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HOUSING EVIDENCE

A cost-benefit analysis of a traditional Glasgow tenement net zero retrofit

107 Niddrie Road

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Non-technical summary

The UK Collaborative Centre for Housing Evidence (CaCHE) has led a multi-stage and holistic evaluation, of a deep traditional tenement retrofit, as part of a Scottish Funding Council Climate Emergency research competition award. The authors of this paper, as part of that evaluation, have undertaken a social cost-benefit analysis of a high-quality green (EnerPHit) retrofit compared to two plausible counterfactuals (demolition and new build and a retrofit to EESSH2 standards).

The project was a partnership with construction funding from Glasgow City Council, Scottish Government and borrowing by Southside housing association (the property owner), The partnership also involved John Gilbert architects and CCG construction. The evaluation was led by the Collaborative Centre for Housing Evidence working with Tim Sharpe, University of Strathclyde. The project was launched in 2020 just before the Covid-19 lockdown, which considerably delayed the work so that, ultimately, the EnerPHit retrofit was only completed in 2022.

The purpose of the project was, for the first time in a traditional tenement, to complete the retrofit work to this very demanding net zero standard (achieved in large part by airtight internal insulation, mechanical ventilation and a series of other complementary refurbishments). As a demonstration project that would provide learning to help the city assess how to retrofit the 73,000 traditional tenement units in Glasgow, the project was enhanced by the Scottish Funding Council evaluation which helps to shed learning and lessons about replicability and scalability. The evaluation is ongoing and this paper presents one of the first outputs from the work.

The approach to assessing the net economic contribution of the project was to follow an orthodox environmental social cost benefit analysis, adopting Treasury Green Book principles. The idea is to capture all of the costs and the benefits associated with the retrofit and to measure these over 30 years creating a cumulative summary estimate known as a discounted cash flow or net present value. The fundamental idea is that net benefits/costs received further in the future are worth somewhat less now (in a similar way to how you will value something received now more than the promise of getting something in the future). The nominal costs and benefits are therefore discounted by a social discount rate which has a larger impact the further in the future the cost or benefit happens.

The basic model has to identify all of the relevant costs and benefits including some less obvious, unmeasured or intangible elements (which is where controversy can arise). This work had the additional complication of seeking to capture the benefits of reduced carbon emissions, including those of embodied carbon i.e. any form of construction work, producing supplies, undertaking demolition, etc. which will generate carbon emissions. It is not, therefore, just about the forms of heat energy or the ultimate airtightness of buildings, important as that also is to the analysis.

Cost benefit analysis then proceeds by comparing the object of study to likely similar counterfactuals of different choices so that we do not just measure the net benefit of the preferred outcome, but look at it relative to other likely choices – in this case, demolition and new build or the 'official' aspiration to do a level of retrofit for Scottish social housing known as EESSH2. The analysis then proceeds by setting up central baseline estimates. Indicative assumptions have been made by which we try to generate the most useful and accurate comparisons, before applying sensitivity analysis where we analyse the impact of changing key assumptions.

The analysis found that, in net present value terms, the high-quality EnerPHit retrofit performs similarly to the less expensive, but also less energy efficient EESSH2 retrofit. We find, in general, that which option is better is highly sensitive to the assumptions used. We also find that the other counterfactual of demolition followed by construction of new buildings has a much lower net present value than retrofitting existing buildings, and that this is not sensitive to our assumptions. Our results indicate that retrofitting is a better social investment than demolition and new building, but that the optimal retrofit efficiency standards and level of investment in this case are uncertain though the EnerPHit model, which has wider benefits, can achieve net zero (unlike the counterfactuals) and consequently make significant, non-marginal fuel cost savings for households. Recognising that this is an ex ante analysis, i.e. we are estimating future benefits and costs rather than looking back at outturn figures, and while this is broadly a positive outcome overall, we also acknowledge that cost-benefit analysis is only one dimension of a more holistic evaluation that includes building performance and user outcomes.

1. Introduction

The UK government is committed by law to achieve net zero greenhouse gas emissions by 2050. The Scottish government is committed to net zero by 2045. Residential use makes up around 15% of total emissions in the UK, including home heating, cooking and electricity usage¹. Total UK emissions have fallen, but residential emissions have grown as a share of total emissions because they fell much more slowly than other sectors². It is recognised that the slow replacement of the existing stock with new build means that there is every likelihood that more than 80% of the housing stock operating in 2045-50 already exists today and hence retrofitting the existing residential stock is a critical public policy challenge. This also suggests net zero will not be reached in time without an acceleration of the reduction in residential emissions.

Reaching net zero will require a housing stock that is energy efficient and also reduces energy demand. The majority of that reduction must come from heating³. Part of the problem is older housing. In Scotland 19% of the housing stock was built pre-1919⁴. These houses tend to be far less energy efficient, with lower efficiency ratings. Around 7% of Scottish housing is pre-1919 tenement flats. These tenements are common especially in Glasgow, Scotland's largest city, where there are around 73,000 such flats⁵. The tenements are often spacious and considered to have cultural value as high density residential neighbourhoods, but are extremely energy inefficient. This is due to the material used to construct them, lack of modern insulation, and the energy systems (usually gas combi-boilers) they use for heating. As such, without major retrofitting, the city will have difficulty achieving net zero while un-retrofitted tenements are such a large part of the housing stock.

For this exercise, we analyse whether such a retrofit provides a better social return than plausible counterfactual investments in housing. In 2020, Glasgow City Council (with the Scottish Government) helped fund a demonstration project to explore whether a high standard, green retrofit in a set of eight tenement flats in one close owned by a housing association (a social landlord) could be a feasible and cost-effective way of upgrading the housing stock and meeting net zero. The tenement was bought from the private landlords operating in the block and upgraded with a high-quality green retrofit to Passivhaus EnerPHit⁶ certification standards (the project is described in more detail in part 3 of this paper). Figure 1 shows the tenement block in 2020, pre-works commencing. Figure 2 shows a diagrammatic summary of the EnerPHit works underway on site.

Figure 1: 107 Niddrie Road, Glasgow



¹ See UK greenhouse gas statistics <https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2019>

² *ibid*

³ See the UK government's net zero strategy <https://www.gov.uk/government/publications/net-zero-strategy>

⁴ Scottish Housing Survey statistics, 2019 <https://www.gov.scot/publications/scottish-house-condition-survey-2019-key-findings/pages/4/>

⁵ *ibid*

⁶ The EnerPHit standard is an efficiency standard developed specifically for retrofitting existing buildings by the Passivhaus institute. See https://passiv.de/en/03_certification/02_certification_buildings/04_enerphit/04_enerphit.htm

We use a standard environmental cost-benefit analyses framework to analyse the net present value of this retrofit compared to plausible counterfactual options. We use standard UK government discount rates, emissions conversion factors, and long run values for energy saving and greenhouse gas emissions abatement.

We find that the EnerPHit standard retrofit has a positive net present value over a 30-year period, and that the net present value is similar to a less expensive, but less efficient, retrofit to the Scottish government’s Energy Efficiency Standard for Social Housing 2 (EESSH2)⁷ standard. Which option is better from a cost-benefit analysis (CBA) standpoint is sensitive to the assumptions used.

Figure 2



We also find that the counterfactual of demolition and construction of a new block of eight flats is always the worst of the three options we consider. We estimate it has both a negative net present value and is the least effective in abating greenhouse gas emissions due to the relatively high embodied emissions of construction.

Our results indicate retrofitting existing buildings is superior to demolition and construction of new dwellings, but that precise efficiency standards and level of investment needed is uncertain and sensitive to the assumptions made. We also recognise that a CBA analysis is only one, albeit important, dimension of any holistic evaluation of such a project. Further evaluation work will examine technical building performance and a more detailed examination of outcomes for residents.

⁷ The Energy Efficiency Standard for Social Housing post 2020. [See https://www.gov.scot/policies/home-energy-and-fuel-poverty/energy-efficiency-in-social-housing/](https://www.gov.scot/policies/home-energy-and-fuel-poverty/energy-efficiency-in-social-housing/)

2. Analytical approach

Economic appraisal and cost-benefit analysis (CBA) aims to provide support to decision making when there is a choice on how to use resources. Robinson (1979) is a classic introduction to the economics of decisions between redevelopment and refurbishment. Several more recent papers have considered the robustness of orthodox CBA and economic appraisal in capturing the net benefits of social housing investment (Denham, et al, 2019; Gibb and Christie, forthcoming). Grant Thornton (2021) is an example of making an economic case based on CBA for a broader housing-retrofit based retrofit programme for a city-region (Glasgow).

