UK COLLABORATIVE CENTRE FOR HOUSING EVIDENCE

Niddrie Road, Glasgow: Tenement Retrofit Evaluation

Project supported by the Scottish Funding Council

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John Gilbert ARCHITECTS

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As part of a city council policy to inject social housing into areas dominated by private renting, traditional tenemental property in Glasgow is being purchased by housing associations with a view to refurbish them, including to bring them into line with national policies to raise energy efficiency across social housing in Scotland. In the autumn of 2019, Southside housing association saw an opportunity to undertake a demonstration project involving the deep retrofit of such a block, made possible by a Scottish Funding Council (SFC) climate emergency research competition.

A partnership of the housing association, the city council, John Gilbert Architects and CCG construction would deliver an EnerPHit level retrofit (PassivHaus for existing buildings), supported by a research evaluation, funded by SFC, led by the UK Collaborative Centre for Housing Evidence and colleagues at the University of Strathclyde (working closely with the housing association and the architect). This report details that research evaluation and its wider lessons for tenements and our older building stock.

107 Niddrie Road, Glasgow, is a standard four storey sandstone fronted block of eight small flats located near the north side of Queens Park and the arterial Victoria road, on the south side of the city close to the M74 motorway. The specific site is two tenement blocks away from the entrance to Queens Park railway station. The neighbourhood is dominated by pre-1919 sandstone tenements. The property was constructed in 1895. The planned project was delayed by Covid-19 which in turn impacted on planning permissions and securing finance. Consequently, construction did not start till the Spring of 2021 and the completed project was handed over to the association a year later, with tenants moving in later in 2022.

The research evaluation consisted of the following components. First, an evaluability assessment established a tenement retrofit theory of change, encouraged stakeholder buy-in to the evaluation and finalised the core elements of the evaluation, building on the proposal to SFC. Second, the team recorded and interpreted the process by which key decisions on the retrofit were taken and why. Third, a formal social cost benefit analysis of the EnerPHit retrofit alongside two plausible counterfactuals was undertaken. Fourth, technical performance of the building with tenants in situ has been underway (and is still continuing) comparing theoretical with actual performance and seeking to understand why any such deviations in performance may occur. Fifth, a series of interviews have been undertaken with tenants post-occupancy in their newly retrofitted flats.

Decisions that shaped the Retrofit

- The decision to commit to an EnerPHit approach was made possible because the association had control of a complete (and empty) tenement block or close. On the other hand, this means that the approach and the standard are not suitable for most situations where ownership patterns are more fragmented.

- Tenement planning policy is critical to aligning the fabric first needs of the retrofit (air -tight insulation combining external wall insulation and internal wall insulation as well as mechanical ventilation with heat recovery and other specific components) alongside renewables to deliver low energy. Niddrie road is a standard sandstone tenement. Even so, planning permission for the retrofit was complex and challenging.

- Like many other older tenements, 107 Niddrie Road had been poorly maintained and suffered from a wide range of long-term problems such as failing finishes and decayed floor structure which significantly impacted on time and costs.

- Air tightness is critical to achieving the EnerPHit standard and while the evidence thus far indicates that the building is performing well on thermal comfort, much reduced energy use (and fuel bills) and other aspects, the airtightness level required by the EnerPhit standard was not achieved. An important lesson going forward is how best to project manage airtightness works and testing.

Cost Benefit Analysis (CBA)

The cost per unit were high but the actual EnerPHit retrofit element was £30,000-£40,000 per unit, recognising also that a significant contingency is required in these sorts of projects because of the hidden costs of older buildings that do not emerge till the work is underway. CBA properly accounts for the wider benefits of reduced carbon emissions which are substantial enough to tip appraisal decisions away from demolition and rebuilding and need to be factored into public policy decision on retrofit.

The CBA is of practical value to decision making about larger scale retrofit investments including public funding but is a major undertaking in its own right. We think robust analysis of the costs and benefits on a consistent basis, including sensitivity analysis and explicit assumptions, can only strengthen the case for investment. The exercise at Niddrie road also noted the positive externalities of retrofit – the benefits accrue to all of us, so funding and regulatory interventions may have more justification to encourage individual owners to invest in retrofit.

Technical Performance

The Niddrie Rd retrofit appears to be very successful in providing dwellings that are very low energy, comfortable, healthy, with high degrees of occupant satisfaction. It is, however, important to note that these are interim results to date and will not be verifiable until we have 12 months of data. It is also based on 6 out of the 8 properties.

The dwellings appear to be performing below the targeted levels of consumption. This low energy use does not appear to have been at the expensive of thermal comfort, with good average indoor temperatures, generally within the Enerphit performance targets throughout this period. The dwellings internal air quality/ventilation remained below 1,000ppm CO_2 for the monitoring period, and there was no evidence from this monitoring of the MVHR systems being switched off or otherwise failing. At this stage there are no obvious concerns about presence of interstitial moisture in the construction. This will require on-going monitoring as conditions may change over time. There were some initial technical problems and delayed maintenance completion with the heat pumps. There are clearly lessons to learn for more efficient and effective training in the use of different aspects of the 'kit' in the properties though as time went on there was also evidence of satisfaction with the homes and their warmth and affordability.

Post Occupancy Evaluation

The post-occupancy evaluation highlights the need to understand the lived experience of place, both within and beyond the building envelope, but the design of action-orientated retrofit itself to consider these dynamics at the urban scale. Initial findings suggest that the residents are enjoying a marked improvement in the thermal comfort of their living space compared to their previous address, but that they are still learning how best to use the heating and cooling controls in their new home (although this includes working together co-operatively to help each other do so). It was too early to say anything definitive about their energy costs. The emerging evidence also shows location matters: a dense, mixed use urban area, allowing residents to easily access public transport, open space and shops and services.

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Wider Learning

1. Low Carbon Emissions. Compared to demolition and new-build, retrofitting buildings saves huge quantities of embodied energy and carbon. At Niddrie Road, we have achieved the best of both worlds; much reduced embodied carbon and much reduced operational energy into the future. However, a highly efficient building is no good, if the occupants don't know how to use it. The post-occupancy work suggests that there may still be work to be done to ensure that residents are in control of their environments.

2. Waste Water Heat Recovery. When the space heating demand is reduced by as much as it is at Niddrie Road, then the biggest component of most peoples' fuel bills are hot water costs. Wastewater heat recovery systems can reduce costs (and carbon emissions) of hot water can be reduced by around 40%. The ongoing monitoring will test this assumption.

3. Thermal Comfort. Tenants will be able to afford to live in comfort. In winter, it will not be expensive to keep the flats warm and in summer, it will be possible to keep the spaces cool. The Niddrie road retrofit project was completing when the cost of living crisis erupted across the UK. The high levels of airtightness and insulation indicate that the building is now highly adapted to require less heating and has already achieved significant fuel savings.

4. Controlled Humidity. Many homes in Scotland suffer from high levels of humidity, often in the form of condensation on cold surfaces. The air in Scotland is often damp and ventilation inadequate. Airtight buildings increase such risks. However, high performance MVHR has been used to constantly bring in fresh air and extract humid, spent air. The risk is also reduced by eradicating 'thermal bridges' which leak heat, but also provide the cold spots that lead to localised damp and mould.

5. Safeguarding Heritage. Safeguarding our heritage is critical to a sustainable future if for no other reason than we couldn't possibly afford to demolish and re-build all of the country's homes. It is surely far better to protect the older homes and buildings that most people know and love, while ensuring that they consume a tiny fraction of the fuel that they currently do. Heritage issues were uppermost, with the street-facing facade carefully re-pointed in a traditional lime mortar, with damaged stone replaced with matching natural stone and other repairs made to restore the building.

6. Landlord benefits. The Niddrie Road project meets the original 2032 requirements of Social Landlords set out by Scottish Government. The difference is that, at Niddrie Road, the practical consequences of the deeper net zero EnerPHit approach means that pressure on energy bills will be less. This will likely lead to reduced arrears on rents, support tenancy sustainment and mean fewer empty or void flats.

7. Net Economic Benefits. We have seen that the project did cost a lot but also that the cumulative 30 years carbon savings and the net benefits make the project better value for money compared to demolition and new build. Future decision making on deeper retrofit of our older buildings, including appraising different retrofit delivery and funding/ subsidy options, should take proper account of these economic issues, especially embodied carbon.

Final Reflections

The demonstration project has worked well. It has also provided lessons and learning for the wider tenement strategy, even if one such lesson might be to consider a wider range of near-Passivhaus alternative retrofit standards for specific situations.

Second, there are important qualifications about the transferability of findings from Niddrie road. This was an empty property wholly under the control of a social landlord aiming to fill a retrofitted empty property with social tenants.

The reality is that most tenement blocks are mixed tenure with different interests. Tenements will generally not be empty, but the need for decanting depends on the nature of the work required. Most of the external work would not require decanting. Some of the internal works could be set aside for periods of void between tenancies. Nonetheless, even for short blocks of time there will be considerable decanting required.

Third, the city's tenement planning policy has to be aligned with the tenement housing retrofit strategy. Three immediate issues are how to address the use of ASHPs in tenements so that they can be developed for all floors; a more supportive stance on external wall insulation; and, re-considering the role of PV panels on tenement roofs.

Fourth, the major fuel cost savings attached to the delivery of near-Passivhaus reduced energy demand through fabric first investment is also the creation of a future flow of financial savings to residents. Can the prospect of these savings be monetised into green financial packages that allow residents like owner-occupiers and private landlords to invest in retrofit without major upfront capital costs?

Finally, the retrofit question is situated within wider problems or challenges that confront the tenement sector more generally – most significantly that the law of the tenement may itself be undermining long term maintenance and investment decisions by owners. It is hard to see how retrofit in mixed tenure tenements can be either comprehensive or fair to individuals without progress in law reform.

1. Introduction and background

This is the main report evaluating the deep 'green' retrofit of a traditional, pre-1919, sandstone tenement in Niddrie Road, Glasgow. The retrofit project was launched as a partnership between the owner, Southside housing association, Glasgow city council, John Gilbert architects and CCG Ltd (the contractors). This was later augmented by the Scottish Government who funded specific renewables (air source heat pumps). The evaluation was financially supported by the Scottish Funding Council who had held a Climate Emergency research competition in the autumn of 2019. The evaluation team was led By the UK Collaborative Centre for Housing Evidence at the University of Glasgow, with a major technical contribution from the University of Strathclyde's School of Architecture. The evaluation also involved, principally Southside HA, John Gilbert Architects, as well as contributions from the city council and CCG.

The evaluation was launched at the end of February 2020, with the construction phase spread over a year from summer 2021 to spring 2022, followed by testing, before the block's eight one-bedroom flats were let out to social tenants by the housing association. Throughout, the project was viewed by stakeholders as a demonstration project of what is possible if one adopts deep fabric-first retrofit to a standard pre-1919 tenement block. A principal purpose of the evaluation was to understand and learn from the process of undertaking an EnerPHit type of retrofit (essentially, the retrofit version of Passivhaus), and seek to pass on lessons that might support the city's tenement strategy and help scale-up the built environment's contribution towards net zero climate targets.

The Context

Sandstone pre-1919 tenements, typically three or four storeys of apartments based around a close or stairwell and single door entrance, make up about a quarter of the city's housing stock (and are prominent across urban Scotland). There is something like 73,000 such flats in Glasgow, all, by definition, more than 100 years old. Many have been remodelled, refurbished and invested-in systematically, for example, in the 1970s-1990s by local housing associations creating Glasgow's unique community-based housing movement of more than 60 local housing associations. At the same time, the best of the stock, in sought-after areas, are high demand family homes for owner-occupation. Elsewhere, the tenements are generally of mixed tenure and mixed income, and the location of social housing, many private landlords, first time buyers, students, and arrival housing for new economic migrants, asylum seekers and refugees. One just has to walk around areas of the south side, west end, and parts of the north and east of the city, to see that this built form is a critical basis for thriving and effective neighbourhoods and residential communities.

However, the condition of the properties is mixed, and many tenement blocks are in critical or serious disrepair. Social housing investment in tenements now needs to be renewed across the city. Also, small scale private landlords often under-invest on their properties, and this is one reason, along with the variable quality of management, why the city wishes to purchase tenement blocks and transfer them to housing associations – an initiative that triggered the Niddrie road project. Part of the reason why disrepair is so common is the serial failure to manage and undertake common repairs among multiple owners of tenement blocks (Scotland and its tenements are not based on leaseholds). The practice of hiring factors to manage and collect the cost of these works is patchy and often ineffective. The Scottish Law Commission is now exploring proposals suggested by a Scottish Parliament working group (2017) to create owner associations, common repair sinking funds and mandatory regular inspections. We may wait some time before this is enabled in law. But it is essential to protect the future of pre-1919 sandstone tenements.

On the face of it, these old tenements would appear to be good examples of difficult to retrofit built form archetypes. The work is difficult to organise, relatively expensive because of the age and specifics of the properties, and many will be likely to face additional technical problems delivering high standards of retrofit (as is examined later in this report). There is also scarcely any reliable or robust evidence about tenement retrofit. The city council is developing a tenement retrofit strategy and at the heart of it is the fundamental concern that as a class of housing and neighbourhood, pre-1919 tenements may be too difficult to retrofit, and many will have to be demolished. This is the case despite the increasing recognition of the embodied cost of carbon emissions associated with demolition and replacement new build (again, a key point returned to later). This is why there was such interest in the Niddrie road project and the lessons regarding the retrofit of older housing that it could produce. This interest grew beyond Glasgow, to Scotland and to an international scale (Niddrie road featured positively in COP26, held in Glasgow in the autumn of 2021).

The Project and the Evaluation

Figure 1 below shows the 107 Niddrie Road site (the block with the red door in the photo nearest the camera) before work started in 2020, and after the retrofit works were carried out, in 2023. This is a standard four storey block of eight small flats located near the north side of Queens Park and the arterial Victoria road, key places in the south side of the city close to the M74 motorway. The specific site is two tenement blocks away from the entrance to Queens Park railway station. The entire locus is completely dominated by pre-1919 sandstone tenements. The property was constructed in 1895.

How did the project (and linked evaluation) come about? Southside HA had successfully acquired ex-PRS properties in Glasgow as part of the city council's programme to return social housing to neighbourhoods with a preponderance of problematic private renting. In 2019, 107 Niddrie road emerged as a candidate for a further acquisition. The eight-unit property had seven units owned by one private landlord. In order to make this tenement block work as social renting, Southside employed John Gilbert Architects to consider options for the necessary refurbishment work. Initially, they looked at a basic refurbishment, and a model that would approach the emerging energy efficiency standard for social housing, known as 'EESSH2' (which would, among other things, require all properties to achieve an EPC rating of 'B').

However, at this point, Patrick McGrath, the director of Southside HA became aware of the SFC Climate emergency competition; he thought that this might be a way to promote tenement retrofit with wider lessons for the sector and that built form. Furthermore, the attachment to a high-quality research evaluation might actually help secure funding to take this project to a higher level. John Gilbert Architects suggested a more ambitious third option for the retrofit – EnerPHit, which would mean seeking to deliver fabric first high-level insulation, some remodelling and other works to reduce radically energy demand and hence fuel bills, while at the same time approaching genuine net zero. Elsewhere in Glasgow such a policy had been successfully developed in a multistorey retrofit by Queen Cross HA - but no-one had attempted this with a pre-1919 tenement.

Figure 1: Photos of Niddrie road, pre works 2020, and completed, 2023

McGrath contacted Ken Gibb, the director of the ESRC UK Collaborative Centre for Housing Evidence, at the University of Glasgow. They agreed to explore putting a bid to SFC together. In under two weeks, they built a team with key support from John Gilbert Architects, the city council, CCG Ltd, and an academic team from CaCHE's Glasgow-based academics and a professor of architecture, now at the University of Strathclyde, Tim Sharpe. Although CaCHE had never worked in this area, the research bid was successful and launched at the end of February 2020, three weeks before the first Covid-19 lockdown.

