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Retrofit of existing housing in the United Kingdom: the carbon reduction possibilities

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ABSTRACT: Feasibility studies were undertaken into retrofitting three examples of social housing stock to meet the carbon reduction targets of the UK government. The results of energy modelling show that the targets cannot readily be met by the combination of passive means and the use of tried and tested technology. On the dwellings modelled up to 50-60% savings in CO_2 were predicted using passive measures combined with established solar thermal technology, at a reasonable cost.

To meet the full carbon reduction objectives of the programme it was necessary to employ, in addition to the passive measures, innovative PV-T (Photovoltaic Thermal) panels, whose effectiveness is untested over the long term. The addition of PV-T predicted further carbon savings of around 50% - theoretically making the dwellings net generators of electricity, at significant extra cost.

The buildings were of medium to low architectural quality and the proposals included the application of insulation to the outside face of external walls – the most effective location for wall insulation. However, this solution, employing external insulation, is unlikely to be acceptable for a significant proportion of UK housing, much of which has a higher architectural or historic value.

A key lesson for the retrofit of housing is that, because of both technical and aesthetic considerations, it is highly unlikely to be possible to meet the UK government's carbon reduction objectives by on-site measures alone.

Keywords: retrofit, carbon reductions, social housing.

1. INTRODUCTION

1.1. The Retrofit for the Future programme

In 2009 the UK Technology Strategy Board launched a competition – *Retrofit for the Future* – for the retrofit of up to one hundred houses owned by registered social landlords (RSLs) [1]. These houses (flats, apartments, maisonettes, and other housing types were not covered by this particular programme) are to act as exemplar projects for the building industry, demonstrating how to meet the UK government's carbon reduction targets. There are 2.34 million low-rise houses and bungalows owned by RSL's in the UK, making this a significant proportion of the 22.2million homes in the UK. [2]

The competition provided up to £20,000 including VAT for the Phase 1 feasibility study, and up to £150,000 including VAT for execution of the works in Phase 2, both grants include all fees and disbursements.

The authors (in collaboration with others) were successful in winning three phase one bids, to research the feasibility of retrofitting individual houses. This paper outlines the results of those feasibility studies and draws some general conclusions on the scope for retrofitting the housing stock as a whole.

1.2. Retrofit standards

The overall aim of the Retrofit for the Future programme was to identify methods by which the government's commitment – to 80% reductions in CO_2 emissions by 2050 in comparison to 1990 Levels– might be met within existing public housing. [3]

Rather than set an 80% reduction target for each house (which would be easy to achieve in a poorly insulated old building, but very difficult in more recent construction) this target was averaged across the housing stock as a whole, resulting in specific absolute energy consumption standards applied to every project.

The standards required were:

- Max CO_2 emissions – 17kg/m^2/yr
- Max primary energy use – 115kWh/m^2/yr

The primary energy consumption figure includes all energy used in the house, including that for appliances (white goods) and consumer electronics.

2. THE CASE STUDY HOUSES

The three houses are all located in East Kent and were built between 1947 and 1994. Their architectural quality is of low to medium standard, and therefore there was a great deal of scope, when upgrading the fabric of the buildings, for making changes to their external appearance.

Figure 1: The Chester house – constructed in 1947 using the Airey method, comprising concrete studs and pre-cast concrete 'weatherboarding'

The first house (Chester) is an *Airey House* comprising pre-cast concrete frame and cladding panels – fixed in overlapping courses like weatherboarding. (Fig. 1) This house was constructed in 1947 and is one of approximately 26,000 constructed in the UK between 1946 and 1955. Typical problems with the construction method include corrosion of steel tube reinforcement in the concrete posts, failure of concrete weatherboard panels, severe draughts, rain penetration through the cladding, condensation and mould growth.

Figure 2: The Nine Acres house, constructed in 1950's using the Wimpey no-fines method

The second house (Nine Acres) was constructed in the 1950s using the Wimpey no-fines method – comprising in-situ cast concrete walls which are then rendered (Fig. 2). No-fines concrete consists of large aggregate (ie, no sand or fine aggregate) and cement only, which can be cast and set very quickly. This construction type often suffers from condensation problems due to lack of insulation, and draughts.

The third house (Grebe) has brick and block cavity walls with partial-fill insulation, and is typical of many thousands constructed in the UK in the 1980s and 1990s. (Fig. 3) It has a suspended concrete beam and block ground floor.

