.22 p/kWh for all properties plus a Fixed Charge of 41.3323 p/day

3. Tariff for privately owned properties as above but also includes their contribution to the Capital Replacement Fund: 24.4800 p/day

Table 9- 8 storey block, energy consumption cost per flat type, January - December 2014.

House type 8 storey block	Annual energy (heat) cost for rented property	Annual energy (heat) cost for private property	Average monthly energy cost	Energy cost for winter month (January).
1 bed flat	£336 (9.43p/kWh)	£425 (11.93p/kWh)	£28.00 (or £35- private property)	£36
2 bed flat	£361 (8.96p/kWh)	£450 (11.17p/kWh)	£30.00 (or £37- private property)	£42

From the data provided the annual energy cost for residents in a 1-bedroom flat in the 8 storey block is £336- this is an average of £28 a month. A typical winter month this may increase to £36. The 2-bedroom flat is not significantly greater with an annual energy cost of £361.

House type 4- Traditional Maisonettes and 'Walk-Up' Flats (Total Flats – 284)

Image 4- Traditional Maisonettes and 'Walk-Up' Flats, before and after refurbishment

March 2008- Maisonette and walk up flats prior to refurbishment

June 2015- Maisonette and walk up flats after refurbishment

The maisonettes are situated throughout the estate. The upper and lower maisonettes are a mix of 2 bedroom and 3 bedroom flats, with the upper maisonettes accessible by a common close that contains seven 1-bedroom flats on four levels. (69 Sheltered and 40 non-sheltered flats). Each flat is double-glazed and has its own veranda. These maisonette blocks have the highest percentage of home ownership. Some owner occupiers had already undertaken cavity wall insulation observed during the 2008 study. Replacement double glazing was also evident in some of these privately owned maisonettes and some had also removed the storage heaters and installed their own central heating system. Owner occupiers were given the option to connect to the district heating system. The maisonettes have undergone a programme of cavity wall insulation - the 50mm cavity within the construction was filled with Knauf Supafill loose fill insulation. The external appearance has been improved with coloured render in keeping with the over clad high rise blocks.

Energy Consumption (for heating and hot water).

The following data has been provided by the utility company and represents a typical year (12 month period from Jan-Dec 2014). N= 194 dwellings.

Table 10- Maisonette block, energy consumption (heat) per flat type, January - December 2014.

House type **4 storey Maisonette block**	**Before refurbishment** Theoretical annual energy (heat) consumption (kWh)[1.]	**After refurbishment** Recorded annual energy (heat) consumption (kWh)[2.]	**After refurbishment** Average monthly energy (heat) consumption	**Percentage Improvement** Heat energy consumption
1 bedroom 95 dwellings	*	4,035 kWh	336 kWh	*

2 bedroom($62m^2$) 47 dwellings	*	6,289 kWh 101kWh/m^2	524kWh	*
3 bedroom($80m^2$) 52 dwellings	12,067 kWh 151kWh/m^2	4,425 kWh 63kWh/m^2	369kWh	63%

1. Theoretical figure calculated by MEARU in 2008 using BREDEM calculation.
2. Figures taken from data provided by SSE for Jan- Dec 2014.

The 3 bedroom flat within the maisonette block proved to have the greatest energy improvement of the whole estate with 63% percentage improvement in heat energy consumption. The recorded consumption averaged over 52 dwellings (3 bedroom) was 4,425kWh whilst the 2 bedroom flats had higher recorded energy consumption. This is initially a surprising result but a review of the floor plan layouts indicates that the 2 bedroom maisonettes occupy the gable end location in the block therefore experiencing greater heat loss than the 2 bedroom ones located in the middle of the plan with less external wall surfaces.

Table 11- Maisonette block, energy cost (heat) per flat type, January - December 2014

House type **Maisonette block**	**Before Refurbishment** Annual energy (heat) cost [1]	**After refurbishment** Recorded Annual energy (heat) cost [2]	**Theoretical annual cost saving**	**Percentage improvement in Cost**
1 bed flat (rented)	*	£361	*	*
1 bed flat (private)	*	£450[3]	*	*
2 bed($62m^2$)rented	*	£478	*	*
2 bed($62m^2$)private	*	£567[3]	*	*
3 bed($80m^2$)rented	£810	£380	£430	53%
3 bed($80m^2$)private	£810	£469[3]	£341	42%

1. Based on the previous tariff of 6.17p/kWh and 18p standing charge per day. However, this tariff would have varied depending on the energy supplier and method of payment.

2.Tariff- Unit Rate of 5.22 p/kWh for all properties plus a Fixed Charge of 41.3323 p/day.

3. Tariff for privately owned properties as above but also includes their contribution to the Capital Replacement Fund: 24.4800 p/day.

Table 12- Maisonette block, energy cost (heat) per flat type, January - December 2014 (after refurbishment).

House type **Maisonette block**	**Annual energy (heat) cost for rented property**	**Annual energy (heat) cost for private property**	**Average monthly energy cost**	**Energy cost for winter month (January).**
1 bed	£361 (8.95p/kWh)	£450 (11.15/kWh)	£30 (or £37.5- private property)	£36

2 bed	£478 (7.6p/kWh)	£567 (9.0p/kWh)	£40 (or £47.25- private property)	£42
3 bed	£380 (8.59p/kWh)	£469 (10.6p/kWh)	£32 (or £39.00- private property)	£37

Significant cost savings will be experienced by residents in the 3 bedroom maisonette blocks- up to 53% improvement in energy bills. There is the greatest percentage of private home ownership within the maisonette blocks and these residents will also be making significant savings to their heating costs albeit not as much as those in rented homes due to the standing charge for the capital replacement fund.

