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Summary From 1953 to 1975, some half a million high-rise flats were constructed in the UK in response to the need at that time for the rapid provision of substantial numbers of affordable dwellings. For a variety of reasons, including environmental and social problems, many of these buildings were subsequently demolished. However, many housing authorities still own a considerable number of high-rise developments which, while structurally sound, will require to be upgraded if they are to continue in service for rental purposes. In Scotland alone, there are over 52,000 high-rise flats, representing about 8% of the total available public sector housing. This paper reports on an environmental monitoring exercise carried out to assess the effectiveness of a extensive refurbishment, which included thermal over-cladding and heating system replacement, to a development of 24-storey buildings in Glasgow, Scotland. Monitoring of temperature and relative humidity was carried out in flats in a pre- and post-refurbishment block over a three-year period to evaluate the effect on occupant comfort levels and condensation risk. A limited energy use comparison was also carried out. An analysis of the monitored data indicates that the refurbishment has been successful in achieving its objectives, namely improved environmental conditions at a reduced overall energy cost to the tenants.

Effectiveness of energy refurbishment measures applied to high-rise dwellings

D Barbour† BSc MSc CEng MCIBSE MIOA, **J Cant**† BSc MIHEEM AMIMechE, **G H Galbraith**† BSc MSc PhD CEng MCIBSE and **R C McLean**‡ BSc MPhil CEng MInstE MCIBSE

†Glasgow Caledonian University, Department of Building and Surveying, Cowcaddens Road, Glasgow G4 0BA, UK

‡University of Strathclyde, Department of Mechanical Engineering, Montrose Street, Glasgow G1 1XJ, UK

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1 Introduction

The construction of high-rise flats was a popular solution to post-war housing needs in the UK, with the majority being of large-panel construction erected during the 1960s[1]. Many of these buildings failed to provide the living environment that had been anticipated and, as a result of rising energy costs, could not be adequately heated by low-income families. Electric heating, combined with poor insulation standards and workmanship, together with the social problems engendered around such developments, made them unpopular with both tenants and owners alike[2].

Although many of these properties have subsequently been removed, there remains a substantial number of structurally sound high-rise developments in the UK, which are now of an age that will require them to be either upgraded or demolished[3]. The cost of upgrading can be high, although many believe that this is a worthwhile investment that can produce comfortable, affordable homes. It is estimated that costs of between £11 000 and £30 000 per flat are to be expected if a full package of upgrading, including heating system replacement, is carried out[4].

The decision whether to upgrade or demolish can be a difficult one, as little definitive information is available on the effectiveness of refurbishing such properties in terms of the improved amenities provided and the increased popularity for rental.

In 1992, Scottish Homes, the national housing agency for Scotland, embarked upon a large-scale refurbishment project to upgrade four 24-storey blocks of flats situated near Glasgow city centre. A feasibility study was carried out on behalf of Scottish Homes to investigate the potential of a range of upgrading measures. This study involved the application of advanced energy modelling tools that enabled the potential energy savings of the various options to be appraised. Phase 1 of the improvements, which comprised external site regeneration works and the installation of a medium temperature hot water (MTHW) district heating network supplied from a centralised gas-fired boiler plant, was completed during 1994. A rolling programme of improvements to the blocks themselves started in 1994, with the works to each block scheduled to take two years to complete. The works included overcladding, re-roofing, window replacement, balcony enclosure and installation of a new heating system. The cost of the improvements per dwelling was estimated as £3900 for the district heating system and £3950 for improving the thermal performance of the structure.

It was decided that the effectiveness of these measures in improving the environmental and energy performance of the dwellings should be carefully monitored in order to provide data that could be used in the feasibility appraisal of similar projects in the future. This paper describes the monitoring programme and summarises the results obtained. The measured data has been analysed to enable a comparison to be made between pre- and post- refurbishment performance in terms of comfort levels, the temperature differences maintained above outside, the risk of condensation and energy use. Corridor and stairwell temperatures have also been included in the analysis to allow any differences in circulation area conditions to be identified.