Figure 3: Photograph of Grebe – with render and brick-faced cavity wall construction typical of many thousands in the UK

2.1. Survey information

In addition to undertaking measured surveys and interviewing tenants on their energy use, we commissioned thermal imaging surveys and air-leakage tests at all three properties. The thermal imaging survey revealed, as expected, weaknesses in the construction just below the eaves soffit and at around window openings. The Chester house was particularly weak at the junctions between the 'weatherboard' concrete panels. Air tightness testing was surprisingly good with Grebe (the most recent building) at $5.71m^3/m^2hr$ at 50Pa, compared to $15.00m^3/m^2hr$ and $13.37m^3/m^2hr$ for Chester and Nine Acres respectively.

3. RETROFIT STRATEGY

Our retrofit strategies were founded on passive design principles, to make major reductions in carbon emissions and achieve comfort in both winter and summer. The aim was to achieve this through upgrading the envelope – by the application of external wall insulation with render finish, and high performance windows. The buildings would therefore be robust and resilient in the future, not totally dependent on technologies or additional energy supplies.

Roof insulation is provided within the existing loft spaces at ceiling joist level. Internal roof insulation was selected to avoid two particular problems had external roof insulation have selected: 1, the very significant costs of renewing external roof finishes and providing a transfer structure as support for those finishes, and 2, as we were only retrofitting one half of a semi-detached house or an end of terrace house, this would have resulted in stepped roof profile above the party wall with resultant cold-bridging problems.

If the entire building were to be retrofitted then it would have been more cost-effective to externally insulate the roofs.

One consequence of the decision to provide internal roof insulation was the need to reduce cold bridging at the eaves where external wall insulation meets the ceiling level insulation. This was achieved by devising an insulating cornice section (manufactured from insulating material such as polystyrene or rigid mineral wool), which maintains a continuous insulation thickness at the junction (see Fig. 5).

In order to meet the demanding carbon reduction standards set, it was necessary to employ renewable energy sources in addition to the passive features. We selected photovoltaic-thermal (PV-T) collectors – a combination of photovoltaic (PV) panels with a flat

Figure 4: Air pressure testing was carried out at all three properties

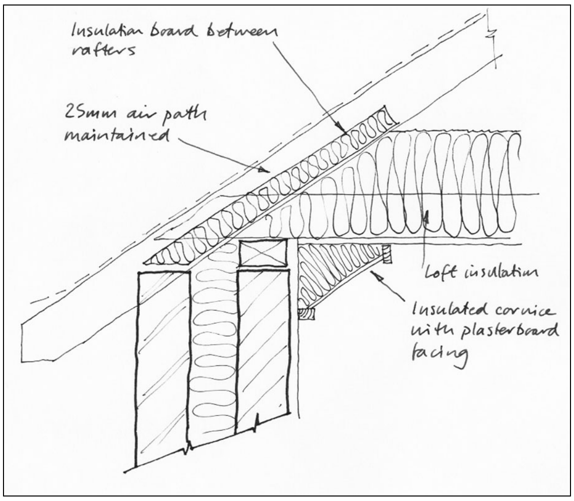

Figure 5: Proposed eaves detail showing special insulating cornice to reduce cold bridging at wall/roof junctions – illustration shown relates to Grebe

plate solar collector. This system uses the solar collector as a cooling system for the PV panels, increasing their efficiency, drawing off the excess heat for hot water and space heating.

However, when the proposed technologies are added, deep savings in energy use and carbon emissions can be achieved. Our aim was to explore how far a Retrofit project can go towards zero-carbon, within strict financial limits, and the practical limitations of a refurbishment project which may not have an ideal orientation.

As part of the package to improve the external envelope, the windows and external doors were all to be upgraded with high performance units.

Measures were taken to reduce air leakage in each, such as sealing gaps, holes around services, wall/ceiling junctions, loft hatches, and to new windows and doors

These measures were provided in all three houses and special provisions were made as follows.

3.1. Ventilation

All dwellings were provided with whole house mechanical ventilation with heat recovery (MVHR) units as part of the proposed services package of upgrade measures.

3.2. Insulation

On the Chester house it is proposed to use Hemcrete as the external insulation material. This has a particular advantage in this case because it will stabilise the existing pre-cast concrete post structure at the same time as allowing any trapped moisture to escape. It is proposed that the external cladding panels are removed, partially to minimise the overall additional thickness of wall, but also to provide thermal mass by wrapping the Hemcrete material around the existing posts. Additional racking strength will be introduced by installing diagonal steel straps across the post frame.