Discussion

The upgrading of the estate has been very successful as the heat energy consumption is greatly reduced with the average reduction across the estate of 49%- as shown in table 20 below. The 4 storey maisonettes have experienced the greatest improvement in energy performance -the recorded data from the utility company indicates a 63% improvement from the theoretical consumption prior to refurbishment works.

Table 13- Comparison of energy and cost savings by percentage.

Housetype	**Percentage Improvement (theoretical)** Heat energy consumption (kWh)	**Percentage Improvement (theoretical)** Cost saving (£)
26 storey block	44%	34%
15 storey block	46%	36%
8 storey	39%	22%
4 storey maisonettes	63%	53%
Average	48%	36%

The average heat energy cost savings across the estate is 36% based on the theoretical ‘before refurbishment’ scenario (and associated electricity tariffs at that time). However residents in the 4 storey maisonettes will see even greater savings in their heat energy costs. For some residents who were paying even higher electricity tariffs and are served by a prepayment meter, the savings will be even greater.

The ‘before refurbishment’ calculations were based on a theoretical heating regime of 21^{o}C for 16 hours a day. However, the likelihood is that fuel poverty was such that both consumption and achieved temperatures were lower in actuality, with consequent risks to health and well-being. Further to the building upgrade measures many occupants may find that their comfort levels have increased and perhaps now have their heating on for longer periods (than the theoretical 16 hour). They may also keep their thermostat above 21^{O}C and open windows more liberally thereby improving air quality and creating a healthier indoor environment.

The constant-rate payment meter system, introduced by SSE, charges a fixed weekly amount to the household based on estimated heat consumption averaged across a year. Initially this rate was based on the utility company estimate of annual consumption for different types of home, and it is revised periodically to reflect actual consumption patterns- once a more accurate pattern of resident usage this fixed payment may reduce.

Despite the energy consumption being greatly reduced, the energy costs appear to be disproportionate to the flat size. From the recorded energy data from SSE the smaller flats (studio and 1 bedroom) are paying proportionately more for their heat energy than the larger 2 bedroom properties. Residents in the 1 bedroom flat types in the 26 storey are still paying on average £36.00 a month to heat their flat and above this, the resident will also be paying for their electricity consumption for power usage within the flat.

The utility company tariff unit rate of 5.22p/kWh for all properties is a relatively low rate and is lower than their gas tariff (although it is difficult to make comparisons with other energy companies due to their complex charging structures and variations in rates). However, the fixed charge of 41.3323p/day for a standing meter charge is very high -despite this including a 24 Hour call out service and all repair and maintenance to the Heat Interface Unit and Meter. Of the 380 privately owned homes on the estate (factored through the HA), 266 opted into the community heating scheme. These residents are required to pay an additional fee of £89 annually.

With the previous levels of standing charge rates residents whose energy consumption was low prior to the upgrade, may find that their energy costs maybe unchanged, while residents whose energy consumption was relatively high will find their energy costs are more affordable than previously. However, the HA has taken cognisance of the affordability of this pricing structure and have instituted a two tariff system, which differentiates based on usage. Now householders with low consumption pay less standing charge; although those with higher consumption pay less variable tariff charge; the net effect has resulted in a more equitable share of costs and improved affordability for householders.

The utility company also offer a low user tariff to tenants that are using less than 1500kWh a year and are in receipt of certain benefits. This is a unit rate of 8.46 p/kWh with no fixed charges, therefore for an analysis of energy consumption data in the estate there are currently between 50 and 60 who have been transferred to this 'low user tariff'. The HA Fuel Advisors are actively identifying customers to support moving onto this tariff. If a resident was staying on a short term basis it would difficult to identify their eligibility for this lower tariff rate and they may have moved before sufficient data has been gathered to apply to the utlity company.

It should be highlighted that this paper reports only on heat energy and some residents may still be experiencing high electricity bills due to personal appliances consumption which may alter their perception that heating costs are still high. Some occupant habits such as using electric feature fires will increase their electrical energy and associated costs as they are choosing to heat their home using energy with a higher tariff.

Conclusions

At this stage data for achieved temperatures and comfort conditions for post-refurbishment properties is not known and this is an important factor. A further phase of study would identify whether residents have increased their levels of thermal comfort and whether they are ventilating their homes more effectively given the enhanced thermal performance of their dwelling. By a programme of indoor environmental monitoring (capturing occupant heating habits during seasonal changes) room temperatures, relative humidity and CO_2 readings can be recorded and analysed from a selection of house types.

A further study to identify electrical energy consumption through an assessment of resident's electricity bills would allow a comparison of occupant's overall energy consumption before and after refurbishment but also whether they experience significant improvements in levels of warmth and control with the new system would need to be evidenced. A more intensive monitoring would also identify whether some residents are continuing with habits of plugging in supplementary fan heaters or feature electric heaters which would be reflected in their electricity bills. In addition to user habits, it would be beneficial to establish tenants understanding of the controls of the new heating system. The new system has time programmers; thermostats and TRV's (which if used effectively) could save the resident money in their energy bill. Scotland's Sustainable Housing Strategy (7) sets out the Scottish Governments vision for warm, high quality, affordable, low carbon homes and a housing sector that helps to establish a successful low carbon economy- this paper highlights that large scale investment in upgrading existing tower blocks can provide warm and comfortable homes and significant energy savings to residents lifting many out of fuel poverty.

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