The analysis that follows is based on a combination of actual and expected costs and benefits of a unique retrofit to EnerPHit standards. It involves eight one-bedroom flats in a single tenement building in a property in the inner south side of Glasgow (a district known as Strathbungo East). Due to Covid-19 and its knock-on consequences, the construction period was delayed and, at the time of writing, is only now coming to an end. This has two important implications: first, the CBA is taking place before handover to the housing association and residents taking up new tenancies; it also is occurring before complementary monitoring of building performance will be undertaken. It is also worth stressing that the purchase of an empty block by the housing association allows complete control over the property and no issues with mixed tenure or other owners within the block. This will not be the normal situation.

To aid comparability with other investments, and policy relevance, we adhere to UK government environmental cost-benefit analysis assumptions and methods. That is, we use the approach set out in the Treasury "Green Book"⁸, along with additional guidance for valuing greenhouse gas emissions from the Department for Business, Energy and Industrial Strategy (BEIS), and guidance on valuing housing investments from the Department for Communities and Local Government (DCLG). All values are given in real Net Present Values (NPV). That is, after adjusting for inflation and discounting future values compared to present values. Expected inflation is taken from the ONS GDP deflator forecasts, as standard in government appraisal. The discount rate used is that set out in the Green Book (3.5% for the first 30 years). We use a 30-year appraisal period as is standard in government housing related cost-benefit analyses⁹. It is also the standard for investment appraisal by housing associations, and for valuing stock transfers between landlords¹⁰. This aids the policy relevance of the analysis.

2.1 Options

The main option we assess is the (near Passivhaus) EnerPHit retrofit (as completed). The retrofit aims to achieve EnerPHit certification. This is a certification standard developed by the Passive House Institute (PHI) for refurbishment of existing, older buildings. It requires low energy demand for heating and cooling, and a high level of airtightness. To achieve this, the key components of the EnerPHit retrofit are:

- Air source heat pumps in half the properties
- Internal wall insulation
- External wall insulation
- Loft insulation and roof repairs
- Ground floor insulation

⁸ The Green Book: appraisal and evaluation in central government: <https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-government>

⁹ DCLG appraisal guidance: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/576427/161129_Appraisal_Guidance.pdf

¹⁰ For example, see the Housing Transfer Manual: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/329907/140704_Manual_2014_Final_2_.pdf

- Triple glazed windows
- Mechanical Ventilation with Heat Recovery
- Wastewater heat recovery throughout the building
- Floor joists improved and fitted with internal insulation to avoid decay risk
- Improved air tightness sealing

We assessed the EnerPHit retrofit against two plausible counterfactuals:

1. Retrofit to EESSH2 standard option

The housing units would be refurbished and retrofitted to the Energy Efficiency Standard for Social Housing 2 (EESSH2) standard. This represents an aspirational “business as usual” option¹¹, where the housing is put back into a decent state for tenants and made compliant with the future legally necessary energy efficiency standards, which all social housing must conform to by 2032. The EESSH2 option includes some improvements to energy efficiency, such as insulation, energy efficient lighting, and improved double glazing, as well as repairs and refurbishment of the interior.

2. New Build option

Given a need to reduce building greenhouse gas emissions, the only alternative to retrofitting is new buildings. For example, Nieto et al., (2020) run a range of macro simulations with different mixes of retrofitting and new building to see how the UK emissions target could be reached. Our New Build counter-factual aims to simulate the new build alternative for this tenement. The old tenement would be demolished and new housing to modern standards would be built for the equivalent tenant households. This would include modern energy efficient lighting, gypsum and glass fibre insulation, and modern double glazing.

The full description of counterfactual specifications is included in table A1 in the appendix. The main EnerPHit specification and the counterfactual costs and benefits are given compared to a baseline of the flats at current specification, with no extra work carried out, not legally habitable and therefore providing no housing benefits. Table 1 provides a summary of the costs and benefits we consider in the analysis, and whether they are included in the NPV.

¹¹ EESSH2 is the revised and more challenging version of energy efficiency improvements being mandated for social housing in Scotland, and is essentially an increase from EPC C to EPC B (SAP-based measures). However, there is controversy regarding this plan and it is currently under review both in cost terms (i.e. public exchequer and tenant affordability), as well as in terms of the significance attached to SAP/EPC measures – also under review. Achieving EPC B will not necessarily improve performance towards net zero.

Table 1: Costs and benefits considered

Type of Cost/Benefit	Group Cost/Benefit falls to	Included in Cost-Benefit Analysis?
Costs		
Initial installation/capital costs	Housing Association	Included
Maintenance costs	Housing Association	Included
Administrative costs	Housing Association	Included
Familiarisation with equipment costs	Tenants	Included
Embodied carbon of Construction	Society	Included
Benefits		
Property value uplift	Housing Association	Not included
Potentially lower energy costs	Tenants	Included
Increased “comfort taking” energy use	Tenants	Included
Improved health outcomes from better ventilation	Tenants	Included
Lower energy use	Tenants	Included
Lower greenhouse gas emissions	Society	Included
Improvements in air quality	Society	Included
Housing Services	Tenants	Included

Each individual cost or benefit we include is described more fully in section 4. For costs, we include the initial capital spend on labour and materials in the year of construction; the long term maintenance costs; the long-term administrative costs for the building factor; training and familiarisation costs for the tenant and the social housing staff for EnerPHit components; and the embodied carbon costs of the New Build. By far the largest of these is the initial capital costs.

For benefits we consider: the lower heat and electricity use for the tenants; the increased heating the tenants use as a result of saving money on heating (called “comfort-taking” and described further in section 4); the better health for tenants from better ventilation, counted in quality adjusted life years (QALYs); the housing services supplied to tenants, which is the same for all options; the value to society of lower greenhouse gas emissions; and the value to society of better air quality due to less gas burned (reduced emissions of health harming pollutants). We do not consider in this cost benefit analysis the value of land value uplift, as we believe this would be double counting once we consider the other benefits, such as lower energy usage. Nevertheless, this may be an important consideration for policy makers, especially if private landlords are to be induced to retrofit their buildings. Nor do we consider jobs resulting from construction and maintenance, as the money used on construction could potentially create jobs in other ways.

2.2 Scenarios

We assess the different options under 3 different scenarios: low, central, and high. Low, Central and High scenarios are used in UK government appraisal of energy and greenhouse gas emissions savings¹², so we follow that convention. The names of the scenarios relate to the future costs of pollution, especially of greenhouse gas emissions. The future is uncertain, and we therefore do not know, for example, how much a reduction of greenhouse gas emissions is worth in the future. If the world is slow to decarbonise, the cumulative effects of climate change will be worse, and each tonne of carbon dioxide equivalent emissions reduced will be worth relatively more at the margin. If you believe this the more likely scenario then you will give more weight to the “high” scenario. Conversely, if you believe the world will decarbonise relatively quickly in the future compared to the current rate (perhaps through an accelerating decrease in the price of decarbonising technology, such as we are witnessing with solar power), then you will give more weight to the “low” scenario. We do not make a judgement here about which rate is more likely but present a range of scenarios for the reader.

The social value of a reduction in each tonne of greenhouse gas emissions is taken from the UK government’s standard valuation for all three scenarios¹³. These represent the avoided costs resulting from greenhouse gas emissions, such as loss of property due to rising water levels, or increased damage from an increase in extreme weather and heat. For an introduction to the social value of greenhouse gas emissions see Watkiss and Downing (2008).

Following the standard UK government guidance, we assume not all the energy and emissions decreases are realised. This is because lower energy use for the same amount of heat is an increase in net income for the tenant. Some of these savings are then “spent” by the tenant to have a more comfortable temperature in their house than before. This is an income effect referred to as the rebound effect. Sorrell et al. (2008) review the literature and propose a plausible rebound effect for home heating of between 10%-30%. That is, between 10% and 30% of the decrease in energy use and emissions will not be realised because the tenant will increase the heat in their home. We take the midpoint of a 20% rebound effect for all our main analysis but investigate the effect of stronger or weaker rebounds in the sensitivity analysis in section 5. Increased heat used by the tenant is a benefit to them and known as “comfort-taking”. Following UK government standard guidance, we value this at the cost of the energy that would have been saved. The greenhouse gas and air pollution emissions abatement from “comfort-taking” are, however, lost.