EnerPHit is the 'established Standard for refurbishment of existing buildings using the Passive House basic principles and components' that are normally focused on new build (Sludd, 2017). There is a recognition that retrofitting existing buildings is likely to be more challenging than when starting afresh – you have to work with what you have got with existing properties.

The five principles of the Passive House Standard are nonetheless used to achieve the EnerPHit Standard; optimising :

(1) Thermal Insulation levels

(2) Thermal Bridge Free design and high thermal performance

(3) Passive House Windows, with very low air-leakage through the building

(4) Airtightness levels, utilisation of passive, solar and internal gains

(5) Ventilation with Heat Recovery system with highly efficient heat recovery levels, maintaining good indoor air quality.

However, as Sludd (2017 notes: 'the target values for some aspects are lower than that required to achieve the Passive House Standard; for example – Airtightness target for Passive House Standard is <0.6 air changes/hr@50, while the target for EnerPHit Standard is <1.0 air changes/hr @50'.

Source: Tracey Sludd (2017) Blog: What is EnerPHit? O'Leary Sludd Architects, Ireland. https://www.olsarchitects.ie/journal/2017/what-is-enerphit

Lockdown brought the construction industry and most normal working to a halt. At this stage, the actual built retrofit project was only designed in outline with many substantive decisions still to be made. The project did not have planning permission nor building control warrants, nor was the funding in place. But it did have the evaluation funding from SFC and a letter of comfort from the council. The retrofit and evaluation then proceeded in parallel with regular meetings between Gibb and Sharpe with McGrath and, from John Gilbert architects, Chris Morgan. Gradually, over a period of a year - all of these decisions were negotiated, agreed and construction finally began in the spring of 2021. In the rest of the report, we discuss the project's outcomes, but also specifics over the key decisions about the nature of the retrofit, seeking funding and its balance between GCC, the housing association (ie rental income and borrowing) and renewables funding from the Scottish Government, as well as planning permission.

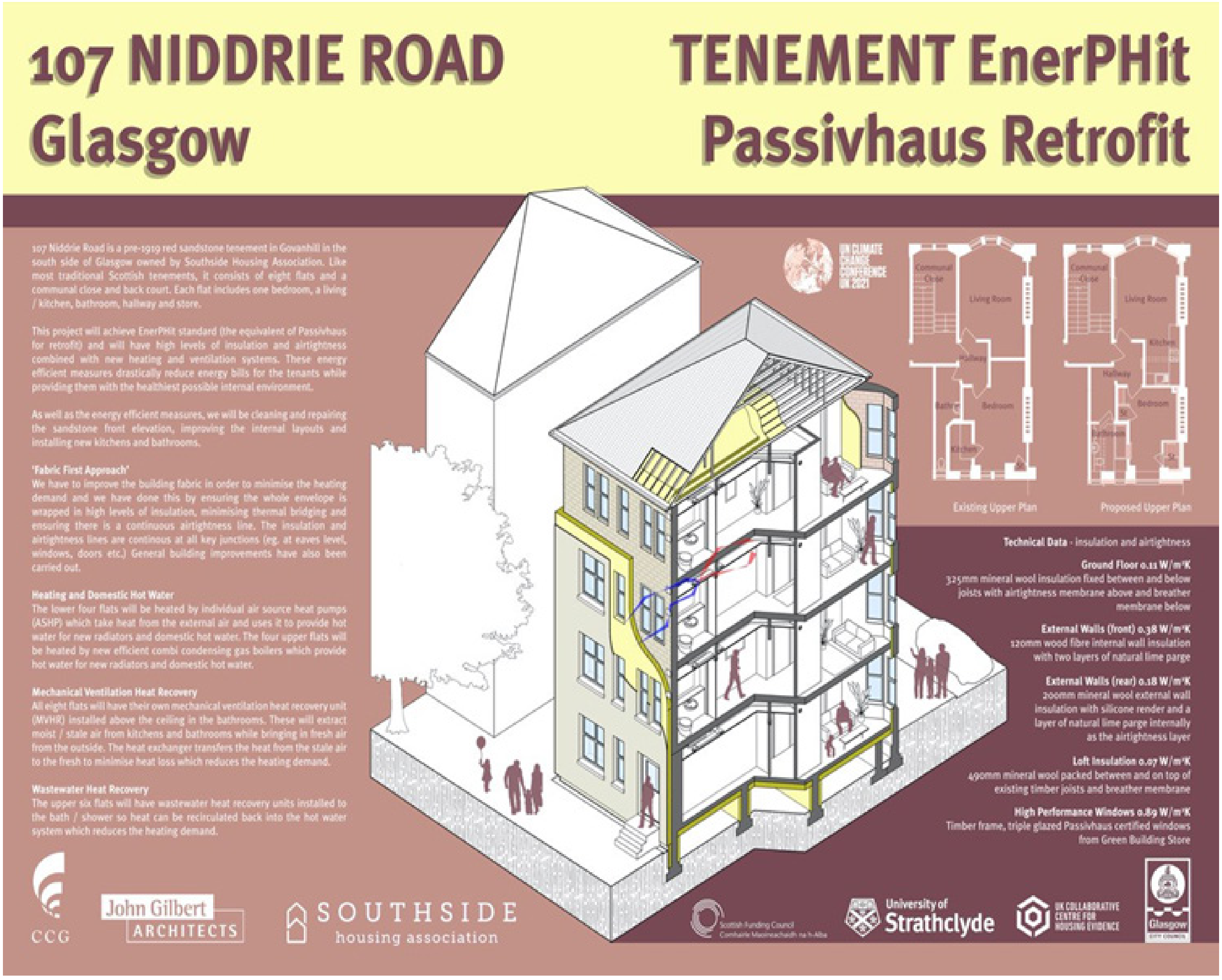
The project had been seen by many to be in danger for a while, and voices in the wider sector wondered aloud whether it would ever see completion. But in fact, this sense rapidly switched once construction began, to a demonstration project of great interest to many. Visitors from local and central government, UK and international, visited the site frequently, as did the media. A video made by the University about the project and evaluation was watched thousands of times[1] and there was great demand for presentation and public speaking about the project, for instance, during the 2021 Festival of Social Sciences around the time of COP26. Niddrie road has now won a number of architectural, design and green awards as well as having some prominence

1 The 2021 video can be seen at: https://housingevidence.ac.uk/news/a-blueprint-for-energy-efficient-traditional-tenements/

at the COP meeting. Eight social tenants finally moved into their new retrofitted homes in the autumn of 2022.

Figure 2 is the project diagram for the retrofit construction project. It sets out the main elements of the work undertaken.

Figure 2 Diagram of the Project Works



The evaluation itself was designed to have several interlocking elements:

- Evaluability assessment workshops with stakeholder within and outside of the immediate project partnership, that developed a theory of change and also produced genuine buy-in to the evaluation form the outset, in support also of future important data and interview requests.

- A process evaluation focused on the key decision-making processes that occurred from 2020-22, and would we hoped generate a set of learnings for future tenement retrofits.

- A full social cost benefit analysis using Green Book good practice and monetised carbon cost estimates, sensitivity analysis and two full counterfactuals to assess costs and benefits over a thirty year life.

- A technical assessment of energy consumption and building performance to test, among other things, the extent to which theoretical performance expectations were met and if not, why not.

- Post-occupancy surveys of the tenants and their experience of living in and with dep retrofitted properties, especially, as it turned out, in the midst of a cost of living crisis focused around very high energy costs.

- A holistic summative assessment of all of these elements in this main report. What are the lessons, learning and implications of this study for the wider retrofit of older tenemental housing?

The Rest of the Report

After the introduction, the report proceeds in five further sections. Section 2 describes and analyses the decision-making process in real time and considers the wider implication for tenement retrofit strategy. Section 3 summarises the cost-benefit analysis (Higney and Gibb, 2022) and draws wider learning from its findings. Section 4 is concerned with the technical performance analysis. Section 5 goes through the post-occupancy survey. Both Sections 4 and 5 are interim updates, as the monitoring and further interview phases will carry on over the next few months. Section 6 pulls together key benefits and lessons from the project, also summarising the evaluation in the round, and concluding the report.

2.Process and Decision-Making

The Original Proposal to SFC

The SFC climate emergency collaborative challenge call came out in August 2019 with an October deadline later that year. Bids were to be led by Universities but be embedded on a consortium including business, public sector and other bodies. Creative and innovative partnerships were sought that would make evidence step change reductions in carbon emissions and help support the green economy. The call expected to fund up to two projects to a level of around £250,000 each. The Niddrie road team bid initially envisaged a multi-strand evaluation that would run over a calendar year. The October 2019 bid had a summary, which argued:

'A critical challenge to the carbon reduction targets is existing housing. Around 80% of the 2040 Scottish housing stock already exists, and a quarter of Scots live in tenemental housing, much of which is pre-1919 traditional sandstone vernacular urban housing. Glasgow is estimated to have more than 70,000 such tenement flats (Scottish House Condition Survey, 2018) and Scotland as a whole, 182,000. These buildings have significant cultural, historical and urban value, but also have the poorest thermal performance, having solid walls and no insulation. Many of these properties are in the private rented sector and face significant common repairs problems, let alone confronting policy makers and practitioners with retrofitting these buildings so that they can reduce carbon and extend their life as vital housing within the city. Solving this problem is a key priority for the city council and its stakeholders.

This collaborative project proposes refurbishing a typical (eight flat) Glasgow inner-city pre-1919 sandstone tenement (107 Niddrie Road) to a standard that tests the cost and efficacy of different comprehensive treatments to deliver a net zero carbon emissions by 2045 and to achieve 70 to 90% emissions reduction by 2030 and 2040, respectively…It will monitor the design, specification and build stages, appraising the various choices available to the Housing Association and its architects and other built environment professionals, and the key financial technical and policy drivers affecting choices, and identifying the barriers to performance, for example lack of constructions skills and knowledge, and a supply chain for appropriate materials and components… The subsequent multifaceted framework will involve carbon reduction measurement, technical assessments of different insulation, heat and power solutions, financial and wider public policy dimensions.'

The proposal also identified the following aspects. First, control of the flats provided the opportunity to experiment with a range of innovative solutions to the climate change targets that can be tested and provide a Glasgow-wide guide for property owners, design consultants, builders, policymakers, funders and residents. Indeed, full ownership allows for a whole building solution as an alternative to a flat-by-flat approach. At the same time, it is perfectly possible to undertake many individual property (i.e. specific flats) retrofits without decanting – depending on the nature of the work.

Second, the retrofit project sought to go beyond the Energy Efficiency Standard for Social Housing (EESSH), which would deliver the standard that according to the Scottish Government will " contribute to reducing carbon emissions by 42% by 2020, and 80% by 2050, in line with the requirements set out in the Climate Change (Scotland) Act 2009 (Scottish Government website)." John Gilbert Architects (JGA) suggested alternative standards that go further. One of these was an "EnerPHit" Standard for retrofit. This is the energy retrofit quality certificate, developed by the Passivhaus Institute. By adopting the EnerPHit approach, Significant energy savings of between 75% and 90% can be achieved for which the following measures prove to be particularly effective: improved thermal insulation, the reduction of thermal bridges, considerably improved airtightness, the use of good quality windows and mechanical ventilation with highly efficient heat recovery. The fact that the housing association had control of the entire block meant that EnerPHit could in theory be accredited (it could not be accredited for a single flat in a block).

Third, it was important to the team that unintended consequences were also identified and addressed, for example, possible Scottish climate effects on fabric performance, the reduction of 'performance gaps' between theoretical and actual performance which are well evidenced, and the need to provide homes which are healthy, affordable, and which can be effectively used by occupants.

Fourth, the proposal noted that there would be top-up funding required for the higher value retrofit projects described above, that was still in the process of being secured at the time of the proposal's submission. Clearly, the evaluation proposal required that the funding was secure. To this end, the evaluation team had a letter of financial support for the retrofit project from Glasgow city council.

Fifth, from a knowledge exchange and lesson learning perspective, the evaluation would provide learning for housing associations, other tenement property owners, funders, and policy makers - on measures to reduce carbon emissions and meeting climate challenge targets in pre-1919 tenements. It would also, at a strategic level, inform the City Council and the Scottish Government on the merits of particular policy interventions on this important segment of the housing stock.

Sixth, the evaluation proposal, if funded, would monitor the design, specification and build stages, appraising the various choices available to the Housing Association and its architects and other built environment professionals. The project partners would conduct a formal evaluability assessment to determine the precise evaluation approach taken. The subsequent multifaceted evaluation framework would involve carbon reduction measurement, technical assessments of different insulation, heat and power solutions, financial and wider public policy dimensions and occupant and user engagement. A rigorous programme of building performance evaluation would be conducted to ensure that the performance of the building was clearly evidenced. An important issue in this regard is the careful building-in of a test of the actual performance versus the predicted performance in terms of carbon reduction. One of the major shortfalls of current policies and regulations has been that targets are theoretical and set at design stages and rarely evaluated in use, thus it is important is to measure the 'pre' performance and compare it with the 'after'.

Seventh, While EESSH is the Scottish industry standard for social housing, it does have limitations, both technically and in the wider context of its financial feasibility for providers. There are reasons to argue that its carbon reduction benefits are overstated and EESSH relies on SAP which a) is not a predictive tool and b) is currently subject to revision. The partnership believed that it was therefore worth looking at a whole energy approach (e.g. including non-regulated energy). The most obvious approach at that point was EnerPHit..

Finally, there was the implied timescale in the proposal, which turned out to be extremely optimistic. The project was to begin in January 2020 working on the design options for the construction project with a view for the retrofit to go on site beginning March 2020. It was expected that site work will take six to eight months (completed August-October 2020). The proposal concluded that 'it should be stressed that having control of the tenement, the fact that it is empty and the partnership framework nature of the team carrying out the works means that many of the construction delays that might have been faced, can be mitigated, though it can never be completely ruled out'.

These points raise several issues and implications:

- The project was not fully funded at this stage, even though there was an important letter of support from the council.

- The project remained only partially specified – it would be determined in detail as the project evolved, but at this point it was not clear whether a deep retrofit, an EnerPHIt style retrofit or some combination would be attempted, even though the proposal could be read as implicitly supporting the latter course of action. This also meant that the actual works involved were, at this point, not yet chosen. It also implicitly meant that there would need to be planning permission and building control approvals sought, too.

- The shape of the evaluation is apparent, though key elements, like the cost benefit analysis and post-occupancy interviews, only arose precisely because of the subsequent evaluability assessment and partnership discussions (there was however always going to be economic analysis of some kind and a budgeted economics researcher was included).

- Even at this initial stage there was ambiguity and a lack of clarity about the additional costs associated with the different possible approaches – this was a theme that was to continue to feature over the life time of the project. As is frequently the case in these situations, the actual costs were quite different, although again this in part because of the choices actually made in the light of the circumstances confronted.

- Undoubtedly, SFC funded a project evaluation with many risks and uncertainties. In retrospect, the timeline looks heroic (even before we consider the delays that did occur as well as the pandemic). It is to their credit that the SFC stuck with the Niddrie road project, which did in the end deliver considerable knowledge and learning.

Evaluability assessment

This section is largely based on a draft report by Chng and Gibb, 2021). Evaluability Assessment (EA) is a systematic and collaborative approach to prioritising and planning evaluation projects. It involves structured engagement with stakeholders to clarify intervention goals and how they are expected to be achieved, as well as development and evaluation of a logic model or theory of change, and provision of advice on whether an evaluation can be carried out at reasonable cost or further development work on the intervention should be completed first. It can make the evaluations that are undertaken more useful through constructive engagement with stakeholders. This should in turn encourage the translation or mobilisation of research findings by ensuring that policy-makers and practitioners are involved from the beginning in developing evaluation choices from the outset.

EA involves a series of workshops aimed at achieving:

- Structured engagement with stakeholders to clarify the intervention or policy goals and how they are to be achieved.

- Development and appraisal of a theory of change, which describes how implementation of a policy contributes to change in longer-term outcomes, via change in a series of linked short- and medium-term outcomes.