With Grebe it is possible to provide a good level of floor insulation: the existing screed will be removed to gain access the beam and block floor, and thick sections of polystyrene insulation will be installed underneath the concrete structure.

The other two houses have solid ground floors, which would be very expensive to upgrade to meet current standards. Therefore a thin layer of cork insulation will be installed, primarily to improve thermal comfort for the tenants, in conjunction with external insulation to the face of the floor slab and insulation to reduce thermal bridging to the floor.

4. MODELLING

4.1. Methods

Whole house energy/carbon calculations were carried out using NHER Plan Assessor v4.4 (SAP 2005) and 'corrected' using SAP-extension-for-whole-house-energy-v1.6.xls which adjusts the SAP results to include household appliances and increases internal temperatures which are suggested to increase as running costs reduce. The SAP extension worksheet was supplied and its use required by the Retrofit for the Future competition rules. The results from the SAP worksheets are shown in tables 1-3 inclusive.

SAP (Standard Assessment Procedure) is the methodology adopted by the UK government for assessing the energy conservation compliance of new dwellings under the Building Regulations and producing Energy Performance Certificates. SAP has developed over many tears from its early origins as the BRE Domestic Energy Model (BREDEM). SAP is standardised with respect to location, weather and occupancy. It is useful for assessing the relative improvements of various envelope and services scenarios. NHER (National Home Energy Rating) plan assessor is one of several software packages which produce SAP output data but, in addition, it models occupancy type, location and some domestic appliance use. NHER therefore gives a more accurate prediction of running cost and resultant CO_2 emissions.

U-value calculations were carried out in accordance with BR443 on Build Desk v3.4 software. U-values for the existing thermal elements were based on generic materials from the software library. The make-up of the existing thermal elements were based on reasonable assumptions, site inspection, and historical evidence. The U-values of upgraded thermal elements were based on calculations of chosen solutions/materials and recognized thermal performances.

System performance for the PV-T was based on manufacturers data and some degree of verification from initial results from a recent installation – however SAP inputting doesn't currently accommodate this technology – so an equivalent PV and separate solar thermal was inputted. This approach does not include the space heating savings that the system provides – therefore additional energy and CO_2 savings are expected.

Thermal bridging of 0.04 W/mK was assumed throughout – based on earlier studies of another project using similar detailing.

4.2. Results

Assessing the benefit of individual measures can be misleading. For example, if MVHR is added to an unimproved leaky building energy costs and resultant CO_2 emissions will rise – if added to a well insulated and airtight building significant savings are realised. Similarly greater savings will be realised if the heating is upgraded in a poorly insulated building than a well insulated one.

It is also virtually impossible to separate the benefits of thermal bridging and air-tightness measures from envelope improvements. Therefore simple packages of measures were assessed

Thermal modelling was undertaken for a variety of technologies, exploring the energy savings that would result from different measures. Three combinations of measures, or scenarios, are summarised in the tables below, in addition to the base case. These are for the following:

- **Base case** – the house in its present condition
- Base case **+ envelope** improvements – external insulation and render, triple glazed windows, and resultant improvements to airtightness and thermal bridging
- As above **+ services** – Replacement boiler, improved controls and lagging, increased low energy lighting provision, MVHR unit plus solar thermal panels for hot water.
- As above **+ PV-T** system – Photovoltaic Thermal panels plus thermal store.

Table 1: Comparison of SAP results for Chester under different scenarios

	Space heating demand ($kWh/m^2/yr$)	Whole house primary energy demand ($kWh/m^2/yr$)	Overall carbon emissions ($kgCO_2/m^2/yr$)
Base	150.14	432.66	64.9
+ envelope	32.98	144.53	24.06
+ services	26.40	90.86	14.87
+ PVT	26.40	11.66	-1.2

Table 2: Comparison of SAP results for Nine Acres under different scenarios

	Space heating demand ($kWh/m^2/yr$)	Whole house primary energy demand ($kWh/m^2/yr$)	Overall carbon emissions ($kgCO_2/m^2/yr$)
Base	111.69	331.91	54.88
+ envelope	28.86	141.23	23.25
+ services	17.10	82.24	13.37
+ PVT	17.10	-63.87	-16.06