¹² See BEIS green book supplementary guidance: <https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal>

¹³ From <https://www.gov.uk/government/collections/carbon-valuation--2>

3. Data and project background

Glasgow city council's housing leadership recognises the challenge of retrofitting more than 70,000 pre-1919 flats and the importance of sustaining them as a built form and basis for many of the city's thriving neighbourhoods. The specific retrofit demonstration project examined here came about because Southside housing association had been first offered the opportunity to take over a privately rented block of eight one-bed flats as part of city strategy to inject more social housing into a particular area of the city. They then became aware of an opportunity to bid for a Scottish Funding Council Climate Emergency research partnership fund, led by one of the authors. By forming a partnership between the academics, the housing association, the city council, the construction firm and the architects – this successful research evaluation brought together a range of complementary evaluative methods, including CBA, to assess the scalability, replicability and underlying efficacy of an EnerPHit retrofit within the context of a pre-1919 standard tenement. This allowed the evaluation to encapsulate lessons learned and precedents set by making decisions in real time working with key partners in the project e.g the planning service; detailed building performance measurement after the works are complete and residents in place; pre and post occupancy surveys; detailed cost benefit analysis; and, synthesis and knowledge mobilisation.

The overall capital cost of the project at funding was £1.091 million. The final project cost is around £1.295 million. The construction project was funded by a combination of Glasgow city council financial support (£488,000), Scottish government grant (£129,000) to support renewables (i.e. air source heat pumps for half of the properties), with the balance coming from private finance funded by the housing association through rents. The tenement acquisition costs were £60,000 per unit. The original cost per unit of the EnerPHit retrofit and refurbishment was £88,000 consisting of £44,000 for the basic refurbishment of the vacant properties plus £32,000 for the initial cost of the EnerPHit retrofit and £12,000 for contingencies. Once on site, the costs per unit rose because of further costs incurred arising from unanticipated problems with the condition of the property e.g. requiring to strip the building back to the bare bricks because of the condition of the plasterwork (note that these realised increases over the two years apply both to the EnerPHit retrofit and the costs of the originally proposed basic refurbishment of the close compared to the original costs).

Data on initial installation costs, maintenance costs, administration costs, and financing costs were provided by the housing association and architects. We also worked with them to estimate the same costings for the counterfactual options. These were based on previous refurbishments for the ESSH2 option, and on recent demolition and new construction for the New Build option.

Data on energy usages and greenhouse gas emissions under the different options was provided by the architect firm using Passive House Planning Package (PHPP) modelled estimates. The PHPP is a modelling tool used for certification of the Passivhaus standard. It takes into account the decreasing returns on energy efficiency from cumulative improvements. That is, for a building without any efficiency improvements, one single improvement, such as insulation, can make a big difference, but for buildings which are already very efficient, one extra efficiency measure will have less of an effect. The model also takes into account the local climate, altitude, the materials used, ventilation and shading, and produces estimates of energy usage. We use these energy estimates for our analysis, minus the rebound effect as outlined in section 2. The more widely used model of energy performance is the Standard Assessment Procedure (SAP), which is used as a compliance tool and provides an energy rating. However, SAP has been shown to be less accurate in some settings than PHPP modelling (Moran et al., 2014) and has been criticised as not accurately measuring actual energy performance (Kelly et al., 2012). The SAP model is also relatively inflexible compared to PHPP. For example, SAP models every building as being in the centre of the UK, for weather and climate parameters, and estimates number of occupants purely on the floor area¹⁴. We therefore use the PHPP model, as we believe it will give more accurate results.

¹⁴ See here for a fuller comparison of SAP and PHPP https://www.passivhaustrust.org.uk/guidance_detail.php?gld=44

4. Results

4.1 Main results

The main net present values and cost-benefit ratios are included in table 2 and table 3, respectively. They are shown under 3 main scenarios as explained in section 2. Further changes and assumptions are tested in the sensitivity analysis.

Table 2: Net Present Value of Options (£, 2021)

Option	Low Scenario	Central Scenario	High Scenario
New Build	-£479,425	-£455,271	-£424,510
EESSH2	£248,159	£277,571	£315,390
EnerPHit	£210,311	£266,506	£331,140

Table 3 – Benefit-Cost ratio of Options

Option	Low Scenario	Central Scenario	High Scenario
New Build	0.70	0.72	0.74
EESSH2	1.28	1.32	1.36
EnerPHit	1.21	1.27	1.34

Table 2 shows the net present value (NPV) for each option (New Build, EESSH2, and EnerPHit) under the three different scenarios. Recall the NPV is the total net value of the option over the 30 years, with costs and benefits valued less the further they are into the future. The Low, central, and High scenarios are the standard government scenarios where Low means that energy and carbon savings from this project are worth relatively less (perhaps because the world reduces emissions relatively quickly), while High means they are worth relatively more (perhaps because the world continually delays emissions abatement).

In every scenario, the “New Build” option has a negative NPV, and the lowest NPV each time. This is mostly due to the larger initial capital costs, and the embodied carbon costs as discussed below. These mean that, even though the New Build is more energy efficient than the EESSH2 option each year, the initial costs are so high, and the future discounted so as to render it the least economically attractive option. This is also reflected in table 3 where it always has a benefit-cost ratio of less than one. The benefit-cost ratio is simply the total NPV benefits over the 30 years divided by the NPV of the costs. This is often used alongside the NPV as an additional metric to aid decision making¹⁵.

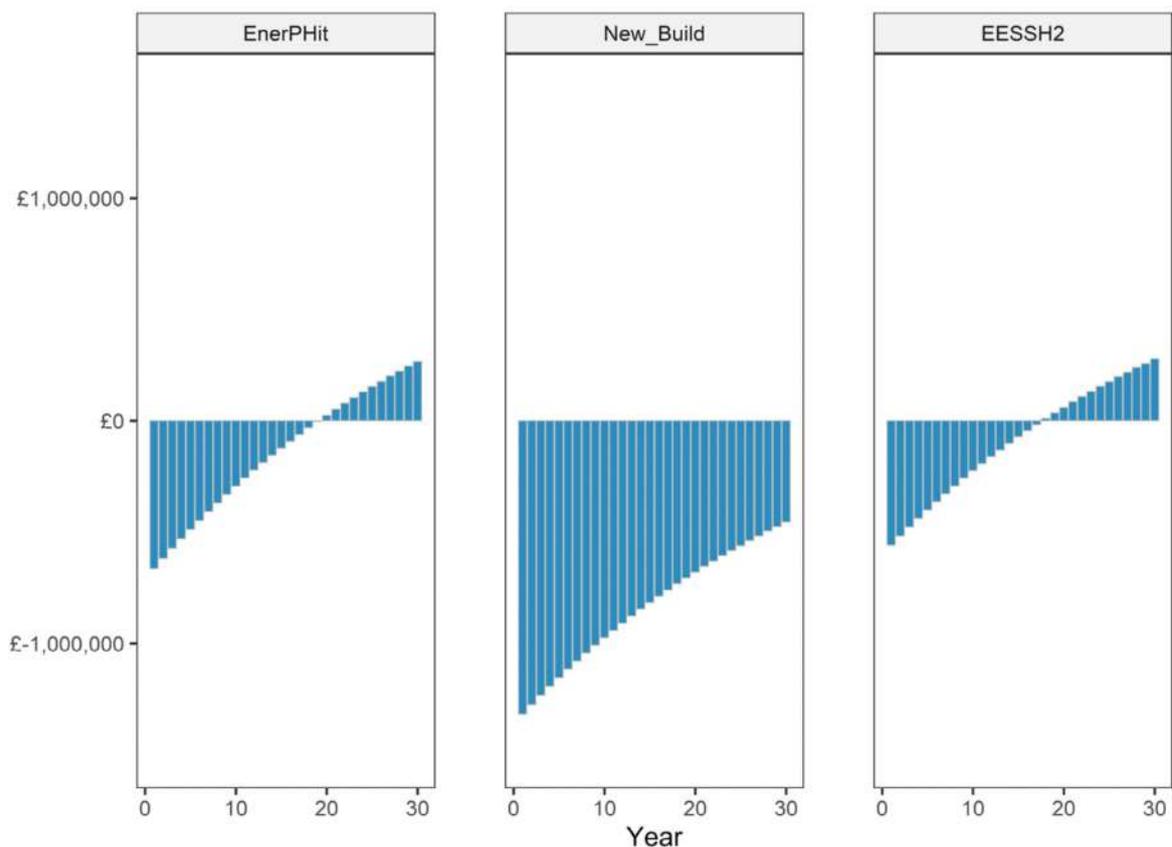
¹⁵ The benefit-cost ratio may give a better impression of the marginal value of the resources used on a project rather than the total value. As in, if the ratio is higher for one project than another then you get more from the last pound spent on the first project than the other. Neither metric is necessarily better, rather they can be used together for better decision making.