- Development of evaluation priorities and research questions.

- Assessment of existing data sources and data gaps, thereby refining evaluation options.

- Provision of advice on whether an evaluation can be carried out at reasonable cost, or whether further development work should be undertaken.

This EA was facilitated and led by Dr Nai Rui Chng of the MRC/CSO Social and Public Health Sciences Unit based at the University of Glasgow. The EA comprised three online workshops, held between June and July 2020. This was to take place as face-to-face sessions between March and April but was postponed and subsequently held online due to the Covid19 pandemic. Stakeholders from the project were identified and invited to take part in the workshops. They included staff from CaCHE, John Gilbert Architects, Southside Housing Association, Scottish Federation of Housing Associations, Glasgow City Council and CCG.

The key messages of the Evaluability assessment were as follows:

- There was clarity about the purpose of the retrofit project and its wider value regarding learning lessons for wider tenement strategies seeking to effect climate change policy within Glasgow's built environment.

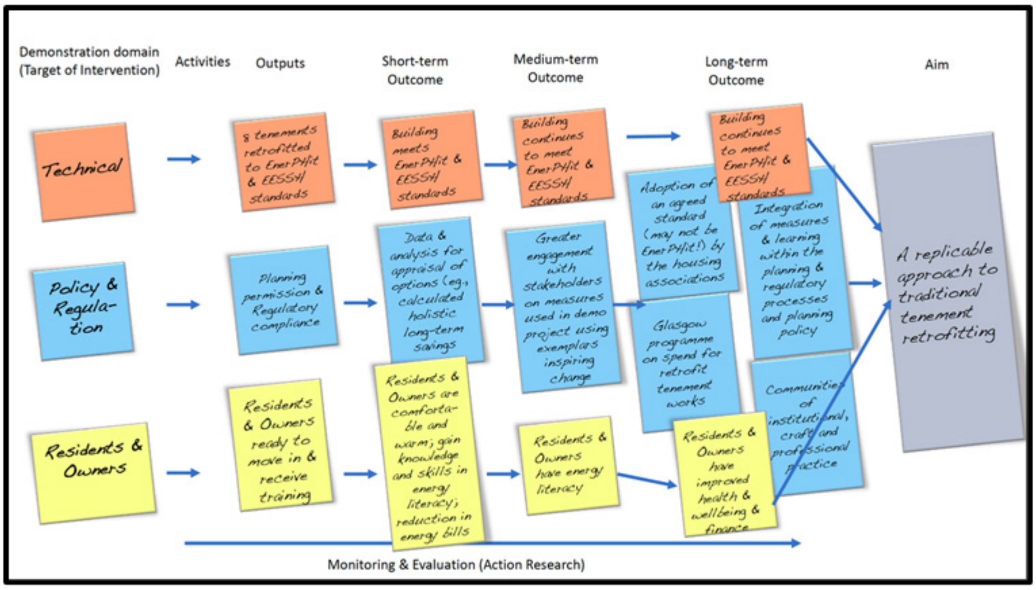
- It was possible to generate consensus about an underlying theory of change from the different perspectives represented within the group (figure 3 below, shows the original general logic model for the project as well as the EA's evolving theory of change, which distinguishes between different demonstration project domains: technical, policy & regulation, and residents and owners).

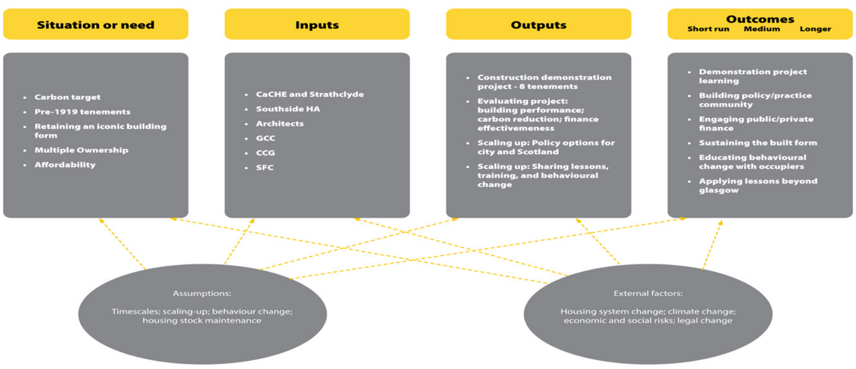
- It was important to situate this project in a wider context of Glasgow's housing and neighbourhoods, the different interests at play, and the different time periods of horizons that retrofit plays out over.

- It was important to recognise that the EA took place in a context where the evaluation has been funded and outlined in general as a multifaceted approach, but not the fundamental shape of the evaluation nor the precise details of the retrofit work itself. Thus, the focus was more on the form of evaluation arising from the theory of change than it was about whether or not to evaluate.

- The assessment concluded that a holistic evaluation would combine quantitative work (cost benefit analysis, technical performance research) with qualitative work (post occupancy survey; elite perspective interviews) and a focus on the real time action research of decision making that moved the project from a general in theory approach as laid out in the original research proposal, towards what can really be done when the projects meets a series of constraints and challenges on the ground.

Figure 3 Evaluability Assessment Theory of Change and Initial Logic Model





Real Time Decision-Making

In the period between bidding for the evaluation and starting the project, the team agreed to pursue an EnerPHit style retrofit at Niddrie Road. This would be the first traditional tenement retrofitted to the Passivhaus certification for retrofit. This ambitious decision meant that there would be a deep retrofit demonstrator, that there would need to be coaching and support of residents, that additional finding would be required and, this would both limit the discretion of what could be done, but also leave a number of choices yet to be made. The EnerPHit standard was made possible because of the control of the block as a whole (it cannot be used for individual flats within a common property). The standard also offered the opportunity to make radical reductions in energy demand and hence in energy costs and emissions.

With a fabric first focus, several decisions were left initially undecided regarding specific components (discussed further below). However, EnerPHit also ruled out certain options e.g. adopting window shutters which would give discretion to residents that goes against the Passivhaus principle. At the same time, the model requires certain things that would need to be agreed with planning, and of course to be fundable. Most important, this would require airtight insulation to conform with the challenges of solid wall sandstone tenements. In addition, airtight insulation also requires properly functioning ventilation. In short, the choice creates challenges as well as a high standard that may turn out, as in practice it did, not to be possible to achieve 100% of that stretching standard.

A second early decision, emerging in this case, from discussions in the evaluability assessment, was to make the economic assessment a formal cost benefit analysis (CBA) based on orthodox Green Book and BEIS (now DENZ) working assumptions on things like the cost of carbon emissions. The CBA would be mainstream and less challengeable on economics grounds (minimising claims of special pleading in how it is designed, etc.), but would also involve two fully worked up counterfactuals using John Gilbert Architects energy performance modelling data, the project's QS data and, where necessary, good practice extraneous information. One counterfactual was to demolish Niddrie Road and replace it with a modern tenement of similar size and scale. The second counterfactual would be to retrofit the tenement block to something equivalent to the then proposed EESSH2 standard – a deep retrofit but not to the depth of the EnerPHit base case. Note that the project financial options are all based on a combination of real and modelled data rather than fully delivered actual costs. Comprehensive sensitivity analysis would help assess the impact of the data strategy followed. The next main section of the report looks at the CBA element more closely.

From the beginning of the project, the principals of the evaluation (Gibb, Sharpe, Morgan and McGrath) met regularly to monitor progress, design out elements of the evaluation and debate and decide on key elements of the project that remained unsettled. This was assisted by the delayed start to construction and the final securing of funding, but it allowed for many substantial meetings, roughly monthly for two and a half years, to go through the detail and record key decisions throughout the project. The mood of these meetings varied considerably as a result of setbacks, positive developments, delays, disagreements with external stakeholders and opportunities assisting what might be achieved.

Covid-19 impacted on the project in both direct and indirect ways. The lockdown periods stopped construction completely and changed the working methods of all parties by moving them to work from home and online. Only the first lockdown had a major impact on site working, and in any case much of the work was only preliminary because of the delays in achieving funding, planning permission and detailed project decisions. As was suggested above, the capacity to have regular monthly Zoom meetings supported the development of a genuinely collegiate ethos to the evaluation.

Indirectly, there were also other major lockdown impacts on the project. Glasgow city council was significantly impacted by shift to working from home, and it took some time to resolve both financial and planning questions. Understandably, the council triaged its housing investment decisions and focused on priorities like the disbursement of funds for the annual SHIP that spent capital finds on new affordable housing supply. A single tenement project retrofit, while supported, was not the same kind of priority. This meant that the housing association had to delay agreeing its own financial contribution through private lending and rents with its board of management, until the council confirmed its willingness to make a specific financial contribution to the Niddrie Road retrofit. But in time they did so, and this enabled Southside HA to move forward with their funding. The Covid-19 lockdowns also impacted on the planning service and building control, both of which were essential to the retrofit project moving off the drawing board and into site work. However, as we discuss below, the sign-off with the planning service created a specific set of challenges for the project.

Niddrie road was the first pre-1919 tenement to seek to undertake a comprehensive deep level of retrofit. While it was funded and supported by the council's housing division, this was in the knowledge that this project would need to meet planning approval before go-ahead. Niddrie road has no special planning status – it is not in a conservation area. Rather, the project sits within the general Glasgow planning policy for tenements. The retrofit has to conform to the application of that policy as applied by the relevant town planners in the city. In simple terms, the crux of the policy seems to be to ensure conformity with the external features of sandstone traditional tenements, thereby excluding certain building changes. The question therefore became can the retrofit be pursued to the standard required and still be consistent with the tenement planning policy's requirements?

Planning guidance initially ruled out external wall insulation (EWI) at the rear and partial gable end of the block. It also later argued that residential air source heat pumps could not be used if attached to the rear of the building at windows. It also ruled out photo-voltaic panels on the roof, and it did not approve proposed wider gutters. Eventually, given the presence of other tenements in the same area with approved external wall insulation to the rear of properties, the planners accepted the EWI at Niddrie Road. Heat pumps were also approved but only if they were located in the back yard on the ground (with timber fencing installed around them) and not through units attached externally to the building (in practice, this meant the top two floors could not have ASHPs). Planning approved major elements of internal work e.g. internal wall insulation at the front of the building, external repairs and cleaning up of the sandstone frontage, some roof repairs and major work on internal joists, and there was some enlarging of windows at the rear, now triple glazed[2].

There are important lessons from the planning permission process for the future of tenement retrofit. There has to be a clear steer from planning that supports the goals of retrofit while seeking to maintain the external appearance of particularly the sandstone fronts of the buildings. The Niddrie road project eventually was allowed to proceed with EWI but the renewable energy systems inherent to the net zero policy have to be supported and strategic decisions made about how this can progress for future tenement retrofit.

Decisions about specific components were made after the evaluation project began and at times occurred in connection to these funding and planning contexts. Important examples of these decisions are briefly outlined below:

- **Joist removal.** It is likely that in future more tenement buildings will be insulated internally to retain their front external appearance. However, once this is done, walls which have been kept warm and ventilated internally for over a hundred years can no longer operate in the same way, they become cold and in some cases unventilated. While the stone walls may survive these conditions, anything organic embedded in the walls may not. Advanced 'WUFI' hydrothermal calculations were run to ascertain if the floor joists in the north, street facing wall were at risk. Even with a vapour permeable insulation they were, so the floor joists were removed and a perimeter beam installed. The wider lesson is that this problem is a risk for most internally insulated older buildings and may cause damage and costs in the future.

- **Chemicals and natural approaches to protect internal air quality.** There is a good deal of low level toxicity built into many conventional building products and finishes, such as paints. These can create or exacerbate health

2 The team initially proposed windows at the back with a greater glazed area, but this was not supported and the end solution was to remove the stone mullion but use a (smaller) timber mullion. This reduced solar gain and increases heat requirements by a surprising amount, but was felt to be a reasonable compromise.

problems for those who are more vulnerable. At Niddrie Road several changes were made to avoid some of the worst offenders. The team used natural woodfibre insulation and lime plaster in lieu of plastic membranes but the most important has been to avoid the widespread use of chemicals which were initially proposed to treat the timbers in the building. The decision was to replace the damaged wood but at the same time, protect the remaining timber by maintaining conditions that are not conducive to decay and insect attack.

• **Responding to realised condition problems once work started.** The condition of the tenement's plastering was found to be much worse than anticipated and required going back to the brick to redo it with an airtight lime plaster.

• **External and Internal insulation within the project:** the project involved high levels of insulation to roof, floors and walls, with external insulation installed on the outside of the walls at the rear, but inside the walls facing the street. Windows were replaced with triple glazed alternatives and a lime plaster was used throughout to drastically improve the levels of airtightness. MVHR (Mechanical Ventilation with Heat Recovery) was used to recycle warmth from outgoing air, and waste water heat was also recovered. The street-facing stonework was carefully restored and improvements and repairs made to the roof area.

• **Mechanical ventilation (MVHR)**. High performance MVHR has been used to constantly bring in fresh air and extract humid, spent air. Ducts were run to every room so that there is no risk of excess humidity building up.

• **Waste water heat recovery.** When the space heating demand is reduced by as much as was anticipated at Niddrie Road, then the biggest component of most peoples' fuel bills is their hot water costs. To reduce these costs, the team designed wastewater heat recovery systems which use the heat from the water going down the shower or bath drain to pre-heat the cold water about to be used. In this way, costs (and carbon emissions) of hot water can in theory be reduced by around 40%.

• **Remodelling.** In common with many retrofits, a large part of the actual work involved re-organising the internal layouts to create more useable and pleasant spaces in line with the client's requirements (see figure 2 above).

• **Air source heart pumps.** While not initially part of the schema for the project, the team agreed that it made sense to include them if and where possible. ASHPs were constructed into the ground and first floor with gas boilers in the upper two floors. This was a direct result of the planning decisions – the hot water piping could only reach the first two floors from the back yard with sufficient heat distribution retained to meet the manufacturing warranty. The ASHPs were funded by the Scottish Government who were clear that would have funded all eight units if a method to do so had been available. However, it was possible explicitly to compare and contrast the relative performance of the two forms of heating.

Finally, a requirement of EnerPhit is that the whole block is tested for air leakage at the same time, to allow gaps to be identified and sealed while the entire airtightness layer is exposed and easy to access. The contractor opted to complete the upper floors first and rely on flat-by-flat testing as they moved down through the building, completing upper floors as they went. This meant that when the whole block was being tested towards the end of the project, it was only possible to access the airtightness layers on the ground floor, with all upper floors now covered up and completed. Despite extensive efforts on the part of both the design team and contractors to improve airtightness on the ground floor, it was not possible to achieve the requisite airtightness level over the whole block. It was agreed by all that with time pressing it was not reasonable to open up the upper levels so the necessary level of airtightness - and EnerPHit certification - was not achieved. As we discuss later, even without certification, we can still test, measure and learn from critical aspects of the impact of the work on thermal comfort, fuel bills, health benefits and other critical features of the deep retrofit.

An important lesson taken from the process has been to ensure that the ability to access and test the airtightness layer across the whole block is built into future contracts.

UK COLLABORATIVE CENTRE FOR HOUSING EVIDENCE

3.Cost-Benefit Analysis

Aims

This stage of the project, undertaken by Anthony Higney and Ken Gibb in 2021-22, sought to bring a strong sense of the net social benefits associated with the project, given its relatively high costs, and to also lay down a sense of the overall value of this type of intervention compared to two plausible counterfactuals, drawing extensively on good practice within government when undertaking 30 years life social cost benefit analysis with explicit environmental sustainability dimensions. This element of the work provides considerable additionality to the wider evaluation. Below, we briefly explore the methods, elements, findings and sensitivity analysis, detailed in more depth in Higney and Gibb, (2022).

The Approach

The approach taken followed an orthodox environmental social cost benefit analysis, adopting Treasury Green Book principles. The idea was 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 (NPV). 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 aims to identify all 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.