Table 3: Comparison of SAP results for Grebe under different scenarios

	Space heating demand (kWh/m^2/yr)	Whole house primary energy demand (kWh/m^2/yr)	Overall carbon emissions (kgCO_2/m^2/yr)
Base	91.12	249.44	41.6
+ envelope	24.69	128.54	21.22
+ services	12.9	76.39	12.39
+ PVT	12.9	-63.49	-15.8

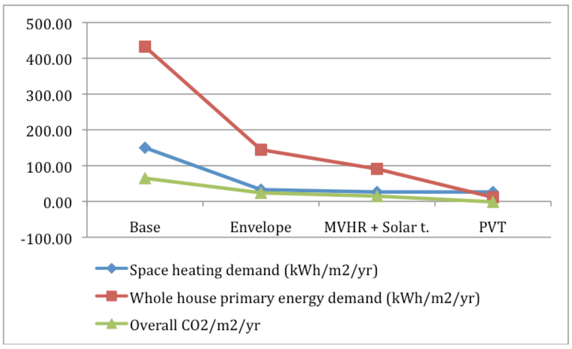

Figure 6: Chester SAP results

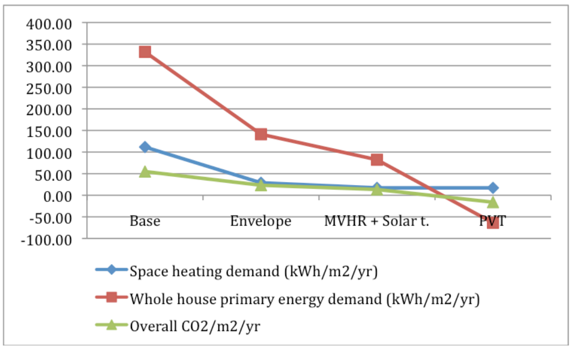

Figure 7: Nine Acres SAP results

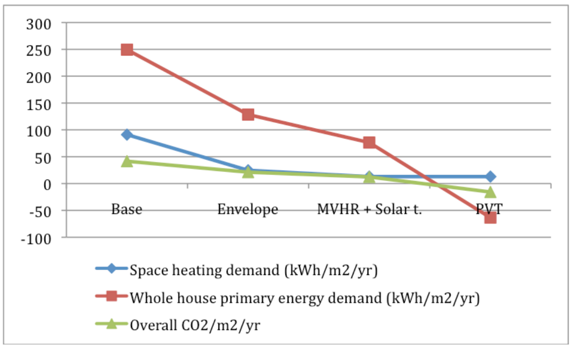

Figure 8: Grebe SAP results

4.3. Cost benefit analysis

A cost benefit analysis was carried out for each measure individually and as groups of related measures using a spreadsheet. All cost and CO_2 savings used in the analysis were from the standard SAP 2005 worksheets.

Looking at simple pay-back periods (cost of measure/s divided by fuel cost saving from measure) results were both surprising and disappointing;

Payback for improvements to the envelope only ranged between 122 yrs and 385 years, improved envelope plus improved services and solar thermal ranged between 129 and 347 years and the scenario including the PV-T ranged between 147 and 207 years.

Table 4: Average percentage reductions across all three houses

DATA	Space heating demand (%)	Whole house primary energy demand (%)	Overall carbon emissions (%)
Base	100.00	100.00	100.00
+ envelope	24.97	42.50	43.48
+ services	15.68	25.47	25.69
+ PVT	15.68	-14.00	-23.03

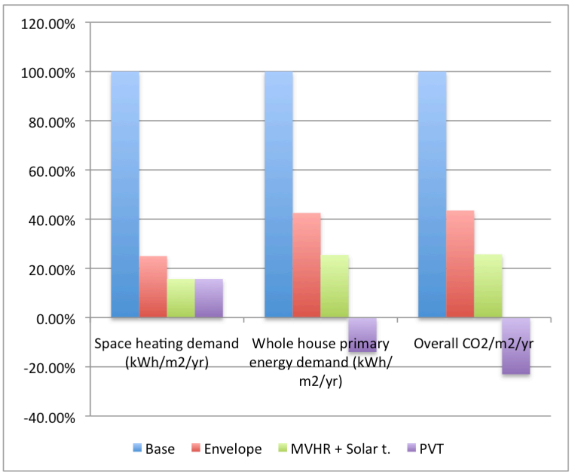

Figure 9: Average percentage reductions in heating, energy and CO2 across all three houses

The lowest pay back periods for the envelope only scenario was for the Chester Ave house which was by far the worst dwelling in its unimproved state.