Table 2 also shows that in the low and central scenarios, the EESSH2 option has the highest NPV, while the EnerPHit option has the highest NPV in the high scenario. This is because the EnerPHit has higher initial capital costs, and while it is more energy efficient, in the low and central scenario this efficiency is not enough to reach the NPV of the EESSH2. In the high scenario however, the increased social value of carbon, value of energy, and value of pollution abatement are enough to give it the highest NPV. The higher costs still mean that the EnerPHit has a slightly lower benefit-cost ratio than the EESSH2 in the high scenario.

Overall, these results show the New Build is never the best option, while the EnerPHit and EESSH2 estimates are similar. The EESSH2 is preferred to the EnerPHit in the low scenario, marginally preferable in the central scenario and worse in the high scenario.

Figure 3 shows the cumulative NPV each year in the central scenario to illustrate when the different options “pay-off”, i.e., reach a positive NPV. The EESSH2 option does so at year 18 and the EnerPHit in year 20. The initial capital costs are clear at the outset, while the benefits are more gradual. The New Build option does not reach a positive NPV in the 30-year period due to its higher initial costs.

Figure 3: Cumulative Net Present Value of Options, Central Scenario (£, 2021)



In table 4 and 5 we perform the same exercise but with distributional weights on costs and benefits. These weights are calculated in accordance with annex A3 of the UK Treasury Green Book¹⁶.

The income profile of the future tenants is unknown, but these are social tenants who tend to have lower than median incomes, and in many cases much lower. We have assumed half of them will be from the bottom quintile of income, and half from the second quintile. This tenant mix is assumed to be the same for every option. These are given weights of 3.28 and 1.56 respectively. All other costs and benefits are weighted at one, the median. These are costs and benefits to the housing association or society in general.

Table 4: Net present value of options, distribution weighted (£, 2021)

Option	Low Scenario	Central Scenario	High Scenario
New Build	£645,748	£681,389	£726,304
EESSH2	£1,367,728	£1,400,886	£1,448,048
EnerPHit	£1,387,080	£1,456,999	£1,538,791

Table 5: Benefit-cost ratio of options, distribution weighted

Option	Low Scenario	Central Scenario	High Scenario
New Build	1.40	1.42	1.44
EESSH2	2.56	2.60	2.66
EnerPHit	2.41	2.48	2.56

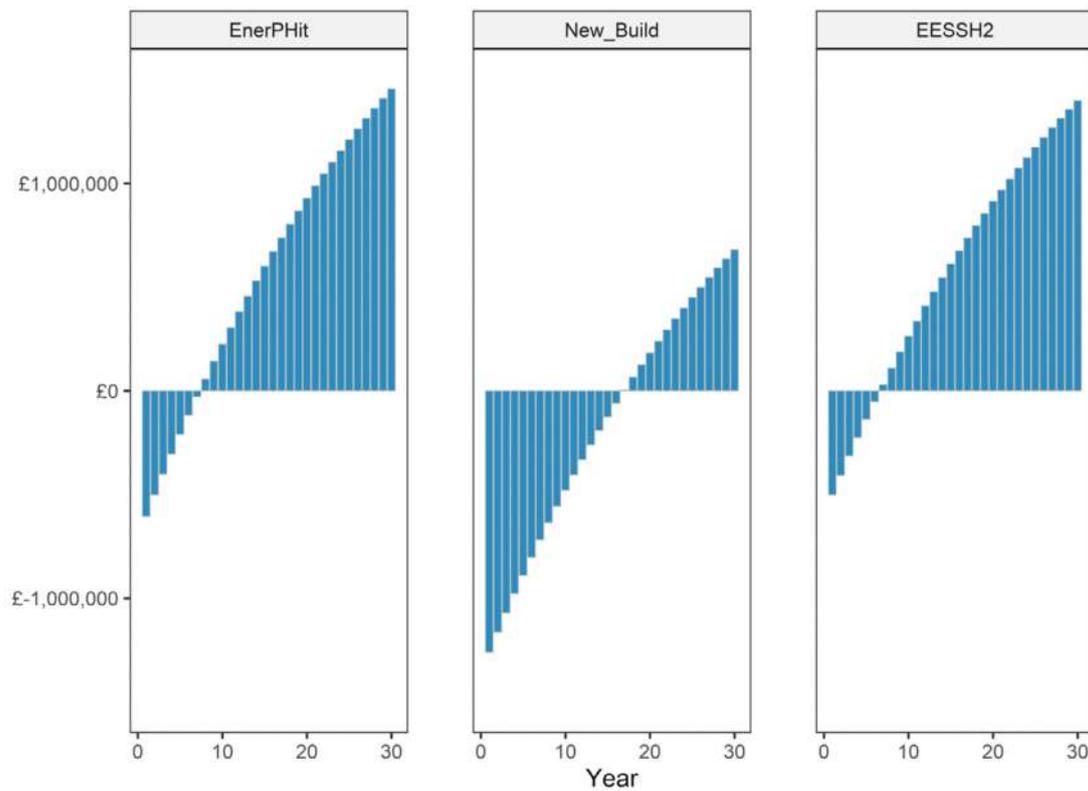
Table 4 shows that with distributional weighting all the options have a positive NPV in all scenarios. This is because the main benefits of the housing services and energy savings accrue to the tenants, who receive a higher weight. For example, the PHPP modelling estimates as much as 81% of energy usage is saved in the EnerPHit retrofit compared to the original specification. A huge saving, especially for low-income tenants. The ranking of the options in table 4 also changes as EnerPHit becomes the highest NPV option in all three scenarios. This is due to the much higher energy savings accruing to the tenants from EnerPHit, which now receive a higher weight.

In table 5 we see that EESSH2 still has the highest benefit-cost ratio, but all cost benefit ratios are higher than in table 3. The New Build benefit-cost ratio is also above one when distributional weighting is used.

We again present the profile of cumulative NPV under the central scenario in figure 4, but this time with distributional weights. The New Build achieves a positive NPV in year 17, EESSH2 in year 7, and EnerPHit in year 8.

¹⁶ The UK Treasury uses an elasticity of marginal utility of income figure of 1.3. That is, the higher your income the less each additional pound is worth to you. For example, for a billionaire an extra £100 does not matter as much as it would do for someone in poverty. Given this suggested 1.3 figure, we divide the median income of the affected group by the median income in the UK and raise the result to the power 1.3. This is the distributional weight that benefits and costs to that group are multiplied by. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/938046/The_Green_Book_2020.pdf

Figure 4 - Cumulative net present value of options with distributional weights, central scenario (£, 2021)

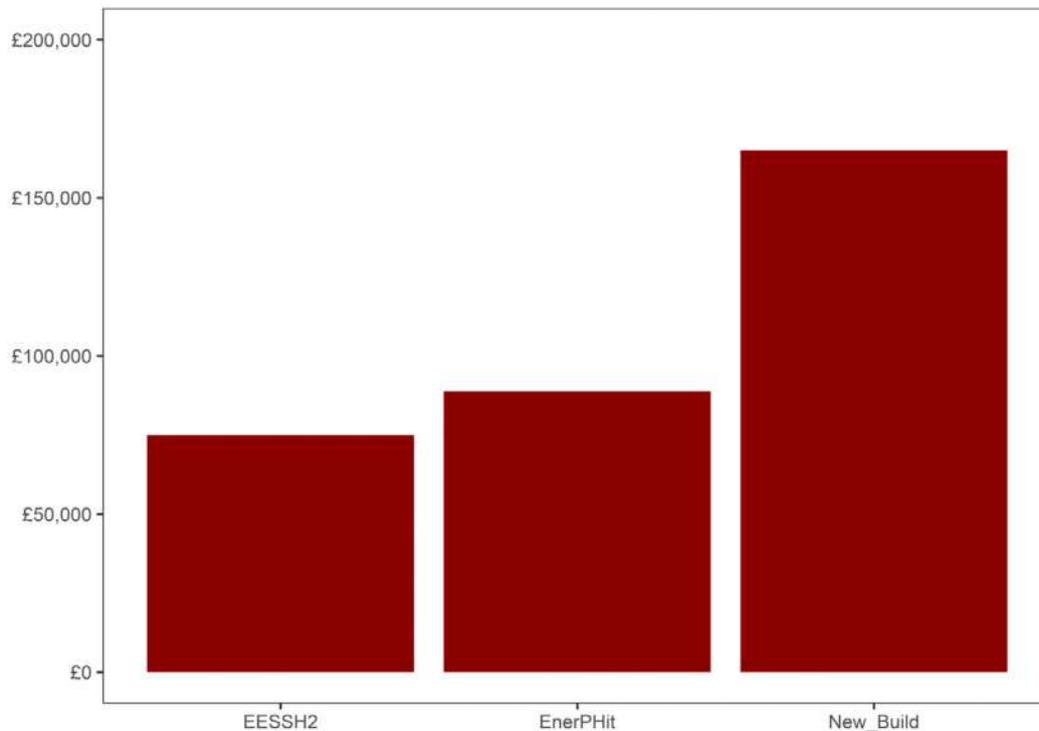


We now present the individual components of the cost-benefit analysis in more detail.