Cost benefit analysis then proceeds by comparing the object of study to likely similar counterfactuals of different choices. This means 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 EESSH). 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. In more detail, the EnerPHit retrofit was modelled against two plausible counterfactuals:

1. Retrofit to EESSH2 standard

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"[3] option , 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 be repairs and EESSH2 of the interior.

2. New Build (and Demolish)

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

3 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.

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.

Table 1 provides a summary of the costs and benefits considered in the analysis, and whether they are included in the NPV. For costs, the items included 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 the study included: 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). Not considered in this cost benefit analysis is 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 did we consider jobs resulting from construction and maintenance, as the money used on construction could potentially create jobs in other ways.

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

The different options are assessed under three different scenarios: low, central, and high. Low, Central and High scenarios are used in UK government appraisal of energy and greenhouse gas emissions savings [4]. The

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

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. 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 scenarios [5]. 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. 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.

The overall capital cost of the project at funding was £1.091 million. The construction project was funded by a combination of Glasgow city council financial support (£445,000), 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 original cost per unit of the retrofit and refurbishment was £88,000 consisting of £44,000 for the basic refurbishment of the vacant properties (nb -this is likely to have increased in the nearly two years of delay for the works) plus £32,000 for the initial cost of the EnerPHit retrofit and £12,000 for contingencies. Once on site, the costs per unit rose beyond £100,000 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.

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 EESSH2 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 John Gilbert Architects using Passivhaus 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

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

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 area[6]. We therefore use the PHPP model, as we believe it will give more accurate results.

Central Results

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

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. 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 making[7].

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

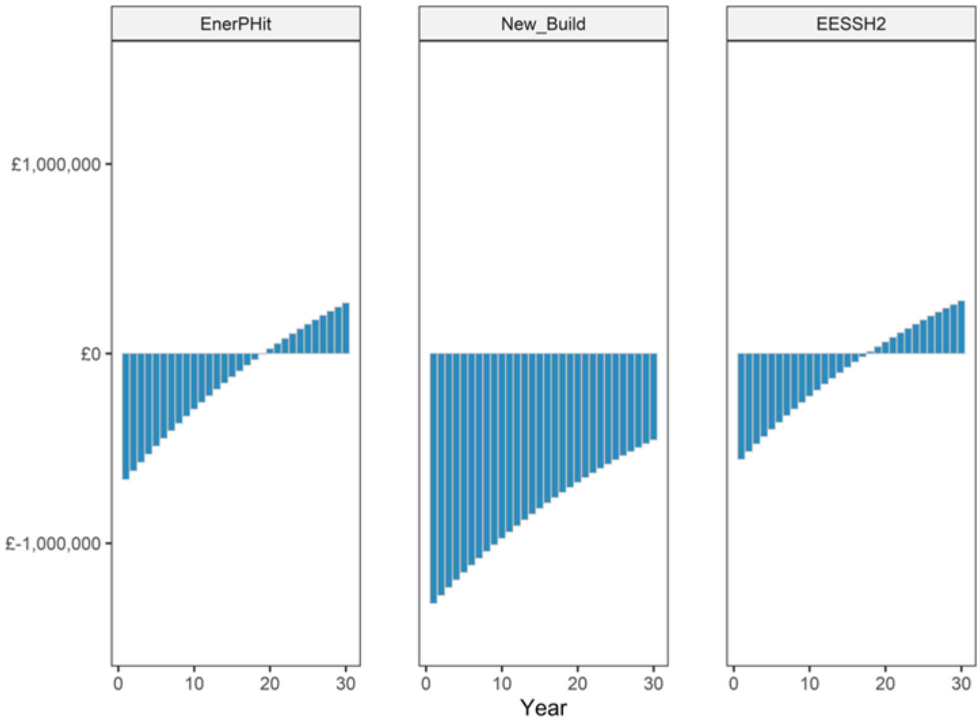
6 See here for a fuller comparison of SAP and PHPP https://www.passivhaustrust.org.uk/guidance_detail.php?gId=44

7 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.

estimates are similar. The EESSH2 is preferred to the EnerPHit in the low scenario, marginally preferable in the central scenario, while the EnerPHit is the best option 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 Book [8]. 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 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

8 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).

is also above one when distributional weighting is used.

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

Sensitivity Analysis

In cost-benefit analysis it is good practice to test how results change if certain assumptions are changed. This is called sensitivity analysis. We carry out a wide range of sensitivity checks and report them in the 2022 working paper. Overall, the sensitivity work found that the 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 option 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.

Main Messages

The analysis found that, in social net present value terms, the high-quality EnerPHit retrofit performs similarly to the less expensive, but also less energy efficient EESSH2 retrofit. The EnerPHit retrofit provides more benefits but is also more costly. 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.

Although the costs are relatively high for Niddrie road, even when we decompose the different elements of the project and focus just on the retrofit, the benefits are considerable and far outweigh demolition and rebuilding.

Adopting conventional government-approved methods to undertake the CBA, the evaluation strengthens the case for embedding carbon emissions costs and scenarios into appraisal of retrofit options for older housing stock like traditional tenements. However, while the cost-benefit analysis shows than investment in retrofitting provides positive social value, this does not necessarily mean it will be viewed as financially beneficial by landlords or owner-occupiers. This is because some of the benefits, such as lower greenhouse gas emissions, are not completely captured by the homeowners. Therefore, left to their own devices, owners may under-invest in retrofitting measures without further regulatory or financial incentives. Finally, while we do not expect or assume that the good practice approach we have undertaken can be readily replicated, we are sure that above a minimum capital cost threshold for a project, the wider application of stripped-down robust models applying standardised assumptions and parameters is perfectly possible and indeed important to the future of retrofit decision making and use of public funds.

4.Interim Results of Energy and Environmental Monitoring Consumption and Performance (February-August 2023)

Background

This section describes the energy and indoor environmental quality monitoring work package led by the University of Strathclyde. There are more than 75,000 iconic pre-1919 sandstone tenement homes in Glasgow, which represent a major challenge to achieving net zero. This demonstration project, including its evaluation, is a collaboration between industry, the voluntary sector and academia. The project will provide shared learning about how deep retrofit of these older buildings can be achieved. Figure 4 shows selected elements of the internal fabric work now underway on-site.

Figure 4. The construction process of the tenement home in Niddrie Road.

Source: John Gilbert Architects.

This project is a demonstration of a deep retrofit of one such typical tenement, works which are also the subject of a careful ongoing research evaluation. The tenement retrofit concerns eight single-bed flats in one traditional tenement close to Niddrie Road. The retrofit of the property was designed to meet EnerPHit standard (the Passivhaus equivalent for retrofit). The retrofit was undertaken by a team consisting of the Southside Housing Association, John

Gilbert Architects, and CCG Construction Ltd. The retrofit works were completed in 2022 with the occupants moving in between October to November 2022. The monitoring project was scheduled to start in November 2022, but was delayed until February 2023.

A key aim of the project was to gather in-use data on the actual performance, and Strathclyde University have commenced a programme of Building Performance Analysis to gather data on the energy and environmental performance of the building. This section provides an interim summary of the data collected to date. It should be noted that the work is on-going, and a more complete report will be provided once we have 12 months of complete data.

Aims and objectives

There are three main areas of current investigation. These are:

1) overall energy consumption,

2) the environmental conditions within the properties, and

3) the risks of interstitial moisture within the construction due to the placement of insulation.

This report provides interim data that addresses the following objectives:

- To understand occupant satisfaction with the building by conducting a survey to understand the occupants' perception of the energy, indoor environment and engagement with the building systems.
- To gather evidence of the potential energy savings by measuring the energy consumption of the building, particularly that related to space and water heating.
- To understand the impact of the retrofit on the indoor environment and occupant comfort by measuring the indoor temperatures and relative humidity.
- To understand the impact of the ventilation system through the measurement of the indoor carbon dioxide (CO_2) as a proxy for ventilation.
- To evaluate the moisture risk in the construction by monitoring the interstitial moisture of the building fabric.
- To conduct a technical analysis on the viability of the EnrPHit standard as a method for retrofit in Scotland.

The monitoring project was due to start after occupancy in November 2022, but the start was delayed due to issues with gaining access and permission from occupants to install monitoring equipment (see below). Hence, the monitoring period started in February 2023 and this section reports on the results to date.

Methodology

The project uses a Building Performance Evaluation methodology that has been developed across a range of projects. In this case, this includes the collection of quantitative and qualitative data to evaluate the performance of the Niddrie Road tenement retrofitted property. The project undertakes physical testing of the building and its systems, gathers data on occupancy and use, and collects measured data on energy use and environmental conditions.

This report describes the findings of the monitoring period between February 2023 to August 2023. While there are 8 flats in total, only 6 engaged with the monitoring campaign from January/February. A subsequent flat was engaged in May 2023, but this was left out of the scope of this report as there is limited data for comparison.

Quantitative data collection

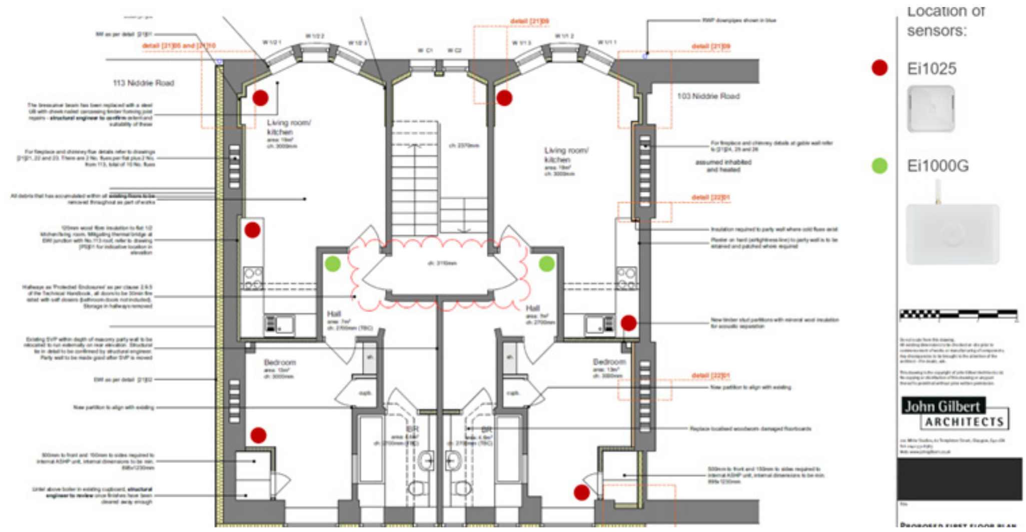
The reported data is the energy use between February and August 2023, and the indoor environment (temperature, relative humidity and CO2) between February and June 2023. Energy consumption is based on fiscal meter readings. The indoor environmental quality was monitored using the AICO Ei1025 (temperature [-10°C to 40°C], relative humidity [15%RH to 95%RH] and carbon dioxide) monitor. The system requires a gateway (Ei1000G SmartLINK) connection that uses a GMS network to transmit the data (Figure 5). An individual system was installed in each of the flats and a unique code was assigned for data analysis.

Figure 5 AICO Ei1025 (left) and Ei1000G (right) indoor environmental monitoring system used.

Source: www.aico.com

The monitors are located in the bedroom, kitchen and living room of each flat and the data is collected at 15-minute intervals. The placement of the sensors was made following the recommendations of international standards (BS EN ISO 16000-1:2006 and ASTM Volume 11.07 Air Quality - D7297-14) and avoiding discomfort to the occupants. The monitor location is described in Figure 6.

Figure 6 Floor layout and monitors' location.



Source: layout – John Gilbert Architects

The use of the AICO system allows the collection of the data remotely and visualisation through AICO's HomeLINK dashboard. The data can be downloaded in *.cvs files for statistical analysis and further processing for data visualisation in SPSS and Excel.

It was intended to collect monthly energy consumption through the smart meters installed in the properties, however, this proved to be challenging. It was expected that all properties would be fitted with smart meters, but this was not the case on completion, and some were installed later on. Furthermore, not all the occupants knew where to find their Meter Point Administration Number (MPAN) and some did not have access to energy bills where this could be corroborated. Consequently, the energy consumption was collected through manual readings which took place on the day when the sensors were installed and a subsequent reading on the 23rd of August 2023. The energy consumption was extrapolated to annual consumption based on individual energy use for each flat and the number of days between the readings. Access to smart meter data at a later point will provide access to historical consumption data.

As part of the quantitative data collection, there is scheduled performance monitoring to evaluate the efficiency of the heat pumps, Mechanical Ventilation with Heat Recovery (MVHR) and Waste Water Heat Recovery (WWHR) systems. This has not been currently possible as heat flow meters which were due to be installed during the construction phase were not fitted, so these will need to be installed at a later date. This is scheduled for the 2023/2024 heating season and will be conducted by the Energy Systems Research Unit (ESRU) at the University of Strathclyde. This will include monitoring of the flow and return temperature of the MVHR units, along with energy consumption of the fans to identify system efficiency and coefficient of performance. The wastewater monitoring will measure the water supply and wastewater temperature to identify the recovery performance. Sub-metering of the heat pumps will allow the collection of energy consumption of these units to separate out space and water heating loads. In this interim report consumption of these units is estimated by comparing electrical consumption in the flats with gas boilers.

Qualitative data collection

The project looks at the relationship of the occupants to energy and the indoor environment. We used a survey to collect the occupant's perception of the indoor environment, the use of the windows and the ventilation system and overall satisfaction with the energy use.

The survey had seven sections in three themes: household characteristics, ventilation & occupants' engagement with building systems and indoor environment. The first section collects information about the household characteristics. The second and third sections collect data about the occupants' understanding and knowledge of the ventilation characteristics of the building and the window and door opening pattern. Section four looks at the engagement with the ventilation system (MVHR). Section five collects data about the advice that the occupants were given when moving to the property, to understand further the level of engagement with the building systems, and to ascertain if the occupants had any prior knowledge about the building systems. Section six collected data about the indoor environment and assessed the occupants' knowledge and engagement with the CO2 monitor in the bedroom (required by the Scottish Building Regulations). Finally, section seven looked at the occupants' perception of the indoor environment, including indoor air quality, thermal comfort, natural light, and noise levels inside of the flats.

Ethical considerations

Ethical approval was obtained through the University of Glasgow's ethical review and consent from each of the occupants was obtained before any research and installation of monitors could start. While the project was in contact with participants, the monitoring did not seek to collect personal information of the participants, but rather about the building and its use. Hence, there were procedures in place for qualitative data collection (i.e., use of the windows and engagement ventilation system) to avoid the collection of personal information.

Limitations and challenges

There were several challenges which delayed the start of the monitoring campaign, scheduled in November 2022. Given the late completion of the project, we want to ensure that occupants had had time to move in and settle in their new homes and familiarise themselves. We also encountered some difficulties in gaining access to some properties, and there were also some delays with equipment procurement and initiation. Initially, the monitoring period was delayed to December 2023 but was further delayed to January 2023 as the researcher had COVID-19 in December 2023 and the Christmas holiday period.

One of the key challenges for the project was initial engagement with the occupants. They received a letter with a printed copy of the participant information sheet explaining the project and why they had been selected for the study. This was followed by a phone call and a site visit for participant recruitment and engagement, which resulted in a better way to engage with the participants.

Further challenges were related to access issues and the monitoring instruments. In terms of access issues, the Housing Association provided the names and contact details of the participants. However, by December 2023 some of the participants had already changed their contact details and it was difficult to communicate. Moreover, the first language of some of the participants was not English, and their English was not at a conversational level. In such cases, some of the participants asked friends or family to be present to translate and initial conversations were made through text translated using online tools. This has resulted in difficulties in following up, for example with further energy readings and making appointments for visits. Two households were difficult to engage for the project. One of them was recruited later (May 2023) and the other has not engaged up to the writing of this report. Once on-site, there were some technical challenges as the phone signal strength required to transmit the data from some of these monitors was weak or very limited.