2 The upgrading measures

The high-rise blocks involved in this study were built in 1967 for the Scottish Special Housing Association, which, along with the Housing Corporation in Scotland, was a precursor to Scottish Homes. Each block contains two 1-bedroom and four 2-bedroom flats per floor, with the 24th floor being an open-space drying area for the tenants, giving a total of 138 flats per block.

All four blocks were constructed using the same materials and methodology, having in-situ concrete frames with precast concrete cladding panels. The precast concrete cladding system formed the main external fabric of the building, with the majority of the panels being situated on the side elevations of the blocks. These external panels deteriorated over the years owing to the effects of weather, and became rather unsightly. The front and rear elevations of the blocks consisted mainly of glazing and partially enclosed balconies, accessed through the living rooms of the flats (Figure 1).

The poor aesthetics of the blocks, combined with an inadequate environmental and energy performance, were the primary reasons for the initiation of the refurbishment. Rather than carry out partial repairs to the cladding, it was decided that it would be more appropriate to refurbish the fabric and heating services of the buildings to increase their life expectancy and amenity value substantially. The total package of improvements to the blocks comprised re-roofing, overcladding (including the addition of thermal insulation), window replacement, balcony enclosure, the installation of low-temperature hot water (LTHW) heating systems, the replacement of sanitary fittings, the installation of a CCTV system and the refurbishment of common areas at ground-floor level. A view showing the external facade of a refurbished block is shown in Figure 2.

The upgrading measures that impact on the environmental and energy performance of the blocks are described briefly below:

Re-roofing. The pre-improvement roof, which consisted of 200 mm cast in-situ concrete, was overclad with profile sheeting. Insulation was then applied to the original roof space to reduce the U-value from 1.99 to 0.5 W m^{-2} K^{-1}.

Overcladding. The overcladding system comprises cladding panels mounted on a metal support system. The system incorporates 100 mm thick slabs of mineral fibre insulation and lowers the main external wall U-value from 0.57 to 0.23 W m^{-2} K^{-1}.

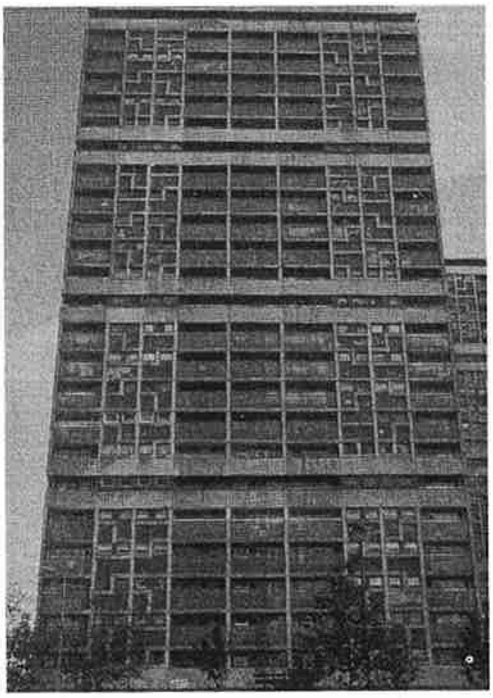

Figure 1 Multistorey block before refurbishment

Figure 2 Multistorey block after refurbishment

Window replacement. The original single-glazed windows (U-value 5.8 W m^{-2} K^{-1}) were replaced by wood-framed double-glazed units, having a U-value of 1.8 W m^{-2} K^{-1} for the facades and 2.35 W m^{-2} K^{-1} for the living room balconies.

Balcony enclosure. One of the major features of the upgrading was the complete enclosure of the balconies. This involved the installation of external double-glazed units (U-value 2.35 W m^{-2} K^{-1}) and in-fill panels (U-value 0.32 W m^{-2} K^{-1}). This has created a partially glazed and unheated conservatory area.

Heating system replacement. The pre-improvement heating consisted of off-peak electric storage heaters located in the living room, hall and bedrooms. Domestic hot water was provided via two electric immersion heaters, one of which was connected to the off-peak supply. The post-improvement heating in the flats is provided by radiators in the living room, bedrooms, hallway and kitchen. These are supplied from the LTHW system (75°C) within the block, which is connected to the MTHW district system (110°C) through a heat exchanger located in a ground-level plant room. An instantaneous domestic hot water system, supplying on demand, is also provided from the LTHW system via a plate heat exchanger in each flat.