4.2 Initial capital costs

The initial capital costs include the labour, materials, and site management. It does not include VAT, legal fees, or land acquisition. Costings for counterfactuals were developed with the housing association and architect firm based on the actual work done on the site, new build and refurbishment and retrofitting sites in the surrounding area carried out in previous years and based on the economic environment in 2021. The average costing per flat is given in figure 5. These do not vary in each scenario.

Figure 5: Average initial capital costs per flat



4.3 Carbon abatement

To determine carbon abatement savings, we first take the estimates of energy saved from gas and electric in kilowatt hours from the PHPP modelling. We use the BEIS conversion factors for both gas and electricity savings to convert these to total tonnes of equivalent Carbon Dioxide¹⁷. The amount of greenhouse gases abated from electricity savings declines over time. This is because the UK government assumes more and more electricity over time is generated by renewable methods, therefore the carbon abatement from saving electricity in the future is not worth as much as saving electricity today is, even before we discount the future value. In contrast, the emissions abated from gas remain constant.

Figure 6 shows the cumulative total tonnes of Carbon Dioxide equivalents saved by each option. The EnerPHit option saves the most tonnes of greenhouse gas emissions, with a final saving after 30 years of 429 tonnes. This is followed by the EESSH2 at 257 tonnes. The New Build starts with a significant emissions deficit because of the embodied carbon in the demolition and building. We use as a guide the concrete frame flat estimates for the embodied carbon from Spear et al. (2019). We estimate the embodied carbon of demolition and construction as 20 tonnes of Carbon Dioxide equivalents. This means that the final abatement for the New Build after 30 years is 205 tonnes.

¹⁷ Several greenhouse gases are emitted in the use of gas and electricity generation. Some have much stronger greenhouse effects. These are all converted to Carbon Dioxide equivalent amounts, so that a tonne of greenhouse gases with stronger effects are worth more than a tonne of Carbon Dioxide.

Figure 6: Cumulative carbon dioxide equivalent emissions abated, tonnes

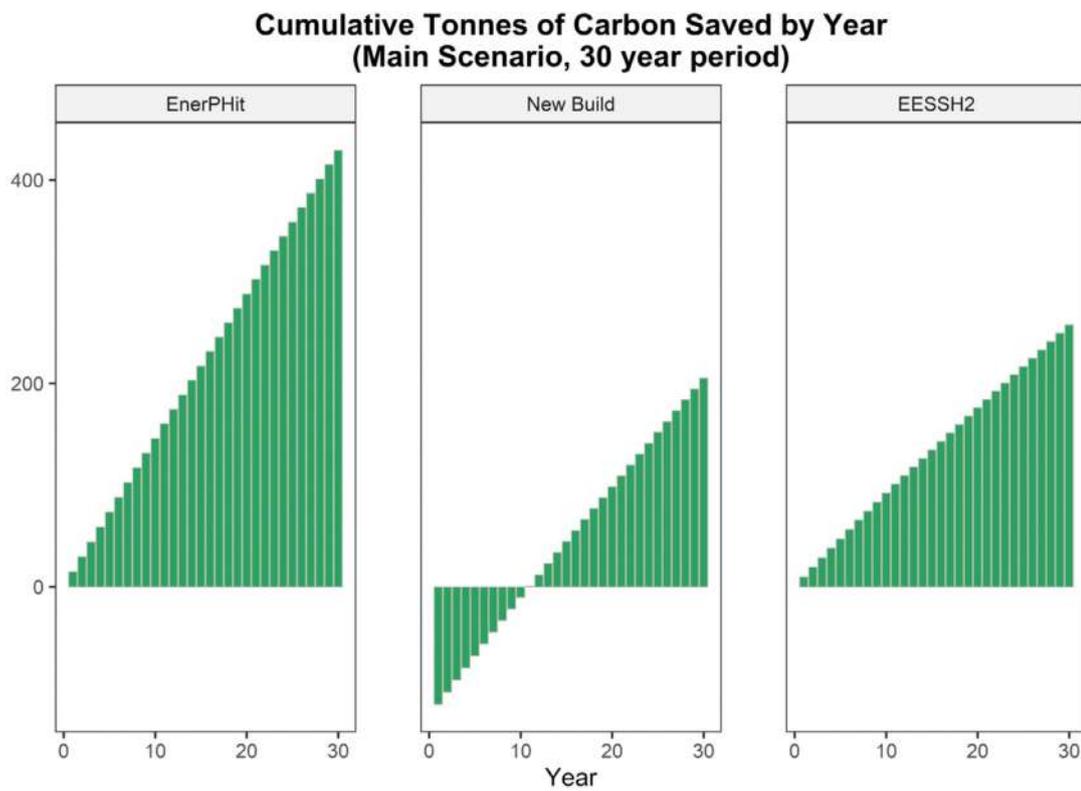
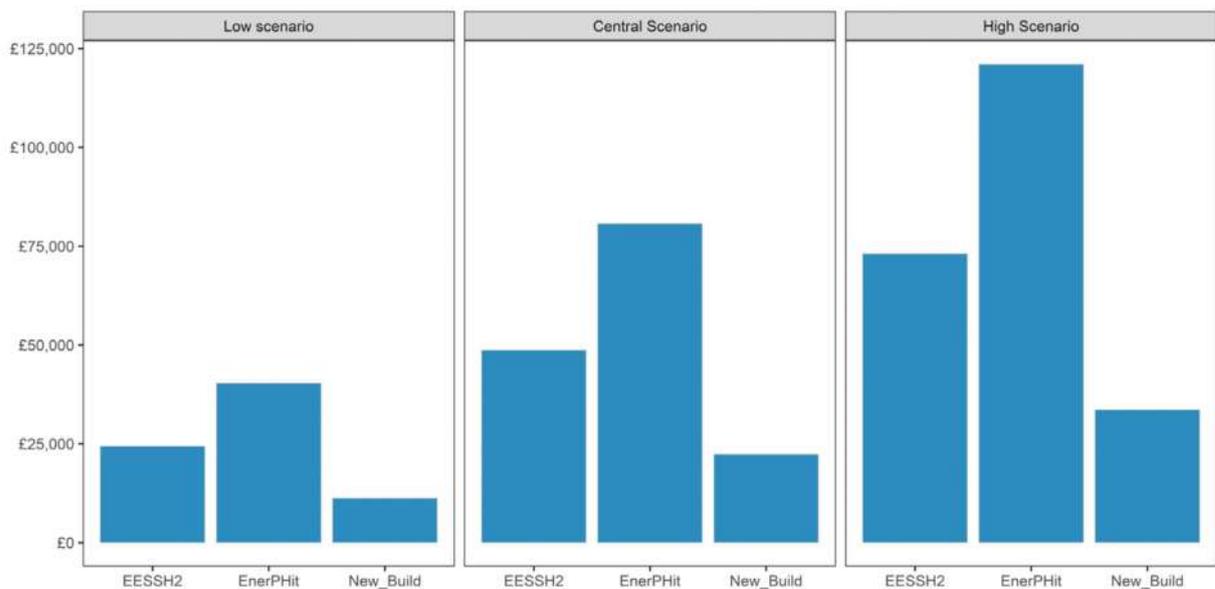


Figure 7 converts the emissions abated into NPV amounts. This is done using the BEIS low, central, and high estimates for the social value of carbon emissions abatement. The EnerPHit has the highest NPV benefit and the distance between it and the other two options grows as the social value of emissions abatement grows.

Figure 7 – Net present value of carbon dioxide equivalent emissions abated, (£, 2021)



4.4 Energy saved

The energy saved per year in kilowatt hours is based on PHPP modelled estimates from the specifications in table A1 in the appendix. We convert to a monetary value by using the BEIS long-run energy values (converted to £,2021). These are discounted to present values as all cost and benefits are. Savings in electricity and gas are treated separately, with separate long-run energy values.