A key element in this interim report is that all data is incomplete, so results will require further verification and analysis before firm conclusions may be drawn. This is particularly important for energy consumption data. This is based on meter readings for a limited period, and there are several uncertainties associated with this. Firstly, this means that estimates of annual consumption are extrapolated from a reduced period between February and August. There will be variations in weather which may account for differences in estimated and actual consumption. Secondly, due to the lack of sub-metered data for the flats with heat pumps, estimates of the space and water consumption are made from observations of electrical use in the flats heated by gas which may not be an accurate representation, and estimates of hot water consumption is based on PHPP assumptions. Thirdly, it is clear from the meter readings and environmental conditions that there are significant variations in patterns of use and consumption, for example flats with higher electricity use due to extended periods of occupancy and use of electrical items in the homes, and homes which prefer higher temperatures. There are also some reports of excessive use, for example heating systems being left on during absences. As result some caution is needed when making comparisons with target figures and further analysis will be required when more complete data is available.

Results

Energy use

The energy consumption (electricity and gas) of the flats is described in Table 6 and estimated energy prices (excluding standing charges) in Table 7. These are based on the recorded meter readings between February and August 2023. The average electricity demand for the 6 flats was 23.94 kWh/m^2 for this period. However, this figure varies when comparing the flats that use electricity as a source of heating via the heat pump against those that use gas. For flats with electric heating, the electricity consumption between February and August 2023 was 29.62 kWh/m^2 and for those using gas for space and water heating it was 18.26 kWh/m^2. For the flats using gas heating the average consumption during this period was 33.20 kWh/m^2.

Table 6 Energy readings from the different flats.

House-hold	Electricity (kWh)		Gas (m^3)		Days between readings	Energy demand (kWh/m^2 between February to August 2023)		Estimated annual demand (kWh/m^{2}y)		
	Initial reading	August reading	Initial reading	August reading		Electricity	Gas	Electricity	Gas	Total
H1	1042	2801	n/a	n/a	219	42.39	n/a	70.64	n/a	70.64
H2	2196	3184	n/a	n/a	212	23.82	n/a	41.00	n/a	41.00
H3	997	1985	n/a	n/a	220	22.67	n/a	37.61	n/a	37.61
H4	199	956	45.79	190.31	222	17.36	35.30	28.55	58.04	86.58
H5	897	1540	92.81	208.20	216	14.75	28.18	24.92	47.63	72.55
H6	241	1229	87.18	217.13	229	22.67	36.13	36.13	50.08	86.21
Av						23.94	33.20	39.81	51.91	65.77

Source: Authors.

Table 7. Estimated energy prices based on the Ofgem.

	February to August 2023 price		Estimated annual price	
	Electricity	**Gas**	**Electricity**	**Gas**
H1	£ 527.70		£ 879.50	
H2	£ 296.50		£ 510.48	
H3	£ 296.50		£ 491.92	
H4	£ 227.10	£ 123.12	£ 373.39	£ 202.43
H5	£ 192.90	£ 98.31	£ 325.97	£ 166.12
H6	£ 296.50	£ 126.02	£ 472.59	£ 174.68
Average	£ 306.20	£ 115.82	£ 508.97	£ 181.08

Energy price based on the Ofgem energy price (July to September 2023): electricity £0.30 per kWh and gas £0.08 per kWh. Price excludes standing charges.

Source: Authors.

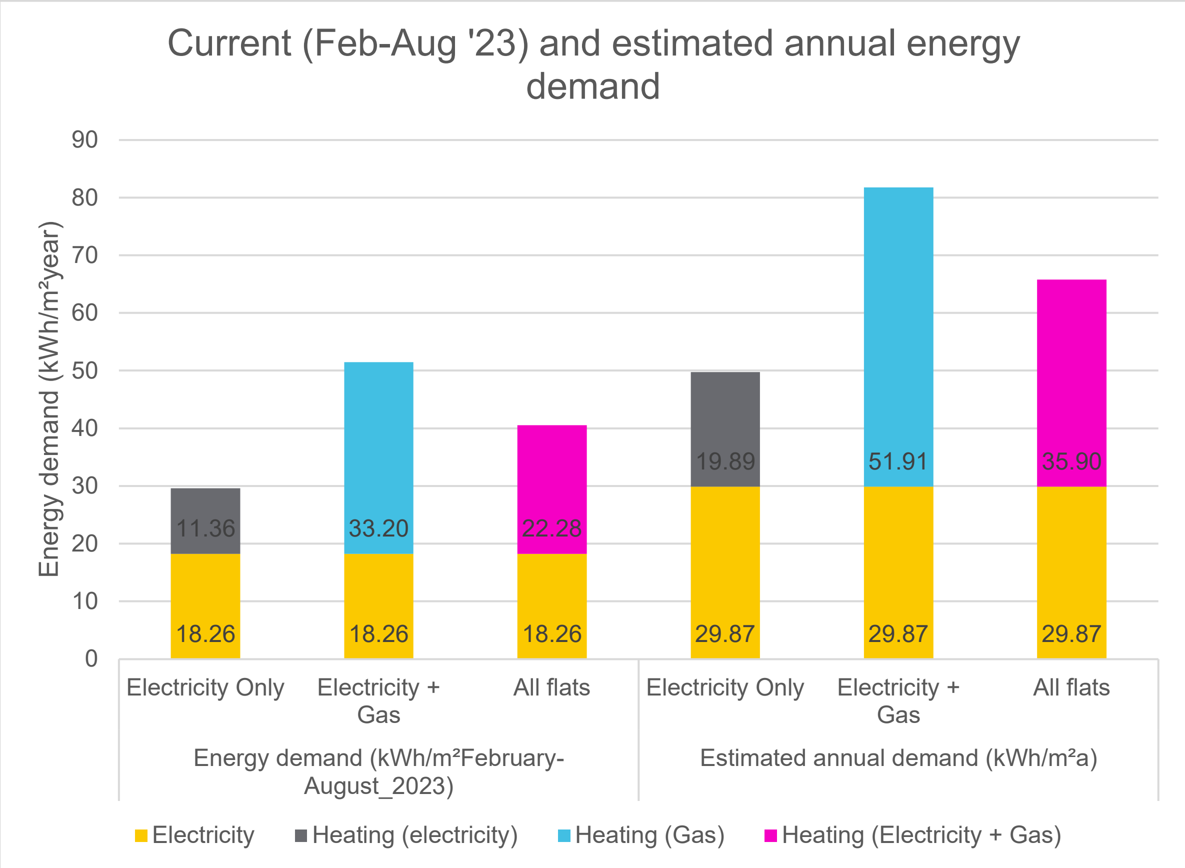
The collected readings were used to estimate individual and overall annual electricity demand. This is based on a simple extrapolation from days with meter readings. The average overall estimated annual electricity demand for all the flats is 39.81 kWh/m^{2}year, compared to 43.4 kWh/m^{2}year from the average home in Scotland according to the Ofgem energy estimations. By comparing the electricity consumption of the gas and heat pump flats, we can estimate the energy required for space and water heating for the flats that use electricity as a source of heating via the heat pump. This indicated an estimated annual demand of 19.89 kWh/m^{2}year for the heat pump flats. A further assumption is a figure of 15 kWh/m^{2}year for water heating. This would indicate space heating demand of 4.89 kWh/m^{2}year. This compares favourably with the EnerPHit target of 25 kWh/m^{2}year[9]

However, the annual space and water heating consumption for the flats with gas heating is estimated to be 51.91 kWh/m^{2}year. Again, taking into account an assumed 15 kWh/m^{2}year for water heating, gives a space heating load of 36.91 kWh/m^{2}year, above the EnerPHit target of 25 kWh/m^2/year.

Based on these numbers the estimated average annual heating demand for the whole building is 20.90 kWh/m^{2}year. Based on the annual estimations, the EnerPHit target would be met on the flats that use electricity as a source of heating via the heat pump. Some caution is needed with these figures as this does not include any measurement of the effectiveness of the WWHR system. If effective this may reduce hot water energy consumption which would then impact on the space heating loads. Based on the data to date this would appear to be less impactful on the heat pump flats.

9 The assumption of 15kWh/m2/year for hot water use (to remove from the total to give us the space heating figure) is robust. However, if estimated by the PhPP model, this suggests that hot water use should be around 23 kWh/m2/year, which if true would mean that the space heating result is (51.91 - 23 = 28.91) which is much closer to the 25 limit than the 36.91 suggests.

Figure 7. Mean annual energy demand for different flats (estimated from consumption between 28/January to 23 of August 2023).



Source Authors.

The EnerPHit target for space heating for cold temperate climates, such as the UK, is below 25 kWh/m^{2}year, and the total annual energy demand should be no more than 60 kWh/m^{2}year. Whilst the current assumptions suggest the former is being met, the latter is an aggregate figure of 65.77 kWh/m^{2}year, but this would appear to be inflated by gas consumption, and higher electrical use in one heat pump flat.

There are several possible explanations for these variances, not least of which is the incomplete data at present. However, observations of the flats in use suggests that this could be due to variances in patterns of use and consumption; the ability of a gas system to 'oversupply' in terms of space and water heating; and a relatively cool spring which may have increased demand. It is clear that some flats are using considerably more energy than others, and further work is needed to understand this. Some possible such issues are raised later in this section of the report. These include lack of information about use of the systems, extended periods of occupancy and appliance use, varying expectations for thermal comfort, and some issues of control. The two missing flats may also affect averages once these figures are known. As noted above, all these figures are estimated and there is a need further verification once complete data is available. However, on the evidence so far, the flats appear to be on target to meet the EnerPHit standards and suggests that the retrofit is technically successful.

Indoor temperatures

Indoor temperature ranges remained within the acceptable temperature range accordingly to the EnerPHit standard (20°C - 25°C) as shown in Figure 2. Indoor temperatures above 25°C were observed for more than 10% of the monitored time in the H2 flat. The rest achieve an acceptable level of overheating according to the Passivhaus standard (>25°C over 10% of the time). Most of the overheating temperatures (>25°C, based on the Passivhaus definition) occurred in the month of June when there were heat waves. The percentage of times on the different temperature ranges are described in Table 8

Figure 8 Overall temperature ranges of the different households (Top) and monthly (bottom) between 27/01/2023 and 26/06/2023.

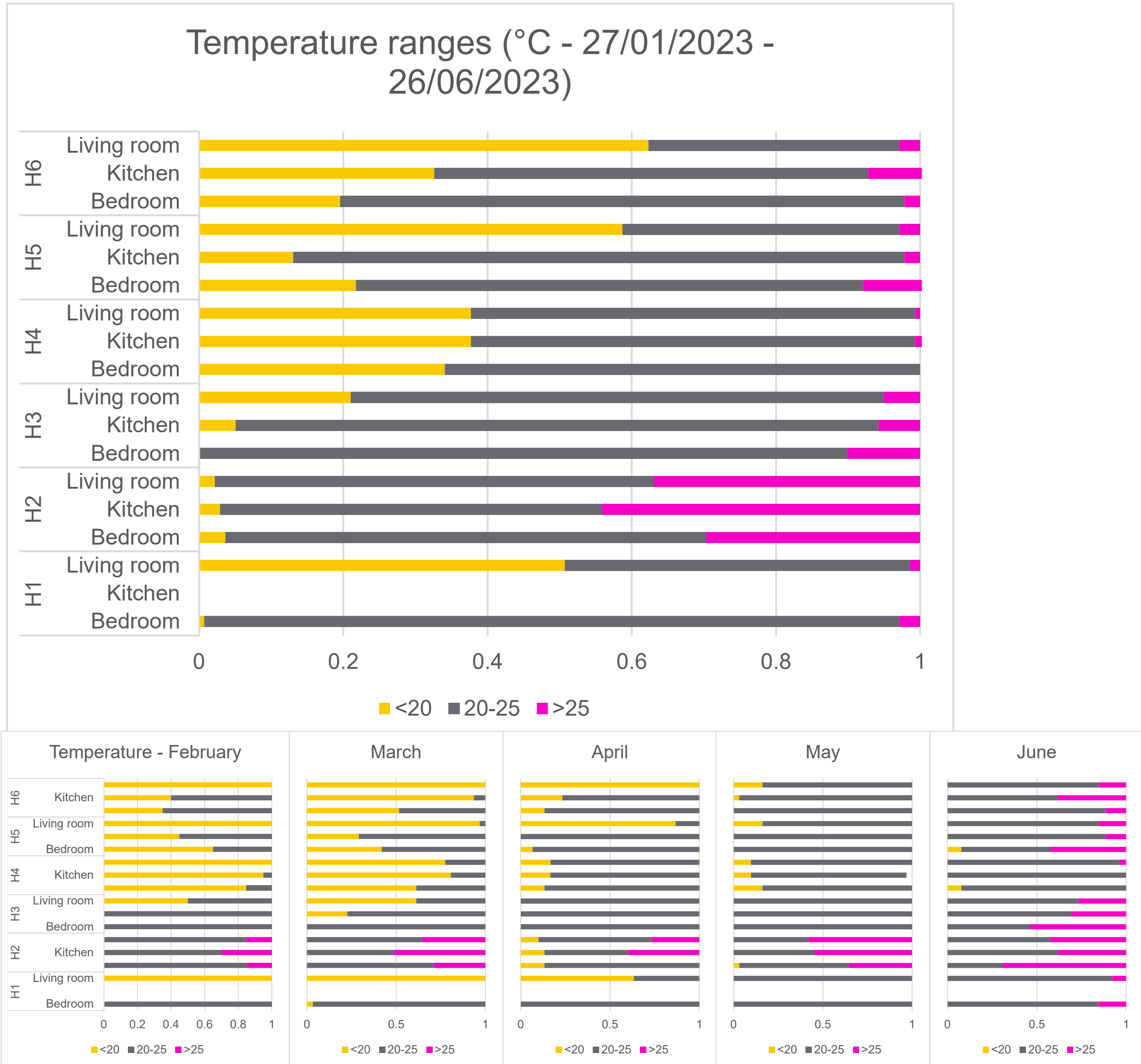


Table 8 Temperature ranges in the different households between 27/01/2023 and 26/06/2023.