3 The monitoring programme

Environmental monitoring was carried out in nine pre-improvement flats during the heating season 1995/96. Post-improvement performance was investigated by monitoring eight flats in a refurbished block during the heating season 1996/97 (post-improvement 1). At that time, a number of these flats were unoccupied and monitoring was therefore continued through the heating season 1997/98, by which time most of the flats were under occupation (post-improvement 2). Although it was not possible to select flats so that the occupancies for the pre- and post-improvement measurement periods were identical, in general occupancy levels did turn out to be very similar.

Each heating season was taken nominally as the 35 weeks from 1 September through to 30 April. Unfortunately, in the case of the post-improvement 1 period, flat monitoring did not begin before October 1996 and, for some flats, did not begin until February 1997. This was due to difficulties experienced in obtaining tenants willing to tolerate the disturbance associated with the installation of the instrumentation. A decision was therefore taken to install the instrumentation in vacant flats as they arose. This resulted in a number of flats being unoccupied for parts of this monitoring period. The post-improvement 2 monitoring period was an extension of the post-improvement 1 period, with the same flats being monitored in all but two cases.

Monitoring involved the half-hourly measurement of temperature in the living room, hallway, kitchen, bathroom and bedroom/bedrooms of each flat. In each case, half-hourly measurements of the relative humidity were made in the living room and main bedroom. The temperatures in adjacent corridors and stairwells were monitored for a number of flats. The measured data were recorded using 'squirrel' data loggers which were installed in the meter cupboards of the monitored flats. The half-hourly measurement regime adopted produced 48 data points over each day of measurement.

A weather station was installed on the roof of the pre-improvement block to monitor wind speed and direction, temperature and total solar radiation, again on a half-hourly basis. This monitoring was continued throughout all three heating seasons.

The energy usage for a number of pre-improvement flats was monitored using optical sensors fitted to the electric meters. These sensors recorded the number of rotations of the meter disc and could therefore only be used on analogue meters. This restricted the flats that could be monitored. In addition, considerable difficulty was experienced with this system as the sensors, if disturbed, lost their focus on the rotating disc and ceased to operate effectively. The servicing of the post-improvement flats from the group heating system precluded the monitoring of energy usage in this way.

Table 1 presents a summary of the numbers of flats monitored during each heating season. Only data recorded in a flat when it was under occupation were used in the subsequent analysis of results. Also, the many practical problems encountered in a site investigation of this nature meant that continuous monitoring was not always possible in any given flat during these occupied times. The effective monitoring period over a heating season thus varied from flat to flat. An indication of the useful monitoring achieved over each heating season is given in Table 1, in terms of the total number of 'effective' monitored flat-days. Table 1 also gives information on the monitoring of corridors and stairwells.

Table 1 Monitoring programme details

	Monitored flats		Additional monitoring		'Effective' monitored flat-days
	1-bed	2-bed	Corridor	Stairwell	
Pre-improvement 1995/96	3	6	4	4	1722
Post-improvement 1 1996/97	5	3	3	4	1029
Post-improvement 2 1997/98	3	5	3	2	1645

4 The flat conditions

4.1 Comfort analysis

The monitored internal environmental data were used to assess the effect of the refurbishment measures on the thermal comfort of occupants by estimating the comfort levels pre- and post-improvement. In all cases, the indicative parameter adopted was the half-hourly measured air temperature averaged over a daily period considered representative of the space under consideration. These values were then compared with a minimum acceptable air temperature. Table 2 gives the internal design temperatures for dwellings recommended by the Chartered Institution of Building Services Engineers[5] and Scottish Homes[6]. For this comparative study, the minimum acceptable air temperature for each location was taken as being 1K below the lowest value quoted in this table. The value of 1K was chosen as a reasonable tolerance to apply to recommended values.