Generally, payback periods improve with the added services improvements but the improvement is not significant.

With paybacks periods of this length a number of things should be considered: building services (MVHR, lights, boilers etc) will need to be replaced several times and will therefore increase the cost of the measures. It is possible that the replacements will be more efficient but this is not likely to have any significant impact on the results.

The costs of supplying and installing the various measures are likely to drop due to economies of scale and familiarity with the techniques but to achieve sensible payback periods these costs would need to be slashed.

Fuel costs are likely to increase significantly, which will improve the payback periods – but the rates of increase and timescales involved can at this stage be little more than guess work.

4.4. Limitations of modelling methods

There are several ways of assessing the energy efficiency of dwellings:

SAP and NHER (which are described under section 4.1).

PHPP (Passivhaus planning package), developed by the Passivhaus Institute for designing and certifying passive buildings.

Dynamic thermal modelling – for the sophisticated analysis of buildings taking into account changes in temperature and energy flows over time. Some packages such as IES and TAS are approved as being compliant with NCM for building regulations for buildings other than dwellings.

SAP was used for this exercise as it is relatively easy to use and can quickly generate fairly accurate results. However, it should be emphasised that in its current stage of development it is a compliance tool, not an accurate emissions prediction tool. SAP assumes a fixed location (in the Pennines) for all dwellings and standard occupancy patterns and behaviours. It only assesses the building and fixed building services (not white goods, computers, TVs etc) For this reason SAP is good at comparing dwellings but will not predict overall energy use or running costs.

Like NHER, PHPP differs from SAP in that its focus is on energy use rather than CO_2 and assesses it in much greater detail using actual location (and therefore more accurate climate/weather data). It also assesses the predicted occupancy behaviour rather than using a single default.

PHPP is very time consuming and was deemed too unwieldy for testing individual and multiple packages for this stage of the feasibility study. It was proposed to use PHPP to get more accurate figures for the chosen measures should the study be taken forward.

Dynamic thermal modelling was ruled out as too expensive and time consuming on this occasion due to the time constraints of the competition, although it may have been more accurate in the long term.

5. CONCLUSIONS

5.1. The three case study properties

The three feasibility studies indicate that it is relatively straightforward to secure approximately 50-60% reductions of CO_2 at reasonable cost, but that to go all the way in meeting the government's 2050 target of 80% reductions is extremely difficult and costly. That target can only be met on site by using electricity generated by renewables.

One of the main weaknesses with retrofit, compared with new-build, is the difficulty of creating an uninterrupted insulated building envelope. This is a particular problem at roof/wall junctions, at party walls and most especially at ground floor level. Other technical problems included the need to find a suitable location for the thermal store that forms part of the PV-T system.

The results of the cost benefit analysis were surprising suggesting that it is not economically viable to achieve the required level of CO_2 reductions through retrofitting existing dwellings.

It could also be argued that generating energy for 22.5 million homes, each with its own inverters and controllers, is far less efficient than large scale systems. Small scale systems are also far more prone to faults, lack of maintenance and substandard workmanship.

5.2. Roll out opportunities

The house types selected for these studies are typical of many houses owned by social landlords in the UK.

Of the overall UK housing stock, 21% may be said to be of medium to high architectural quality built before 1919 with facing materials of brick or other fine facing materials or with external details of historic or architectural interest. The retrofit strategies adopted for the case studies discussed above – in particular that of external insulation and render – will not be an acceptable retrofit solution in these cases. [2]

6. ACKNOWLEDGEMENTS

This paper builds on work done in collaboration with partners on the Retrofit for the Future programme, which was funded by the UK's Technology Strategy Board. In addition to the authors, other partners who contributed to the feasibility studies included [Names of contractor and consultants to be inserted here following peer review].

7. NOTES AND REFERENCES

[1] Social housing is defined as housing which is owned and maintained by a local (government) authority or by a housing association or other social landlord and which is let on a not-for-profit basis by Registered Social Landlords (RSLs).

[2] English Housing Survey, Housing Stock Report 2008, published October 2010, Department for Communities and Local Government. ISBN 978-1-4098-2601-9

[3] In addition to requiring an 80% CO_2 reduction by 2050, the government also has an intermediate target to reduce the UK's carbon dioxide emissions by 34% compared to 1990 levels, by 2020.