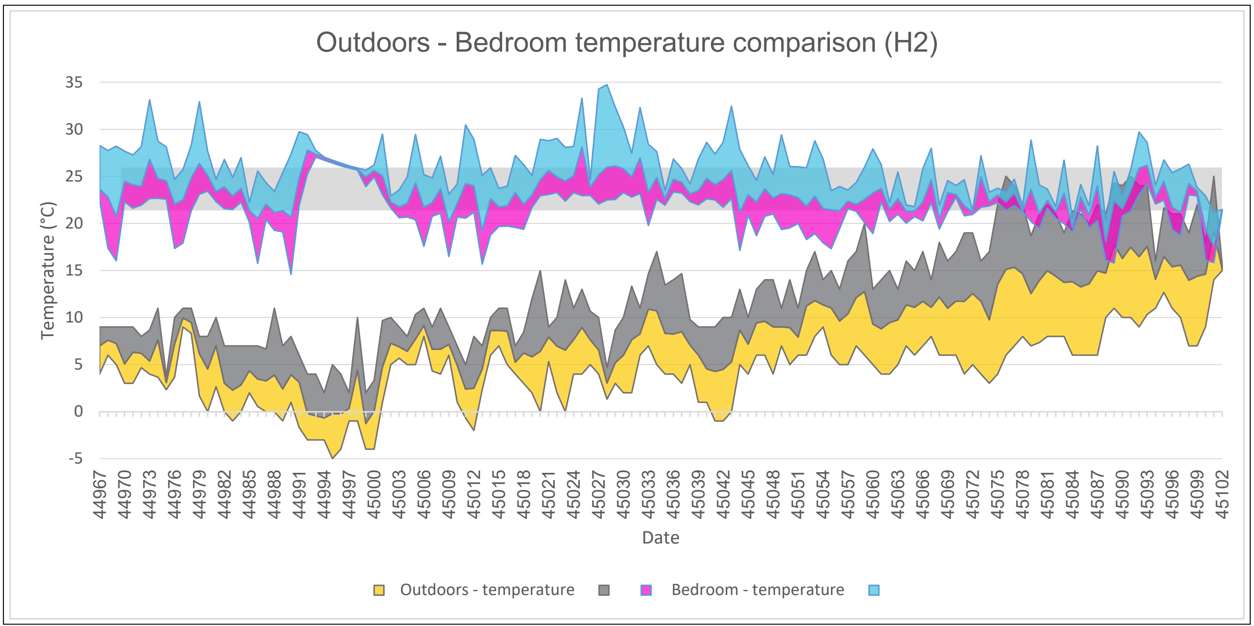
		<20	20-25	>25
H1	**Bedroom**	1%	96%	3%
	Kitchen	DATA LOST		
	Living room	51%	48%	1%
H2	**Bedroom**	4%	67%	30%
	Kitchen	3%	53%	44%
	Living room	2%	61%	37%
H3	**Bedroom**	0%	90%	10%
	Kitchen	5%	89%	6%
	Living room	21%	74%	5%
H4	**Bedroom**	34%	66%	0%
	Kitchen	38%	62%	1%
	Living room	38%	62%	1%
H5	**Bedroom**	22%	70%	9%
	Kitchen	13%	85%	2%
	Living room	59%	38%	3%
H6	**Bedroom**	20%	78%	2%
	Kitchen	33%	60%	8%
	Living room	62%	35%	3%

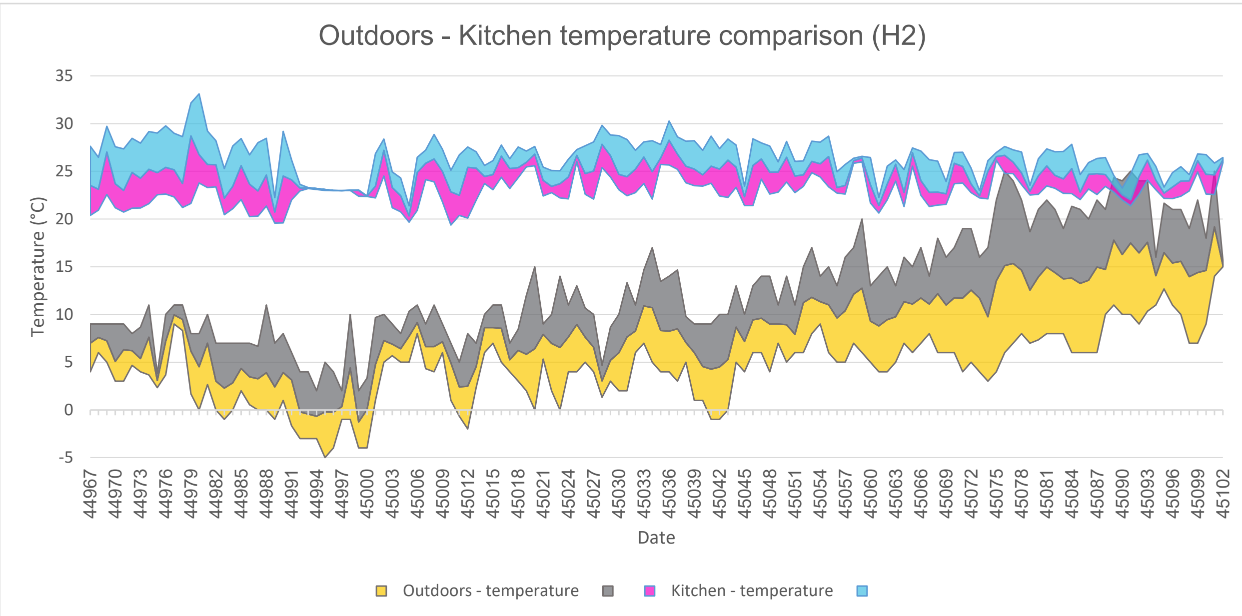
Source: Authors.

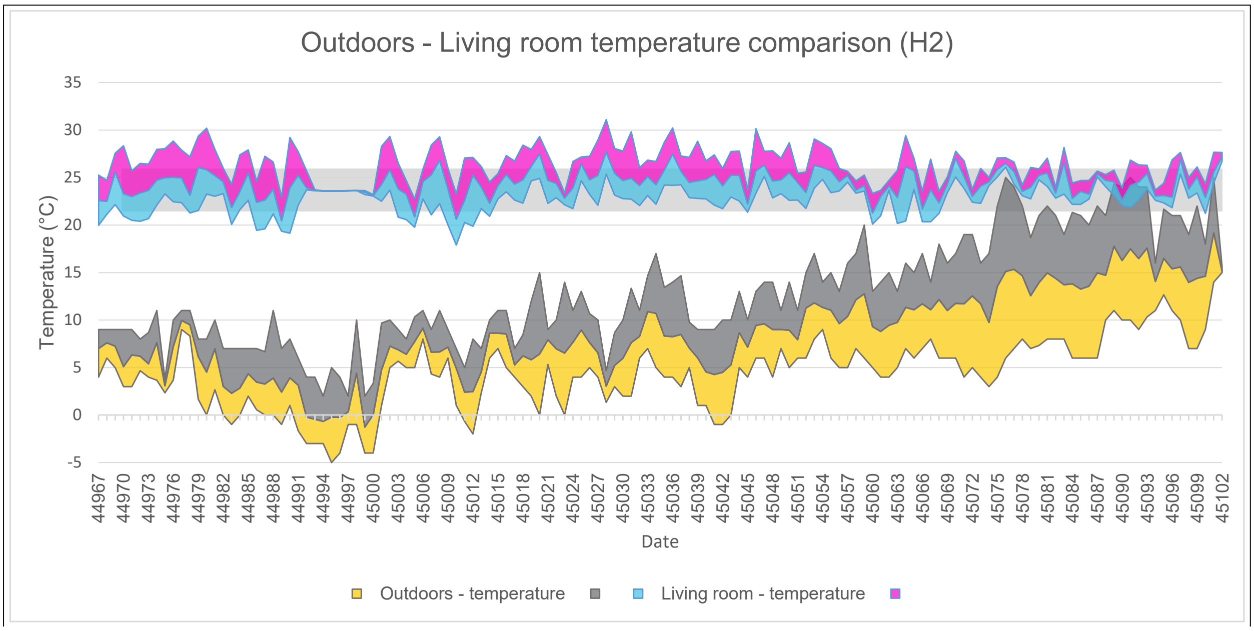
The indoor temperatures were lower in the upper flats compared to the lower flats. However, there were some problems with temperatures during the 2022 heating season in the H2 flat. The occupant of this flat reported enjoying warm temperatures and that it was peasy to heat the flat to a desired temperature. Typical daily average indoor temperature levels in the different rooms of the flats were [daily average mean (daily average min - daily average max)]:

- Bedroom: 21.8°C (18.0 – 26.4°C)
- Kitchen: 21.8°C (15.2 – 50.8°C)
- Living room: 20.7°C (17.0 – 25.9°C)

Figure 9 Outdoor and H2 Indoor temperature levels comparison in each of the rooms bedroom (top), kitchen (centre) and living room (bottom).





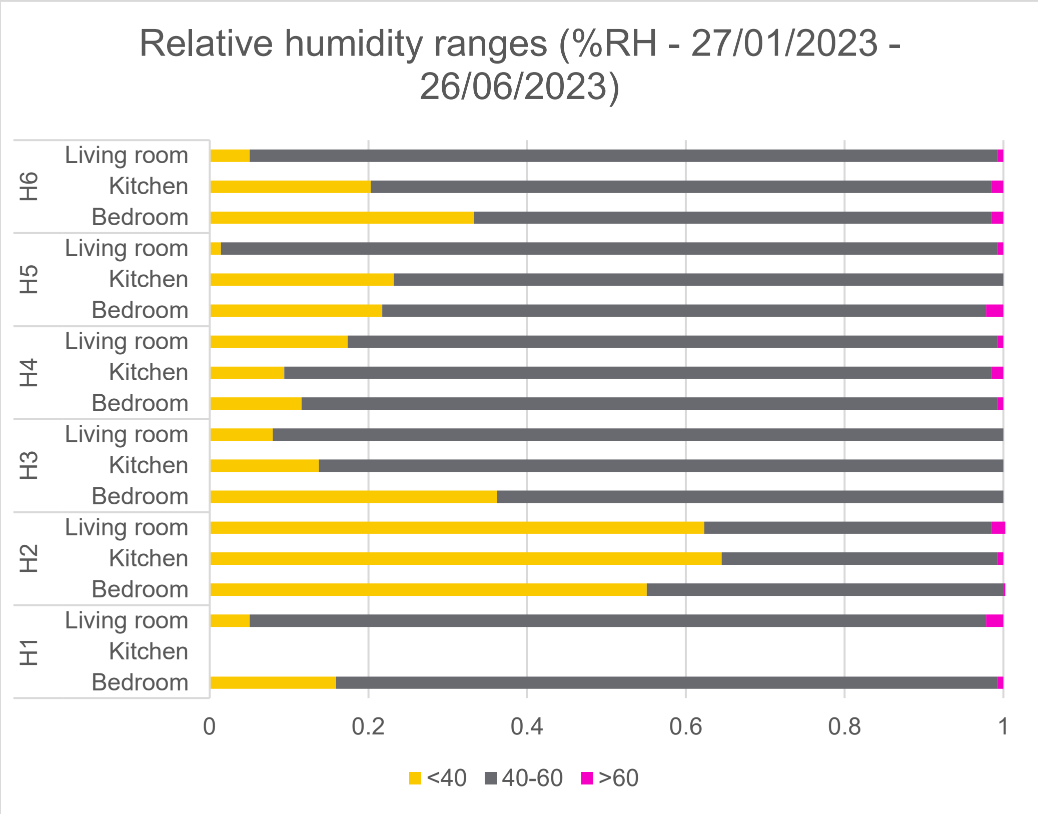


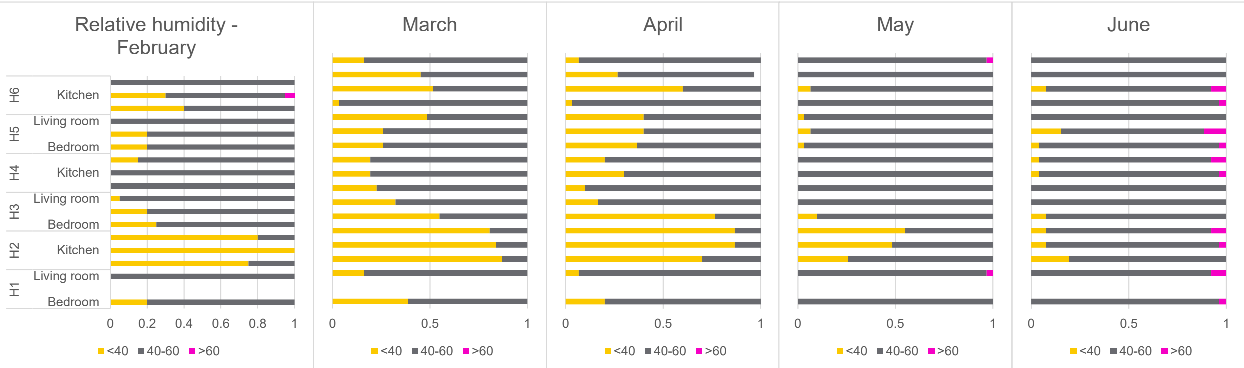
Source: Authors.

Relative humidity

Indoor relative humidity ranges remained between the recommended 40%RH to 60%RH for most of the time (Figure 10). The observed relative humidity levels indicate a high overall satisfaction with the levels with low mould problems, which was corroborated by the occupant satisfaction surveys. However, it is worth noting that, levels below 40%RH were observed frequently, particularly in March and April, and the H2 flat had significantly high occurrence of relative humidity levels below 40%RH. Extended periods of time below 40%RH are associated with dry skin, itchy skin and dry eyes. Nonetheless, the H2 occupants stated to feel comfortable as they found it close to the levels that they were used to.

Figure 10 Overall relative humidity ranges of the different households (Top) and monthly (bottom) between 27/01/2023 and 26/06/2023.





Source Authors.

The indoor relative humidity levels were lower in the lower flats compared to the upper flats. A potential explanation is that the temperature levels could mask the real humidity levels (warmer air can hold a higher moisture level), as warmer temperatures in the bottom floors were more frequent. The indoor relative humidity ranges are described in Table 9.

Table 9 Relative humidity ranges in the different households between 27/01/2023 and 26/06/2023.

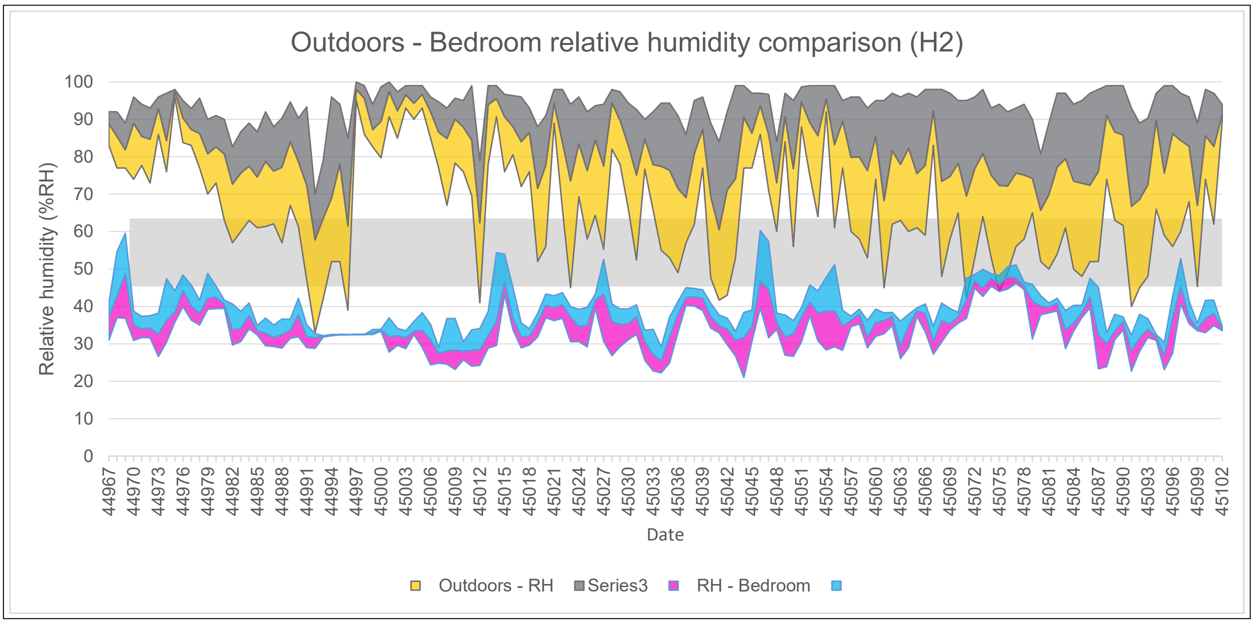
		<40	40-60	>60
H1	**Bedroom**	16%	83%	1%
	Kitchen	DATA LOST		
	Living room	5%	93%	2%
H2	**Bedroom**	55%	45%	1%
	Kitchen	64%	35%	1%
	Living room	62%	36%	2%
H3	**Bedroom**	36%	64%	0%
	Kitchen	14%	86%	0%
	Living room	8%	92%	0%
H4	**Bedroom**	12%	88%	1%
	Kitchen	9%	89%	1%
	Living room	17%	82%	1%
H5	**Bedroom**	22%	76%	2%
	Kitchen	23%	77%	0%
	Living room	1%	98%	1%
H6	**Bedroom**	33%	65%	1%
	Kitchen	20%	78%	1%
	Living room	5%	94%	1%

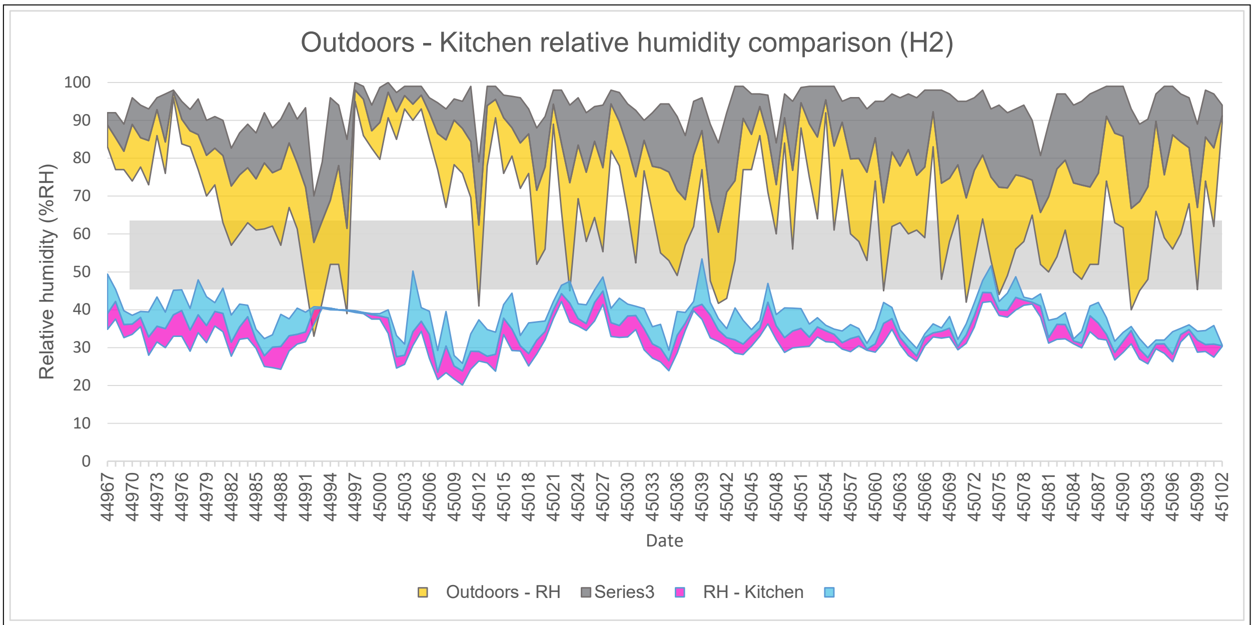
Source: Authors.