The evaluation of overall comfort performance involved the following analysis of the measured data:

— For a given flat, a daily mean temperature was calculated for each room for each monitored 24 h period. For the living room, hallway and bathroom, this was based on the hours between 0800 and 2300, which was taken as a representative 'occupied' period for these spaces. For the bedroom/bedrooms, the mean temperature was based on the complete 24 h period.

— The number of days for which these mean temperatures exceeded the accepted minimum air temperatures, given in Table 2, were summed for each location in the flat over the heating season.

— These were then summed over all the flats and expressed as a percentage of the total number of 'effective' monitored flat-days for the heating season, as given in Table 1.

Figure 3 displays graphically the percentage of daily mean values that satisfied the adopted comfort criterion. The data from the two post-improvement periods are in good agreement. It is clear from the figure that there has been a significant improvement in comfort levels as a result of the upgrading. The improvement in conditions is substantial in all cases, but particularly so for the bathrooms and bedrooms.

4.2 Maintained temperatures above outside

Because the external climatic conditions during the three measurement periods were likely to be different, the results presented in the previous section might be regarded as representing a potentially unfair comparison. In order to investigate this issue in more detail, the half-hourly temperature measurement data for the flats were re-analysed as follows:

(*a*) For a given flat and monitored 24 h period, a daily mean temperature was calculated as a floor-area-weighted average of the measured temperatures in each room.

Table 2 Recommended dwelling temperatures (°C)

Location	CIBSE	Scottish Homes	Minimum comfort
Living rooms	21	21	20
Bedrooms	18	21	17
Bathrooms	22	21	20
Hallways	16	16	15

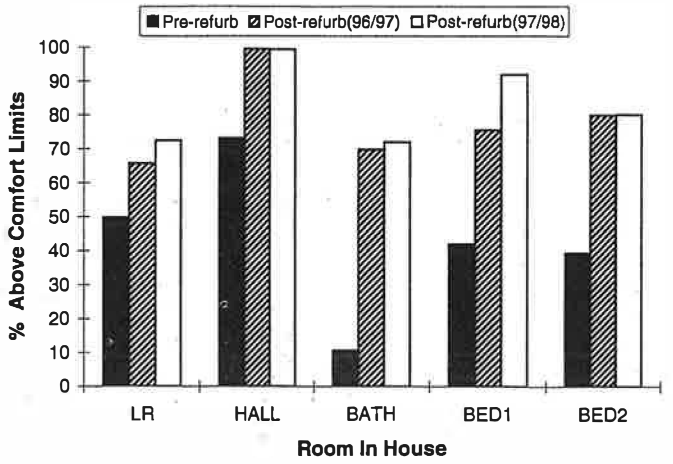

Figure 3 Percentage of mean daily values above comfort criterion

(*b*) The corresponding daily mean outside temperature was determined from the climate data for the same 24 h period.

(*c*) The subtraction of (*b*) from (*a*) gives a 24 h maintained temperature difference between inside and outside.

(*d*) These 24 h maintained temperature differences were summed for the given flat over all monitored days of the heating season. These were then summed over all the flats. The total obtained was averaged by dividing by the total number of 'effective' monitored flat-days, as given in Table 1.

(*e*) A similar analysis to the above was carried out for corridors and stairwells where they were monitored.

(*f*) The mean daily value in (*b*) was summed and averaged, as in (*d*), to give a weighted average outside 'exposure' temperature. Because the effective monitoring period varied from flat to flat over a heating season, this parameter provides a good indication of comparative climate severity.

The results of the above analysis are presented in Figure 4. An inspection of this figure shows the following.

— The outside 'exposure' temperatures from (*f*) are all within 0.5 K of 7°C, which is the value often taken as representative of an 'average' winter day for the West of Scotland[7]. The three heating seasons can therefore be considered comparable in terms of climate for the actual periods in which measurements took place.

— The refurbishment has resulted in a significant increase in the temperature differences above outside maintained in the flats for both post-improvement monitoring periods.

— The refurbishment has produced a large increase in the circulation corridor temperatures at the core of the building, to such an extent that they are now comparable with the average flat temperatures recorded.