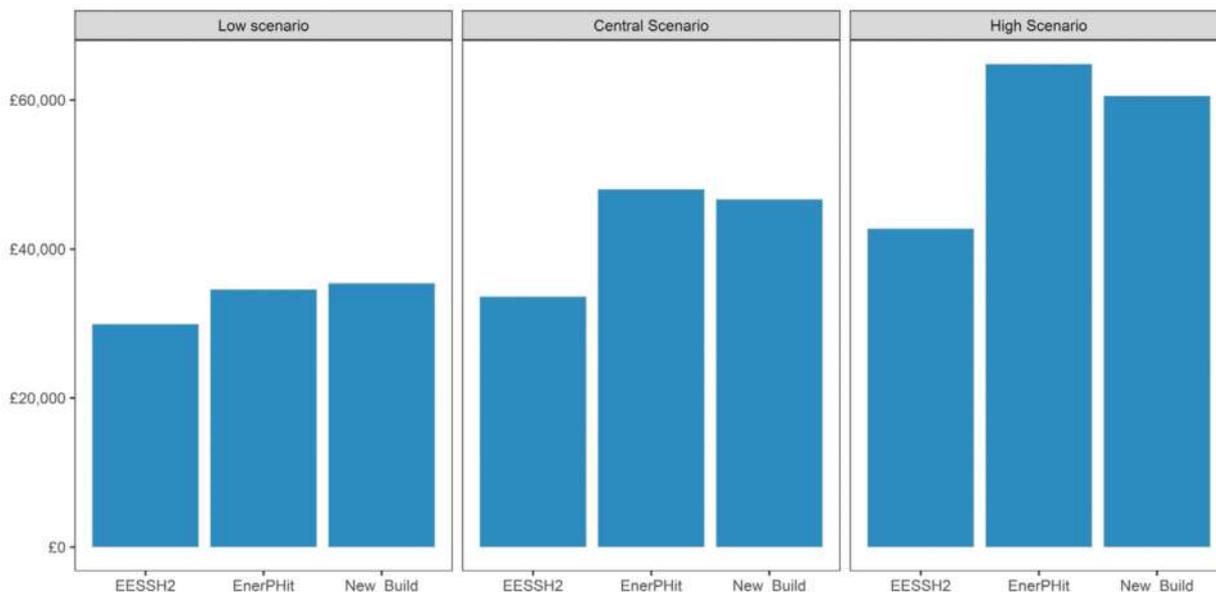
Table 6 shows the estimated total energy saved in kilowatt hours. The majority of the savings are in gas used for heating, with a smaller amount in electricity savings. EnerPHit saves less electricity compared to the other two options due to the use of heat pumps in half the flats, whereas in the other options all flats have combi-boilers. Heat pumps do not use gas, but require electricity to run. Therefore, the EnerPHit option uses slightly more electricity than the other options, but less gas.

Table 6: Total energy saved (8 flats, 30 year period)

Option	Electric (KWh)	Gas (KWh)
EnerPHit	84,240	2,877,338
EESSh2	198,960	1,655,258
New Build	203,760	2,169,578

Figure 8 shows the KWh savings converted to NPVs using the long-run value of energy estimates from BEIS. The EnerPHit has the highest NPV benefit in the central and high scenario, while the New Build has the highest in the low scenario. This is due to the higher New Build electricity savings and the lower variation between electricity long run values in the three scenarios compared to gas. Both EnerPHit and New Build have higher NPV benefits of energy savings than EESSh2, as they are more efficient.

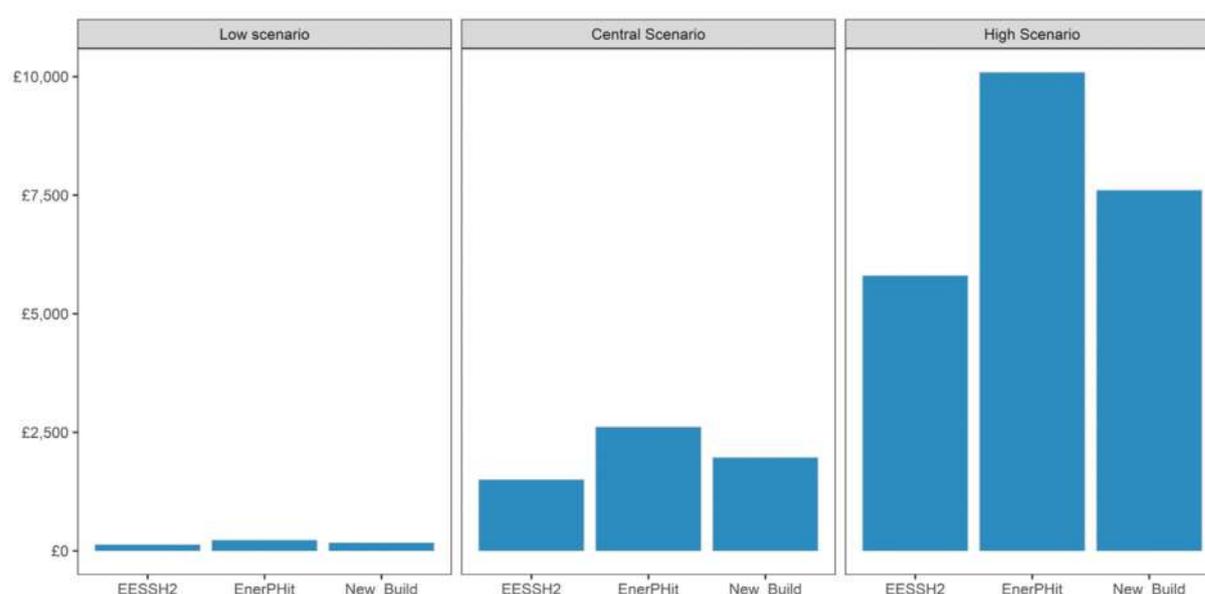
Figure 8 - Net present value of energy savings, (£, 2021)



4.5 Air quality

The reduction in natural gas use for heating reduces harmful pollutant emissions such as Nitrous Oxide. This has been shown to harm health and increase risk of death (Faustini et al., 2014). We use the BEIS emissions factors¹⁸ to convert kWh of gas usage into pollutant emissions. These are converted into NPVs using the UK Government guidance on air quality assessments¹⁹. Again, these have low, central, and high prices. The total value of the improvement in air quality is shown in figure 9. EnerPHit scores highest in NPV terms for each cost scenario.

Figure 9: Net present value of pollution emissions abated, (£, 2021)



4.6 Housing services

The largest component of the benefits is provided by the housing services enjoyed by the tenants. However, net of the energy savings, pollution abatement, potential health benefits of improved ventilation, and costs of training on Passivhaus tools, we consider the housing services of each build option to be the same. Following guidance from the UK Department for Levelling Up, Housing & Communities (DLUHC)²⁰, we value the housing services at local market rent. We use the mean rent of a 1-bedroom flat in Greater Glasgow from Scottish Housing Statistics as this value. This gives a total NPV for 8 flats over the 30 years of £1,067,888.

¹⁸ <https://naei.beis.gov.uk/data/emission-factors>

¹⁹ <https://www.gov.uk/government/publications/assess-the-impact-of-air-quality>

²⁰ <https://www.gov.uk/government/publications/department-for-communities-and-local-government-appraisal-guide>

4.7 Familiarisation costs

The components of the EnerPHit option require some training of tenants and housing association staff for full efficiency gains to be realised. We estimate a total of 24 hours of tenants' time and 6 hours of housing association staff time. We value both at the median UK wage in 2021. This gives a total NPV cost of training as £186 for staff and £746 for tenants.

4.8 Health benefits

Literature reviews find that EnerPHit standard housing have better air-quality than conventional housing (Moreno-Rangel et al., 2020). This is due to the mechanical ventilation and strict standards required to meet the EnerPHit standard. Hamilton et al. (2017) show that more energy efficient homes without this improved ventilation may even lead to worse health outcomes. We use the estimates in Hamilton et al. (2017) as a starting point for assumptions on health benefits. We assume health benefits of 0.033-0.038 QALYs in total each year. This is multiplied by the estimated value of a QALY from the UK Department of Health, which is £76,729 in £,2021. We then sum this across all years after discounting to give the NPVs in table 7 for the low, central, and high scenarios.

Table 7 – NPV of improved health due to better ventilation with EnerPHit option (£,2021)

Low Scenario	Central Scenario	High Scenario
£48,725	£52,371	£56,017

4.9 Maintenance and factor management

Housing needs continual maintenance. There is regular maintenance, such as clearing of gutters, and intermittent maintenance, such as unblocking drains, boiler breakdown etc. It is possible for the Passivhaus components used in the EnerPHit option to lead to more or less spending in maintenance, depending on how they are used and the state of the market in the future. We do not consider we have information to judge the maintenance profile over the next 30 years, so we use the average maintenance amounts across the housing stock for the housing association for all options. However, we explore how different maintenance spending would affect the results in the sensitivity analysis. The NPV of the maintenance cost we use is £243,658.