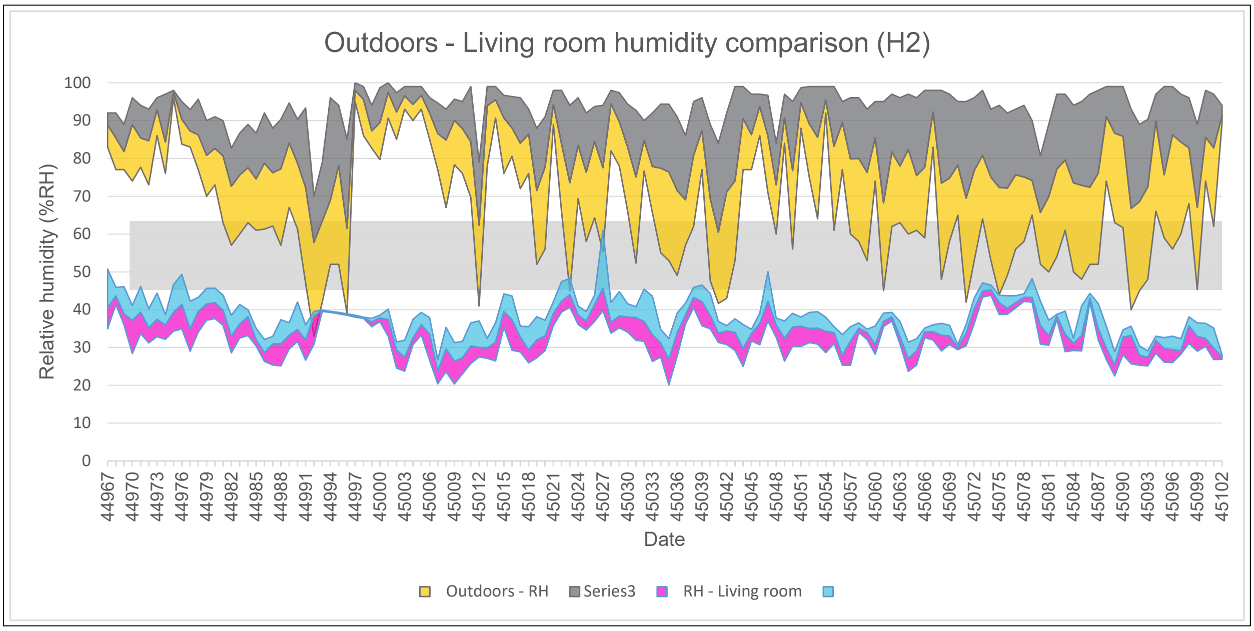
Typical daily average indoor relative humidity levels in the different rooms of the flats were [daily average mean (daily average min - daily average max)]:

- Bedroom: 43.61%RH (29.4 – 62.5%RH)
- Kitchen: 44.4%RH (25.4 – 50.8%RH)
- Living room: 46.5%RH (33.1 – 61.4%RH)

Figure 11 Outdoor and H2 indoor relative humidity levels comparison in each of the rooms bedroom (top), kitchen (centre) and living room (bottom).







Source: Authors.

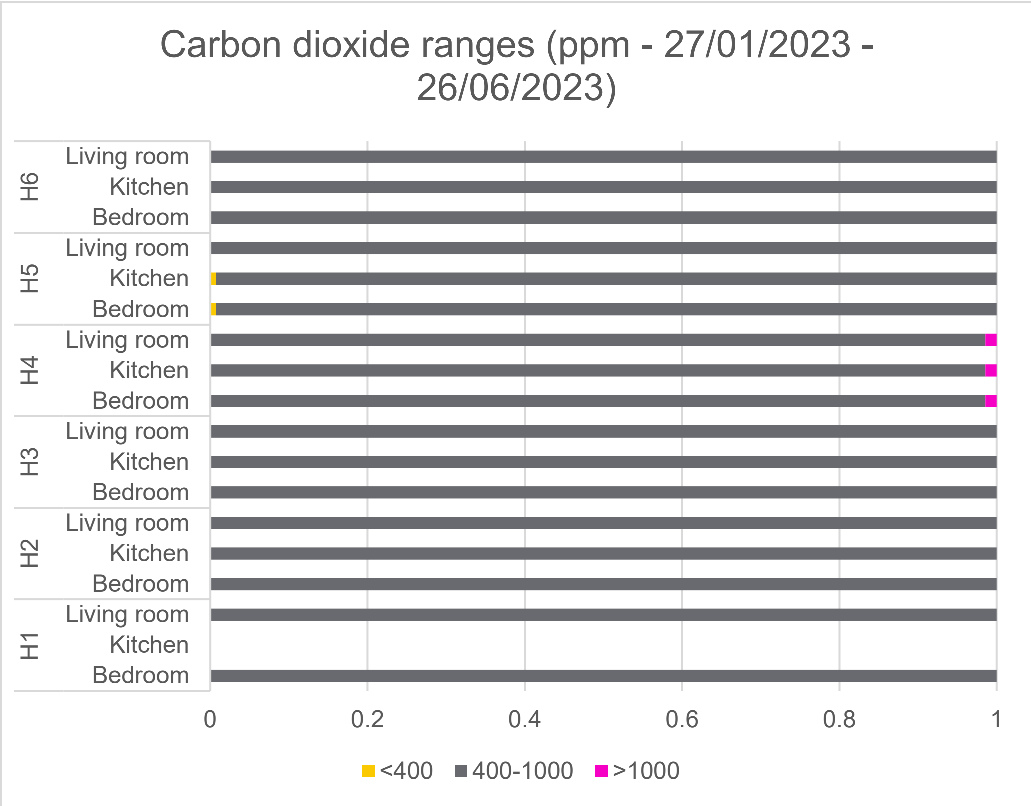
Carbon dioxide

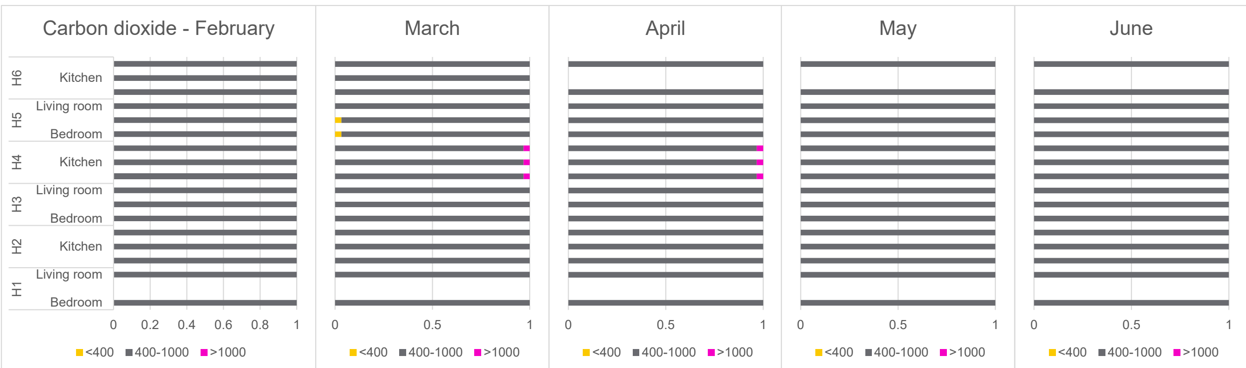
There are well established associations between health and ventilation, and maintaining good Indoor Air Quality is an important objective for the health of occupants, and the prevention of associated detrimental conditions such as damp and mould. Measurement of Carbon Dioxide (CO_2) is used as a proxy for ventilation in environmental monitoring of occupied spaces. Occupants breathe out CO_2 at known rates and therefore levels of CO_2 measured in parts per million represents the fraction of air that has been exhaled by individuals in the space. It is an effective proxy for occupancy and/or ventilation. 1000ppm is broadly equivalent to a ventilation rate of 10 l/s/person and maintaining CO_2 below 1,000 ppm is widely accepted as a measure of good ventilation. There are significant associations between ventilation and health and there is a concern that some energy efficiency measures in retrofit may reduce ventilation levels.

It should be noted that these are small flats with relatively low occupancy, so it would not be expected that CO_2 would be excessive under normal conditions. The ventilation provision in the properties uses a Mechanical Ventilation with Heat Recovery (MVHR) system, which mechanically extracts air from kitchens and bathrooms, and supplies air with recovered heat into the occupied space. An indication of raised CO_2 may therefore be indicative of the system being disabled or failing in some way.

The monitoring showed that indoor carbon dioxide remained below 1,000 ppm most of the time (Figure 12). The observed carbon dioxide levels indicate good levels ventilation and indoor air quality, which was corroborated by the occupant satisfaction surveys.

Figure 12 Overall carbon dioxide ranges of the different households (Top) and monthly (bottom) between 27/01/2023 and 26/06/2023.





Source Authors.

Table 10 Carbon dioxide ranges in the different households between 27/01/2023 and 26/06/2023.

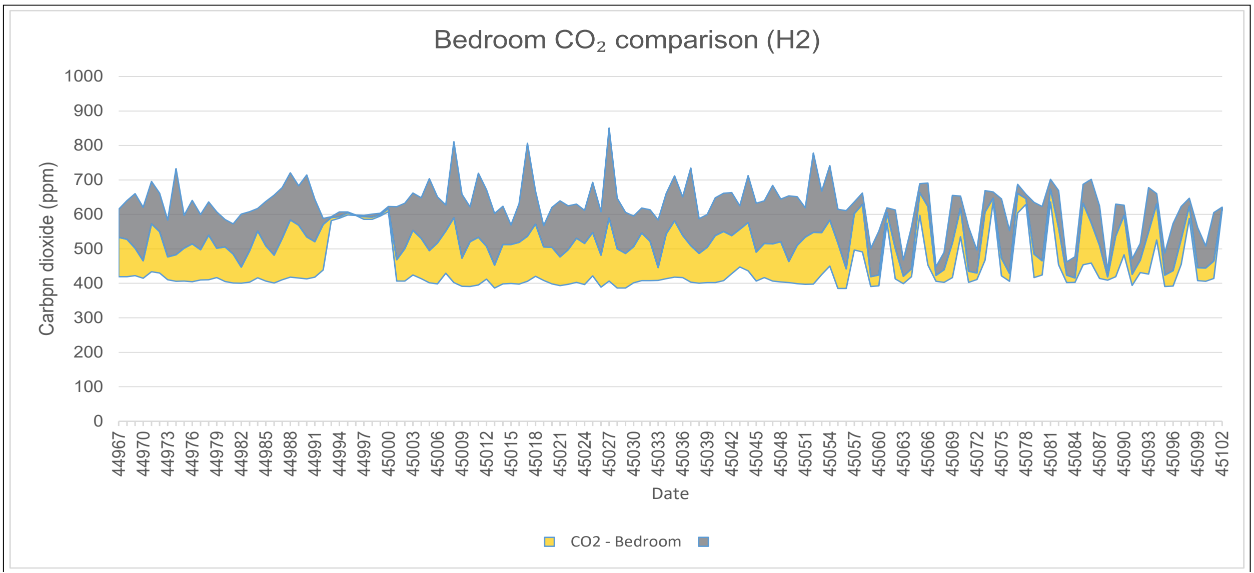
		<400	400-1000	>1000
H1	**Bedroom**	0%	100%	0%
	Kitchen	DATA LOST		
	Living room	0%	100%	0%
H2	**Bedroom**	0%	100%	0%
	Kitchen	0%	100%	0%
	Living room	0%	100%	0%
H3	**Bedroom**	0%	100%	0%
	Kitchen	0%	100%	0%
	Living room	0%	100%	0%
H4	**Bedroom**	0%	99%	1%
	Kitchen	0%	99%	1%
	Living room	0%	99%	1%
H5	**Bedroom**	1%	99%	0%
	Kitchen	1%	99%	0%
	Living room	0%	100%	0%
H6	**Bedroom**	0%	100%	0%
	Kitchen	0%	100%	0%
	Living room	0%	100%	0%

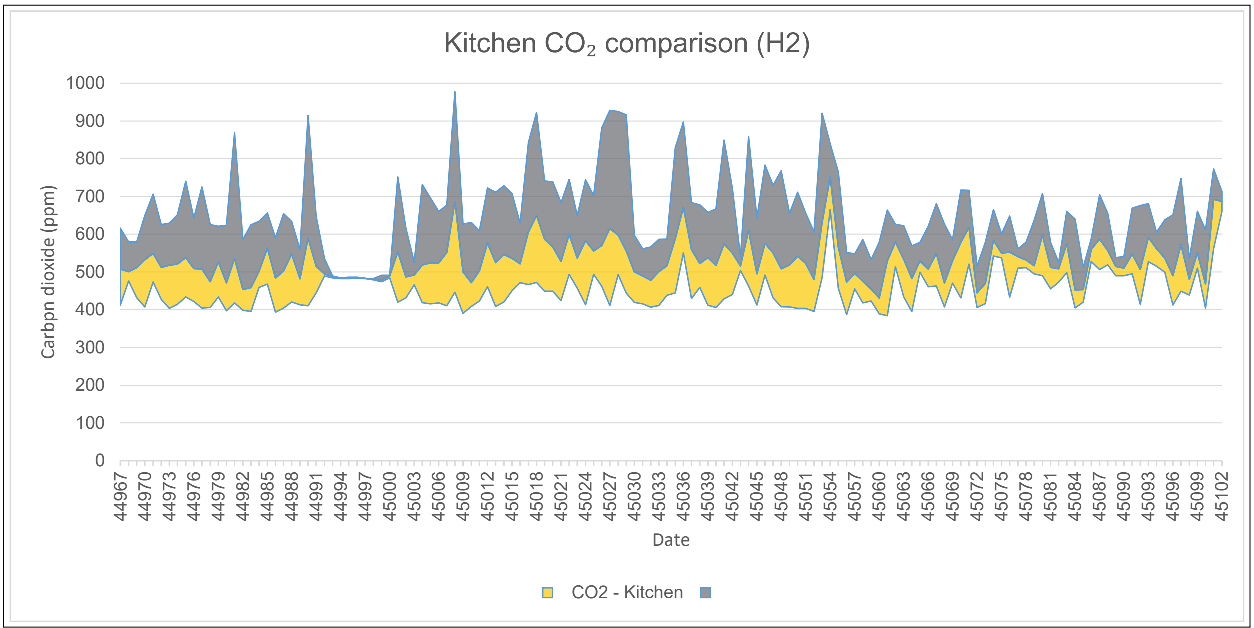
Source: Authors.