— The stairwell temperatures also show an increase, although not of as great a magnitude as for the corridors.

These results support the conclusions of the previous comfort analysis. They also explain the very significant improvement in the flat hallway temperatures, which are adjacent to the circulation corridors. The improvement in these temperatures can be partly attributed to heat gains from the LTHW

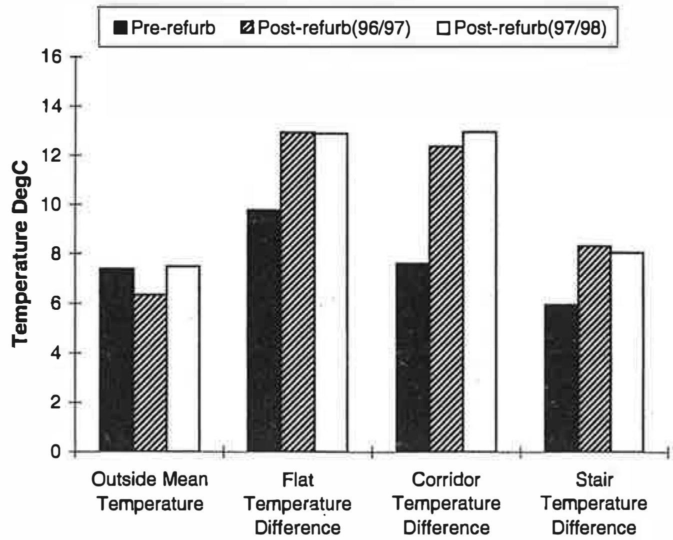

Figure 4 Maintained daily mean temperature differences above outside

heating system riser-pipes, which pass through the hallway cupboards.

4.3 Condensation risk analysis

Relative humidity values were recorded in the living rooms and main bedrooms of the monitored flats. The primary objective in collecting these data was to enable an assessment to be made of the relative risk of condensation both pre- and post-improvement.

A simple and convenient measure of condensation risk is as the fraction of the time the relative humidity rises above the recognised danger level of 70%[8]. An estimate of this risk has been made from the number of half-hourly readings in excess of this value. These were summed over all the flats for each heating season and expressed as a percentage of the total number of half-hourly readings taken over the monitored period, i.e. 48 times the number of 'effective' monitored flat-days (Table 1). The results for the three heating seasons are presented in Figure 5.

The figure shows that, even in the pre-improvement living rooms and bedrooms, the relative humidity values only occasionally exceeded the 70% limit. The effect of the refurbishment is a further decrease in the risk of condensation to effectively zero. This suggests that there is very little risk of

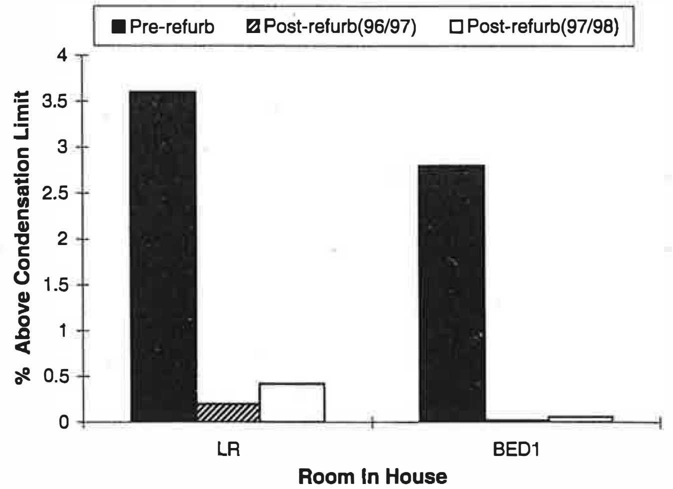

Figure 5 Percentage of Readings (0.5 h) above 70% RH

condensation occurrence in these flats, which is supported by their physical condition.

5 Flat energy usage

The energy usage data available for the pre-improvement block involved a combination of consumption figures from Scottish Power (the electricity supplier) and readings obtained from the optical sensor arrangement on the available analogue meters. The post-improvement data comprised electrical usage information from Scottish Power and heating/hot water usage information for the district heating system from Raab Karcher, who operate the flat metering and payment system.