Social housing also comes with factor management costs. The factor being the housing association. They are responsible for cleaning of common areas, organising repair and insurance for the tenement, and making periodic reports to the tenants. The NPV of the factor costs are the same for all options at £30,457.

5. Sensitivity analysis

In this section we carry out several tests to see how sensitive our findings are to the assumptions we have made.

5.1 Exclude health benefits

Since the health benefits of ventilation are only added to the EnerPHit option, and it requires strong assumptions about the effects on health over the 30 years, a natural sensitivity check is to see the effect on the NPV when this is excluded. The results for EnerPHit are in table 8 and table 9. The other two options are unaffected as they did not include the ventilation health benefits. The EnerPHit option has a lower NPV than the EESSH2 in all scenarios now, and the cost-benefit ratios are lower.

Table 8: Net present value of options excluding health benefits (£, 2021)

Option	Low Scenario	Central Scenario	High Scenario
New Build	-£479,425	-£455,271	-£424,510
EESSH2	£248,159	£277,571	£315,390
EnerPHit	£157,940	£214,135	£278,769

Table 9 – Benefit-cost ratio of options with excluding health benefits

Option	Low Scenario	Central Scenario	High Scenario
New Build	0.70	0.72	0.74
EESSH2	1.28	1.32	1.36
EnerPHit	1.16	1.22	1.28

5.2 Value of a social tenancy

It is possible we are undercounting the benefits of putting the housing back in to habitable use due to excluding the wider social benefits (non-market based) of a social tenancy (ie going beyond the market rent assumption we make). A social tenancy provides housing for many people not able to afford market housing, and who may be in vulnerable groups in need of support. Organizations such as the Collaborative Centre for Housing Evidence (CaCHE) and the Housing Associations' Charitable Trust (HACT) have worked on providing evidence and monetary values for this added value, including the positive externalities it generates (Gibb, et al, 2020). HACT provide a social value bank and calculator to help generate these values. However, precise values require detailed data and surveys from the surrounding area which is beyond the scope of this paper. We therefore use as a guide the estimate of the social value of a tenancy in Barnes et al., (2018). This will not affect the relative rankings of our options, but it is important to the absolute NPV and thus aids comparability with the NPV of other investments.

The results are included in tables 10 and 11. They show an approximate doubling of the NPV for the EnerPHit and EESSH2. The New Build option still has a negative NPV and a benefit-cost ratio below one.

Table 10: Net present value of options with social value of tenancy included (£, 2021)

Option	Low Scenario	Central Scenario	High Scenario
New Build	-£157,606	-£133,452	-£102,691
EESSH2	£569,977	£599,390	£637,209
EnerPHit	£532,130	£588,324	£652,959

Table 11: Benefit-cost ratio of options with social value of tenancy included

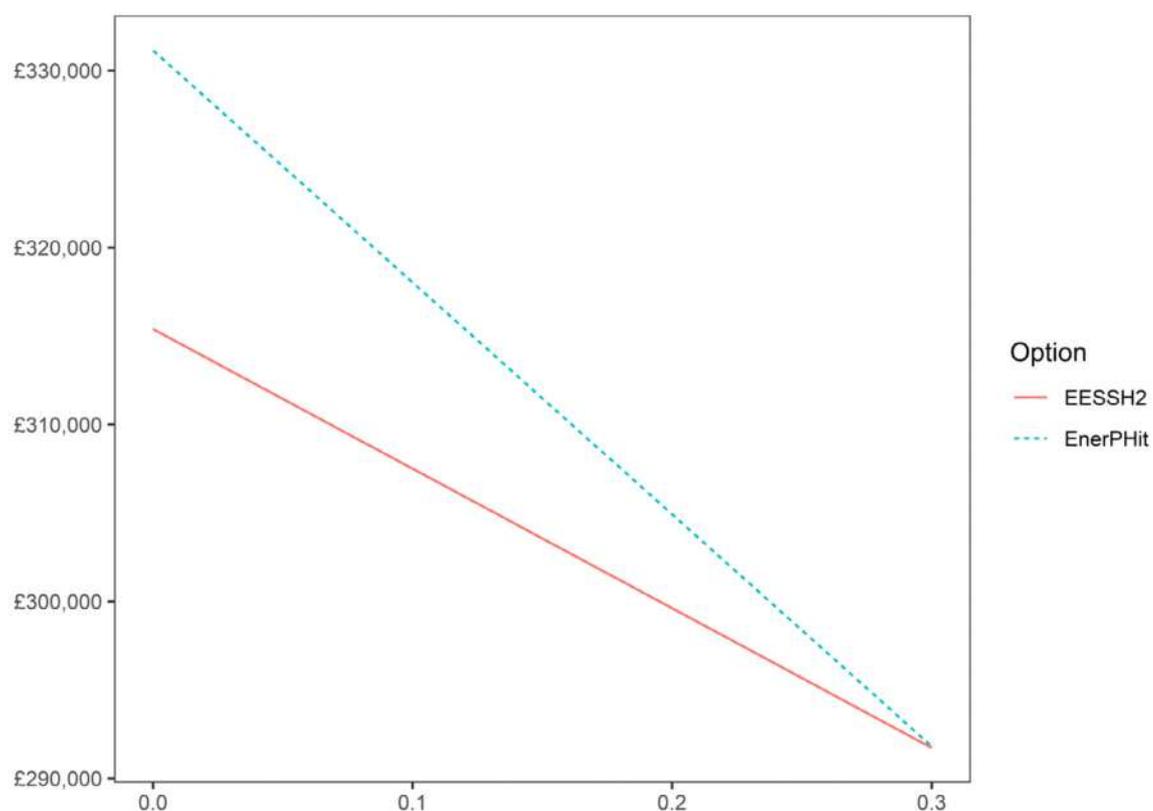
Option	Low Scenario	Central Scenario	High Scenario
New Build	-£157,606	-£133,452	-£102,691
EESSH2	£569,977	£599,390	£637,209
EnerPHit	£532,130	£588,324	£652,959

5.3 Maintenance

As explained in section 4, we do not have enough information to estimate the maintenance schedule over the next 30 years. However, we can see that it only requires a small change in maintenance amounts to change the relative rankings in table 2 between the EnerPHit and EESSH2. If the EnerPHit was relatively cheaper to maintain by only £11,000 it would be the better option in the central scenario, while if it were £15,000 more to maintain, it would be the second-best option.

5.4 Rebound effect

As explained in section 2, we assume a rebound effect of 20% throughout. Here we test the effects of varying this rebound effect to see if it affects the relative rankings of the EnerPHit and EESSH2 options. The EnerPHit is more efficient than the EESSH2, so will be most affected by the changes in the assumed rebound effect. We vary the rebound effect between the upper end of the estimates for heating in Sorrell et al. (2008), which is 30%, and 0%. We can see in figure 10, that in the high scenario the EnerPHit remains the highest-ranking option at all rebound effect sizes from 0%-30%.

Figure 10: Net present value of options with varying rebound effect, high scenario (£,2021)

5.5 Optimism bias

Research on cost-benefit analyses suggest realised benefits of preferred options are often less than estimated, and realised costs are often higher (Flyvbjerg and Bester, 2021). This may happen for several reasons: the cost of scope-changes in the future, optimism about price variations in material or labour, optimism about time needed for building, and unforeseen complexity.

We use the optimism bias correction factors for cost-benefit analyses suggested in Flyvbjerg and Bester (2021) to estimate a different NPV of the preferred option (EnerPHit). In principle, optimism bias could also affect the other two options if that work was carried out instead, therefore the following estimates should be considered a stress test of the Retrofit option.

Flyvbjerg and Bester (2021) show cost-benefit analyses of buildings work tends to underestimate costs and slightly overestimate benefits. Their correction factors inflate costs by a factor 1.26 and deflate benefits so they are worth 0.99 of the given amounts.

The NPV of the EnerPHit after these corrections is given in table 12, with the other options presented alongside unchanged. Similarly, the benefit-cost ratios are presented in table 13. These tables show that under this amount of optimism bias, the EnerPHit would no longer have a positive net present value under any scenario, and therefore no longer has a benefit-cost ratio above 1 in any scenario. This would make EESSH2 the preferred option in all cases.