5.1 Pre-improvement energy use

Of the nine test flats, only six were suitable for optical sensor monitoring. Three of these had single dual-tariff meters, which gave a combined recording of the domestic and off-peak tariffs. The other flats had two meters, which recorded these tariffs separately.

During the early stages of the project, it became clear that the optical sensor method of monitoring, although theoretically attractive, was completely unsuitable owing to the practicalities of the situation. Only three of the flats produced data that could be recorded on the data loggers, and the uncertainties associated with these data were such that no meaningful interpretation of the results was possible. It was therefore decided to abandon this approach and to neglect the recorded figures in the analysis of the overall energy usage.

It was obvious that the acquisition of accurate and reliable data would require direct metering of the electrical loads to and from the fuse box of each flat. Unfortunately, neither Scottish Power, the landlord nor the tenants themselves were willing to accept such direct measurement. As an alternative approach, data on energy billing for a number of flats were obtained from Scottish Power. This was not a straightforward matter and involved individually signed tenant agreements for the release of this information. The Scottish Power records obtained in this way are summarised in Table 3. The data obtained covered different time periods and has been extrapolated to provide estimates for both domestic and off-peak annual energy consumption separated into 1-bedroom and 2-bedroom flats. Table 3 includes an estimation of the energy costs. These costs have been calculated using an average domestic and off-peak unit cost figure taken over both monitoring periods, to give a common energy price for comparative purposes.

5.2 Post-improvement energy use

The estimated costs of energy for the post-improvement flats are based on Scottish Power accounts for varying periods (74 to 356 days) and Raab Karcher accounts, again for varying periods (52 to 56 weeks), during 1997/98. On the basis of these accounts, the estimated annual energy use has been derived by proportion and is summarised in Table 4. The associated energy costs given in this table have been calculated using average unit costs taken over both pre- and post-improvement monitoring periods to provide a common basis for comparison. It is important to note, however, that the unit cost to the tenants for the district heating system was higher (3.87 p $(kWh)^{-1}$) than that for off-peak electricity (2.93 p $(kWh)^{-1}$) owing to the overall maintenance and running costs incorporated within the charge.

5.3 Pre- and post-improvement energy use comparison

Table 5 provides a direct comparison of energy usage before and after the improvements were carried out. This table indicates an overall reduction in energy usage of 34% for the blocks, with the biggest improvement being for the 2-bedroom flats. The domestic energy usage would have been expected to have remained the same over both monitoring periods, but this is clearly not the case. An average increase in domestic energy usage of 20% has been recorded which cannot be easily explained but could be related to a difference in lifestyle of the tenants between the monitoring periods. The heating energy use, in contrast, has reduced overall by 60%. This is in line with predicted energy savings for heating of just over 50% predicted by the computer-based energy models that were applied to the building both at the design stage (TAS) and after refurbishment (BREDEM).

An overall comparison of actual heating and hot water energy costs given in Tables 3 and 4 indicates a cost reduction of approximately £35 per annum for a 1-bedroom flat and £105 per annum for a 2-bedroom flat. It is important, however, to appreciate that a cost comparison on this basis would give a false impression of the effectiveness of the installation, as the money spent on heating for the pre-improvement flats was inadequate in providing temperatures even approaching those considered to be acceptable for comfort. Overall it would seem that the tenants have continued to pay approximately the same in energy and have decided to benefit by having improved environmental conditions and lifestyle.