Table 12: Net present value of options with optimism bias correction (£, 2021)

Option	Low Scenario	Central Scenario	High Scenario
New Build	-£479,425	-£455,271	-£424,510
EESSH2	£248,159	£277,571	£315,390
EnerPHit	-£156,259	-£100,627	-£36,639

Table 13: Benefit-cost ratio of options with optimism bias correction

Option	Low Scenario	Central Scenario	High Scenario
New Build	0.70	0.72	0.74
EESSH2	1.28	1.32	1.36
EnerPHit	0.88	0.92	0.97

6. Discussion and conclusion

We find, given our assumptions, that the retrofitting of an existing block of old stock dwellings, either to the future mandated EESSH2 standard or to the more efficient Passivhaus EnerPHit standard, is superior to demolishing them and building new housing. By superior, we mean they both have higher net present values and higher benefit-cost ratios. We also find that EESSH2 and Passivhaus retrofits (the “EESSH2” and “EnerPHit” options) perform similarly, and which is the better option is sensitive to which assumptions are used.

The unambiguous finding of our analysis is that demolition of old dwellings to replace with new dwellings, when these buildings could be put back into use, is the worst value option. Not only in terms of the net benefit to society, but also purely in terms of greenhouse gas emissions. This matches previous research, for example McGrath et al. (2003) find a retrofit to have generally lower environmental impact than new building, while Nieto et al. (2020) using the University of Leeds’ MARCO-UK macroeconomic model, found that retrofitting could have substantial benefits and energy reduction compared to building even 3 million highly efficient new dwellings.

Our second finding is that ranking of the EESSH2 and EnerPHit retrofits is sensitive to different scenarios and assumptions. With the relatively more optimistic “low” and “central” scenarios, with low to medium values on greenhouse gas abatement and energy savings, the EESSH2 standard had a higher NPV. With high values for emissions abatement and energy saving, the EnerPHit standard had a higher NPV. Similarly, if distributional weights are used, which weight higher costs and benefits to those with lower income than the median, then the EnerPHit standard has a higher NPV. Conversely, when we assume some optimism bias or exclude the assumption of health benefits due to improved ventilation, the EESSH2 standard has a higher NPV. We also note that only the preferred EnerPHit options reaches or approaches net zero (in theory) because of the significant energy cost savings associated with it. EESSH2 would need further investment to bridge that gap. It is also the case that building performance analysis tends to suggest that less rigorous retrofit is more likely to suffer poorer performance over time.

There are several unavoidable limitations to our study. We do not model some costs and benefits which would be excluded from the cost benefit analysis due to potential double-counting, but which are nevertheless important factors. For example, land value uplifts are not considered, where the value of the property increases due the efficiency investments making it more attractive. This may even have effects to surrounding properties (Maclennan, 1993). Nor do we consider the potential benefits that would arise if this project successfully demonstrated the benefits of retrofitting tenements, and this led to a substantial increase in such retrofits, with the resultant gains in emissions abatement.

Our results suggest that post-occupancy monitoring of actual energy usage and therefore emissions abatement will be crucial. This will inform which assumptions were more reasonable and therefore which option is the better choice ex-post.

Overall, our analysis indicates that retrofitting to some reasonably efficient standard is a worthwhile investment, given the need for large scale reductions in domestic greenhouse gas emissions, but the optimal standards and investment required is highly uncertain.

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Appendix

Table A1 – Detailed Specifications of Option

	As Existing		Southside HA current retrofit specification		Niddrie Road retrofit specification		Southside HA current new-build specification	
	Mid-terrace, mid-floor flat	Ground floor, mid-terrace flat	Mid-terrace, mid-floor flat	Ground floor, mid-terrace flat	Mid-terrace, mid-floor flat	Ground floor, mid-terrace flat	Mid-terrace, mid-floor flat	Ground floor, mid-terrace flat
Building envelope, description	Walls: 600mm solid sandstone+ lath and plaster. Windows: 100% uPVC windows (pre 2003, double glazed. Ground floor: uninsulated suspended timber floor. Loft: uninsulated loft.		Walls: solid walls lined internally with 100mm Kingspan Kooltehrm + and internal lining. Suspended timber floor+100mm quilt insulation between existing joists+ 22mm chipboard. Windows: double glazed, CCG timber frame windows.		Walls: existing solid stone walls clad in silicone render finish and 50mm internal wall in fibre insulation. Windows internal and externally with 150mm EWI Insulation with insulation. Ground floor: 350mm mineral wool and wood: triple glazed timber frame windows.		140mm timber kit structural frame + vented confirmed. Double glazed, uP Cavity and facing brick finish. Ground floor build-up to be VC frame windows with trickle ventilators.	
Building envelope, performance targets	Fabric u-values: walls 1.6 W/m ² K, floors 1.8 W/m ² K, roof 1.5 W/m ² K, windows 2.5 W/m ² K. Airtightness target 15m ³ /hr/m ² . Thermal bridges: average 0.15 psi value.	Fabric u-values: walls 1.6 W/m ² K, floors 1.8 W/m ² K, roof 1.5 W/m ² K, windows 2.5 W/m ² K. Airtightness target 15m ³ /hr/m ² . Thermal bridges: average 0.15 psi value.	Fabric u-values: walls 0.22 W/m ² K, floors 0.18 W/m ² K, roof 0.15 W/m ² K, windows 1.6 W/m ² K. Airtightness target 7m ³ /hr/m ² . Thermal bridges: SAP Approved psi values	Fabric u-values: walls 0.22 W/m ² K, floors 0.18 W/m ² K, roof 0.15 W/m ² K, windows 1.6 W/m ² K. Airtightness target 7m ³ /hr/m ² . Thermal bridges: SAP Approved psi values	Fabric u-values: walls 0.15 W/m ² K, floors 0.12 W/m ² K, party ceiling as existing, windows 0.8 W/m ² K. Airtightness target 0.6ACH or better. Thermal bridge free: 0.01 W/mK	Fabric u-values: walls 0.15 W/m ² K, party floor as existing, party ceiling as existing, windows 0.8 W/m ² K. Airtightness target 0.6ACH or better. Thermal bridge free: 0.01 W/mK	Fabric u-values: walls 0.22 W/m ² K, floors 0.18 W/m ² K, roof 0.15 W/m ² K, windows 1.6 W/m ² K. Airtightness target 7m ³ /hr/m ² . Thermal bridges: SAP Approved psi values	Fabric u-values: walls 0.22 W/m ² K, floors 0.18 W/m ² K, roof 0.15 W/m ² K, windows 1.6 W/m ² K. Airtightness target 7m ³ /hr/m ² . Thermal bridges: SAP Approved psi values
Building systems, description	Space heating: non-condensing combi boiler. Programmer, room thermostats and TRVs. DHW: from main heating system. Ventilation system: intermittent fans + trickle ventilators.	Space heating: non-condensing combi boiler. Programmer, room thermostats and TRVs. DHW: from main heating system. Ventilation system: intermittent fans + trickle ventilators.	Space heating: condensing combi boiler feeding wet radiators Worcester Greenstar Cdi 25. Programmer, room thermostats and TRVs. DHW: from main heating system. Ventilation system: dMEV Greenwood Unity CV3 + trickle ventilators in windows	Space heating: condensing combi boiler feeding wet radiators Worcester Greenstar Cdi 25. Programmer, room thermostats and TRVs. DHW: from main heating system. Ventilation system: dMEV Greenwood Unity CV3 + trickle ventilators in windows	Space heating: condensing combi boiler Worcester Greenstar Cdi 25. Programmer, room thermostats and TRVs. DHW: from main heating system. Ventilation system: MVHR Zehnder ComfoAir 300 with rigid ducting and controls.	Space heating: ASHP ECODAN 4kWh QuHZ-W40VA feeding wet radiators, 150 litres cylinder. DHW: from main heating system. Ventilation system: MVHR Zehnder ComfoAir 300 with rigid ducting and controls.	Space heating: condensing combi boiler feeding wet radiators Worcester Greenstar Cdi 25. Programmer, room thermostats and TRVs. DHW: from main heating system. Ventilation system: dMEV Greenwood Unity CV3 + trickle ventilators in windows	Space heating: condensing combi boiler feeding wet radiators Worcester Greenstar Cdi 25. Programmer, room thermostats and TRVs. DHW: from main heating system. Ventilation system: dMEV Greenwood Unity CV3 + trickle ventilators in windows
Renewable systems, description	N/A	N/A	Wastewater Heat Recovery: Recoup Easy fit + System C, fitted mixer showers in rooms with bath.	Wastewater Heat Recovery: Recoup Easy fit + System C, fitted mixer showers in rooms with bath.	Wastewater Heat Recovery: Recoup Easy fit + System C, fitted mixer showers in rooms with bath.	Wastewater Heat Recovery: Recoup Easy fit + System C, fitted mixer showers in rooms with bath.	Boiler flue heat recovery (to be confirmed)	Boiler flue heat recovery (to be confirmed)