Table 3 Pre-improvement estimated annual energy costs from energy bills

Flat identifier	No. of days	Domestic energy use			Off-peak energy use			Standing charge (£)	Total annual cost inc. VAT (£)
		Actual account (kWh)	Annual estimate (kWh)	Annual cost (£)	Actual account (kWh)	Annual estimate (kWh)	Annual cost (£)		
1-bedroom									
Pre_1	341	1695	1814.30	127.00	5883	6297.05	184.50	57.13	398.13
Pre_2	245	1140	1698.37	118.89	1500	2234.69	65.48	57.13	260.81
Average			1756.33	122.94		4265.87	124.99	57.13	329.47
2-bedroom									
Pre_3	391	3089	2883.59	201.85	1311	1223.82	35.86	57.13	318.43
Pre_4	330	5340	5906.36	413.45	4648	5140.97	150.63	57.13	670.90
Pre_5	335	3992	4349.49	304.46	3011	3280.64	96.12	57.13	494.33
Pre_6	385	2454	2326.52	162.86	11667	11060.92	324.09	57.13	587.60
Pre_7	142	826	2123.17	148.62	2854	7335.99	214.94	57.13	454.35
Pre_8	246	1529	2268.64	158.80	8314	12335.81	361.44	57.13	623.56
Average			3309.63	231.67		6729.69	197.18	57.13	524.86

Table 4 Post-improvement estimated annual energy costs from energy bills

Flat identifier	Domestic energy use				District heating energy use				Electrical standing charge (£)	Total annual cost inc. VAT (£)
	No. of days	Actual account (kWh)	Annual estimate (kWh)	Annual cost (£)	No. of weeks	Actual account (kWh)	Annual estimate (kWh)	Annual cost (£)		
1-bedroom										
Post_1	356	1723	1766.56	123.66	52	1241	1241.00	48.03	57.13	247.13
Post_2	278	1475	1936.60	135.56	18	1184	3420.00	132.37	57.13	351.06
Average			1851.58	129.61			2330.50	90.20	57.13	299.09
2-bedroom										
Post_3	227	1848	2971.45	208.00	52	3136	3136.00	121.37	57.13	417.43
Post_4	145	1996	5024.41	351.71	56	2581	2396.64	92.76	57.13	541.73
Post_5	356	4757	4877.26	341.41	56	2183	2027.07	78.46	57.13	515.15
Post_6	74	591	2915.07	204.05	56	702	651.86	25.23	57.13	309.33
Post_7	303	3993	4810.05	336.70	55	3885	3673.09	142.16	57.13	578.88
Average			4119.65	288.38			2376.93	92.00	57.13	472.50

Table 5 Comparison of energy usage before and after improvement

Flat type	Domestic energy			Energy for heating			Overall
	Before ($GJ\ y^{-1}$)	After ($GJ\ y^{-1}$)	Change (%)	Before ($GJ\ y^{-1}$)	After ($GJ\ y^{-1}$)	Change (%)	change (%)
1-Bedroom	6.32	6.67	6	15.36	8.39	−45	−31
2-Bedroom	11.92	14.83	24	24.23	8.56	−65	−35
Block totals	1387	1671	20	2936	1173	−60	−34

To obtain a reasonable estimate of the savings that tenants have realised, it is necessary to restrict the comparison to those flats that were found to be adequately heated.

An inspection of the monitoring data for the pre-improvement period led to the conclusion that only flats Pre_6 and Pre_8 could be considered to be adequately heated. On this basis, a reasonable estimate for the average pre-improvement heating and domestic hot water costs would be £370 when VAT at 8% is included.

For the post-improvement period, three of the monitored flats were excluded from the analysis for the following reasons:

- Flat Post_1 was above the plant room and experienced non-typical casual gains
- Flat Post_2 energy usage was estimated from only 18 weeks of monitoring and is therefore unreliable
- Flat Post_6 was mainly unoccupied, observed temperatures being caused by mains casual gains.

On this basis an appropriate post-improvement energy and hot water cost can be estimated as £120 including VAT at 8%.

This suggests that a saving of £250 per annum would be a reasonable estimate of the cost reduction that a tenant might be expected to obtain as a result of refurbishment. It is important, however, to appreciate that this figure is only an approximate estimate based on very limited data and assuming that the tenant has been able to afford to heat the pre-improvement flats to comfort levels.

It is also important to emphasise that the unit energy cost for heating was higher for the post-improvement flats. In hindsight, with the recent changes to the energy supply industry and the open market for domestic users, the decision to adopt a district heating system may not have been the most cost-effective option and certainly did not result in competitive energy prices for the tenants.

6 Observations

On the basis of the analysis of monitored environmental data, the following observations can be made:

- Comfort levels within the flats have improved significantly as a result of the refurbishment. The percentage of time the temperatures exceed the minimum specified values is now generally greater than 70%. The improvement is most marked in the bedrooms and bathrooms, where the pre-refurbishment temperatures failed to meet the criterion for 90% of the time.
- The maintained temperature differences above outside for the flats have increased by more than 3 K, thus supporting the results of the thermal comfort analysis.
- The circulation corridor and stairwell temperatures are significantly higher after refurbishment. This improvement in the building core temperature has resulted in higher flat hallway temperatures, even in unheated flats.
- The risk of condensation, which was small pre-improvement, has been reduced to practically zero as a result of the refurbishment.

Energy usage data from Scottish Power and Raab Karcher indicate the following.

- Overall total annual energy costs have reduced marginally after refurbishment. Tenants in general have elected to continue to pay the same for energy and take the benefit in improved conditions.
- Heating energy use has fallen overall for the block by 60%, which is in line with computer predictions carried out during the design stage and after refurbishment was completed.
- Domestic energy usage has in contrast risen by around 20%, which cannot easily be explained, but must be related to a difference in lifestlye between the occupants before and after refurbishment.

— When restricted to flats that were adequately heated, a comparison of heating and hot water energy usage indicated an average cost reduction per flat of approximately £250 per annum.

— Unit heating energy costs are relatively high for the district heating system and this has lessened the impact of the reduced energy usage on the actual cost savings realised. (Off-peak electric costs were 2.93 p $(kWh)^{-1}$, while district heating energy was charged at 3.87 p $(kWh)^{-1}$)

— The decision to adopt a district heating system may have resulted in less competitive heating energy unit costs to the tenants than would have been desired.

7 The tenant survey

In conjunction with the monitoring programme, a survey of tenants was carried out to gauge their subjective reactions to the effects of the refurbishment[(6)].* Forty tenants were interviewed both before (1995) and after (1997) improvement.

The interviews were based on a comprehensive questionnaire of over 50 questions, which covered a whole range of 'lifestyle' issues. It would not be practicable to enumerate here the individual questions or the responses of the interviewees. However, it is clear from the results of the survey that the refurbishment has evoked a very positive response from the tenants. They perceive a significant improvement in all aspects of the internal environment in the refurbished blocks (temperature, draughts, condensation) and their resulting quality of life. The overwhelming majority (88%) also feel that the associated costs of the new heating and hot water arrangements are either 'reasonable' or 'cheap'. Only 2% consider it 'expensive', as opposed to over 60% pre-refurbishment.

8 Conclusions

The monitoring programme was effective in assessing the effects of the refurbishment in terms of the environmental conditions within the flats investigated. Considerable difficulty was experienced with the monitoring of energy using optical sensors on the supply meters which, if disturbed, lost their focus and ceased to operate accurately. Direct recording of energy loads to and from the flat fuse boxes would have been preferable but was not acceptable to the supply authority, the landlord or the tenants themselves. Energy consumption figures were therefore restricted to data from energy bills, which was less reliable and less detailed than would have been desired.

The results of the project demonstrate that the refurbishment has significantly improved the environmental conditions within the high-rise blocks, while the energy costs to the tenants have been reduced. The overall financial benefit to occupiers is less than might have been desired. This is partially related to the observed increase in domestic energy use of around 20% after refurbishment and the unit cost of energy from the district heating system, which is relatively high. The fact that the pre-improvement flats were in general inadequately heated made cost comparisons problematic. However, by utilising data only from adequately heated flats, an annual heating and hot water cost reduction of around £250 per flat was observed.

The tenants have clearly continued to pay approximately the same for energy use and have taken benefit from the refurbishment in the form of increased comfort levels and quality of life. It would seem that, before improvement, the tenants were spending to their affordability limit and having to accept the resulting poor environmental conditions.

The decision to adopt a district heating system may not have resulted in the most competitive energy prices being available to the tenants. The appraisal of fuel/heating system options requires careful consideration in future projects of this nature.

9 Acknowledgements

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