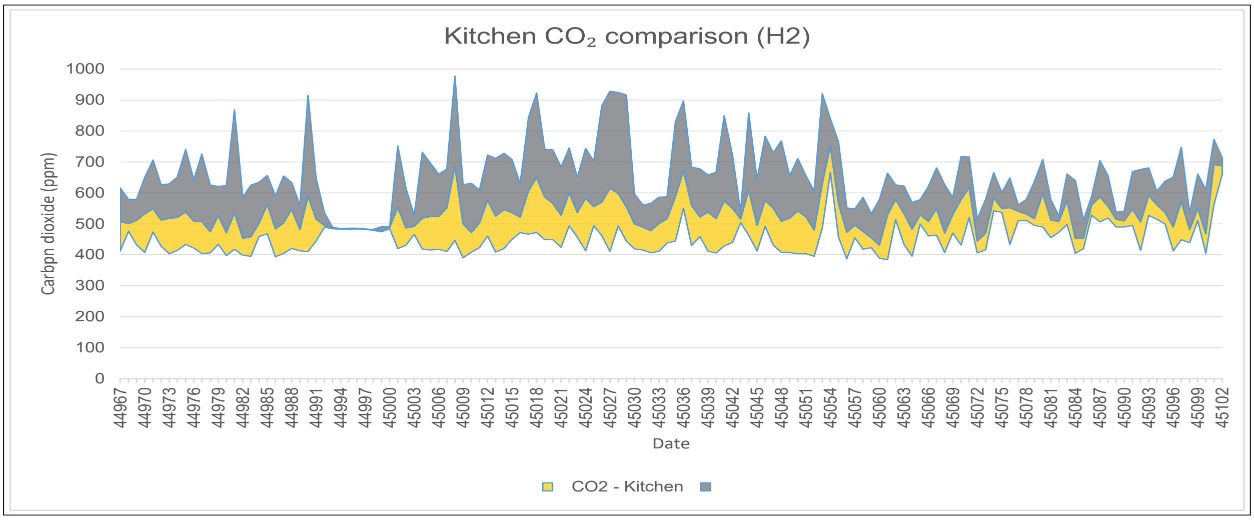
The daily average carbon dioxide ranges are described in Table 10. Typical daily indoor carbon dioxide levels in the different rooms of the flats were [daily average mean (daily average min - daily average max)]:

- Bedroom: 527 ppm (418 - 1,013 ppm)
- Kitchen: 515 ppm (356 - 899 ppm)
- Living room: 506 ppm (419 - 992 ppm)

Figure 13 Outdoor and H2 indoor carbon dioxide levels comparison in each of the rooms bedroom (top), kitchen (centre) and living room (bottom).





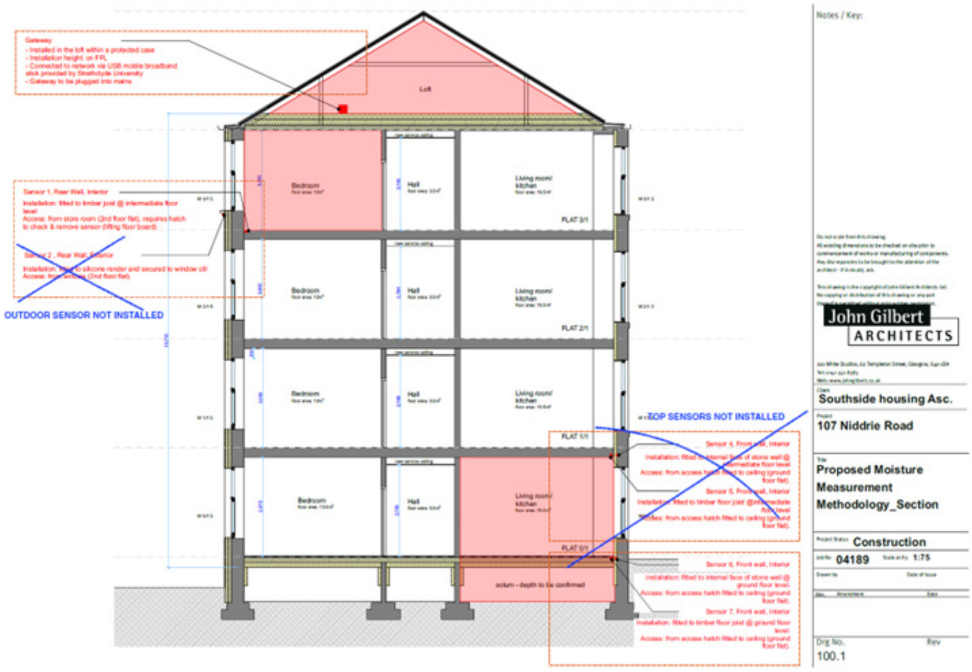


Source: Authors.

Interstitial condensation

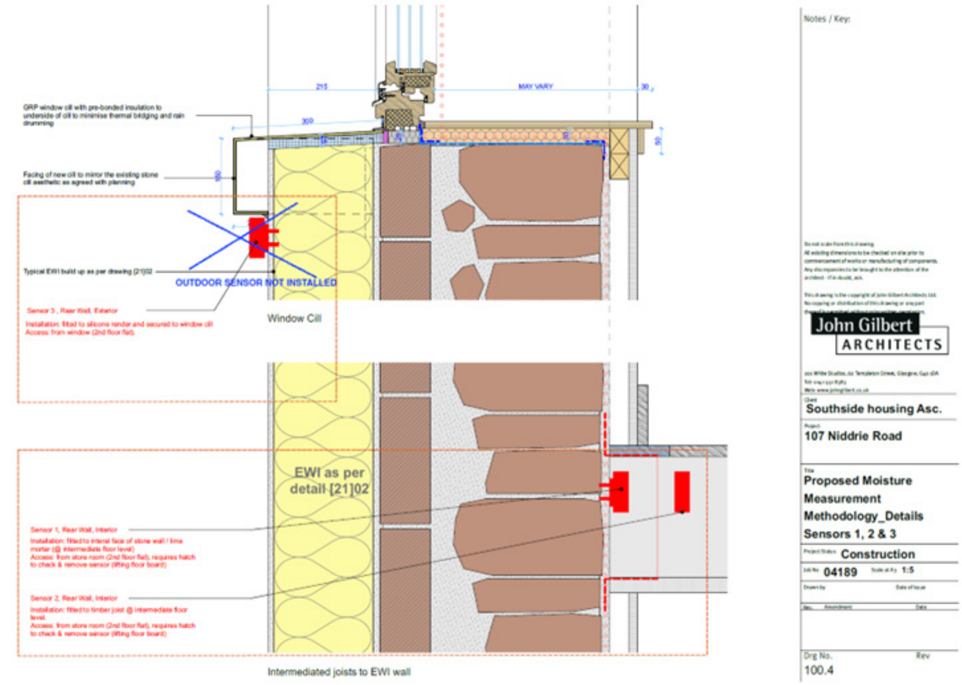
The nature of traditional stone tenements is such that there is a reluctance to place external wall insulation (EWI) on stone façades. Whilst EWI was possible on the rear and side brick elevations in this property, improving U-values on the stone façade requires the use of internal insulation. A concern with this approach is that that the stonework will then be outside the thermal envelope and therefore colder and potentially wetter. The risk that arises is when timber elements such as the floor joists project into the stonework, where they may be subjected to higher moisture levels, increasing a risk of rot. To evaluate this, interstitial moisture sensors were installed in beams during the construction. These use an OmniSense G-4-NBIOT-EU Gateway with 4G Cellular Data which allows wireless connection with temperature and moisture sensors embedded in the construction, with a wireless powered gateway in the loft space. The sensors for interstitial condensation were located during the construction process in the bottom front side of the building, the top back of the building with the gateway located in the attic as shown in figure 14 and Figure 15.

Figure 14. Section of the building showing the rooms where the interstitial condensation sensors were installed.



Source: John Gilbert Architects.

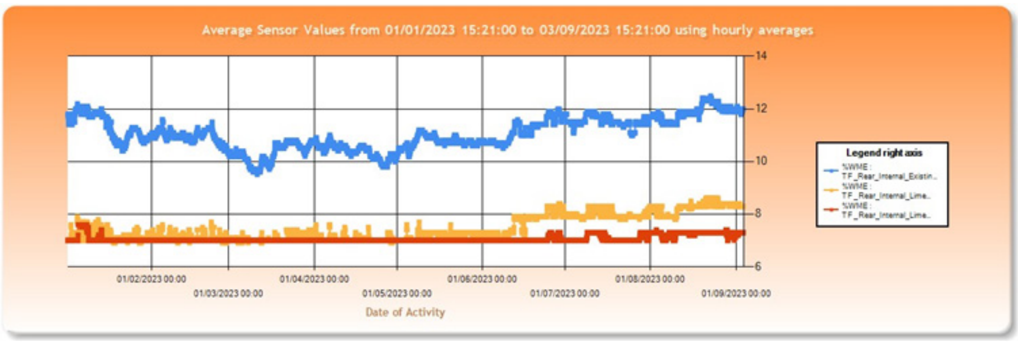
Figure 15. Construction detail showing the installation process of the interstitial condensation sensors on the back wall (EWI).



Source: John Gilbert Architects.

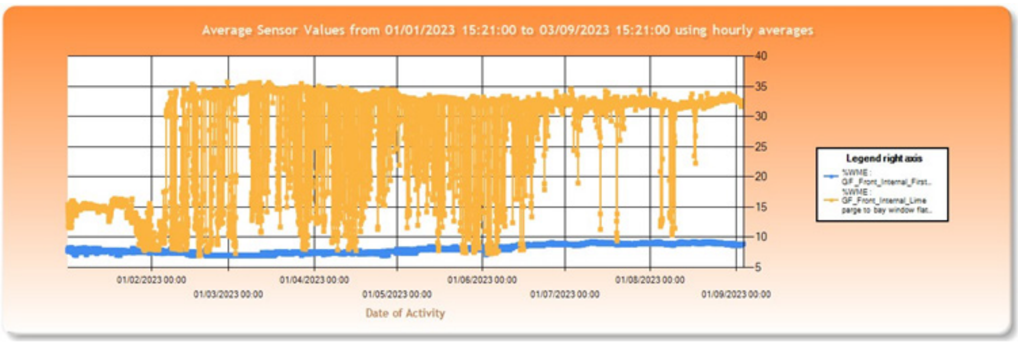
Moisture issues can arise when interstitial condensation occurs within an enclosed wall, roof or floor cavity structure. This type of condensation happens when moisture-laden air vapor permeates through a building's fabric elements, encountering temperature variations along the way, and condensing internally rather than on the surface. Wood moisture equivalent (WME) is a measurement of the (theoretical) percentage of moisture content that would be attained by a piece of wood in contact with, or in close proximity to, a moisture equilibrium across a host of materials. We can use the %WME to determine how fast a wall is drying and the risk for the occurrence of rot and fungus. Based on the WME levels (Figure 16 and Figure 17) the wall was drying up between February and mid-March and then stayed relatively stable until June when it started to get some moisture. However, the levels remain below the recommended levels for dry rot, cellar fungus, white pore or mini fungus (>25 %WME). The recommended WME levels are below 15%WME. Measured WME levels are constantly below 15%WME – the recommended levels to avoid any risk of rot, although common furniture beetle may proliferate above 12%WME. The high variability on the yellow line (internal lime parage to bay window) is internal and it is likely that the variability here is due to proximity to central heating pipes.

Figure 16. WME levels of the top floor rear wall.



Source: Omnisense dashboard.

Figure 17 WME levels of the bottom floor front wall.



Source: Omnisense dashboard.

Occupants' feedback

Occupants' feedback on the indoor environment, energy use and overall satisfaction was collected on first visit to each flat. Occupants reported overall satisfaction with all the aspects of the home, particularly the low energy bills. Several of the occupants reported not having to pay for electricity during the period of the energy rebate from the Government between October 2022 and March 2023. From a fuel poverty and affordability perspective, this was very positive for occupants as this suggests that the monthly energy bills were below £66.00 even with particularly high energy prices and that some of this credit may have even rolled out to the further months. Some quotations from the interviews are:

"I wish all the homes were like this one. I have been very happy since I moved in and I don't need to worry about the energy bills"

"The house was too warm during winter, but after a visit from the engineers to look out to my boiler everything was good. I haven't had any problems since then"

"My house is comfortable and cheap to heat"

Key issues or problems

One of the key issues with the flats related to the heat pumps. There was a problem with the operation of a heat pump during winter and one of the occupants was particularly affected as they were left without heating for about 1.5 weeks as the heat pump was broken. The engineers needed to visit 3 times only to diagnose the problem, plus another one to fix it. They were trying to find the problem next to the system or inside the building, but the outdoor pipes were frozen. The occupants were very disappointed that this happened as it happened on some of the coldest days in December. This suggests that there still some skills gap related to the operation and proper maintenance of the heat pumps, which would need to be addressed as the uptake in the region develops. Unfortunately, we do not have monitored data during this period to identify the effect on internal temperatures.

A further issue relates to patterns of occupancy. One example of this was occupants not turning off heating, perhaps related due to higher comfort expectations and low energy prices. One example of this was when the heating was left on for a couple of days during winter. In this case, the surrounding flats complained about the effects, as it become too hot to be comfortable in the flat. Whilst this might be something that is not unusual, and in other buildings this 'free' heat may be beneficial, the external fabric is designed to keep the heat inside but there is little thermal barrier between adjacent flats. The occupants indicated that there should be a safety feature to avoid this in the future. The only solution they had was to reach the housing association to mediate.

Occupant engagement and satisfaction

Most of the occupants stated that they had not received any training on how to operate the system. However, one of them stated that they have received a booklet with information about the house but could not remember where they put it. This is an important issue as all of the occupants reported not knowing how to operate the systems. The MVHR settings were at default at all times (as stated by the occupants) as they don't know how to boost or use the low ventilation setting for when they are leaving the house for prolonged time or use the bypass of the system for the summer months. Some other occupants of the flats with heat pumps reported to have problems with the domestic hot water and stated that they did not know what to do to get hot water and often need to call the engineers to get hot water. Regardless of these issues, they all started to feel satisfied with the homes as they see that the pros outweigh the cons.

Conclusions

Energy Consumption and targets

It is important to note that these are interim results to date and will not be verifiable until we have at least 12 months of data. It is also based on 6 out of the 8 properties. The monitoring period was also during a relatively mild winter, but a cool spring and in the context of the UK energy fuel crisis which may have constrained use. There are some issues which may be affecting energy use – for example one of the flats with heat pump heating has quite high electrical consumption which may be due to patterns of occupancy and electrical equipment used in the home.

From an energy perspective the dwellings appear to be performing well below the targeted levels of consumption, with estimated annual consumption for space heating of 36.91 kWh/year for the gas flats and 4.89 kWh/year for the heat pump flats. From the 6 monitored combined flats and extrapolating to annual figures for the whole block suggests consumption of 20.90 kWh/m^{2}a.

Good thermal environmental performance

At this stage, this low energy use does not appear to have been at the expensive of thermal comfort, with good average indoor temperatures, generally within the Enerphit performance targets throughout this period. The dwelling also appeared to not have been unduly adversely affected by a period of very warm weather in the early summer. One dwelling is anomalous, but this is understood to be a comfort preference for this occupant.

Good IAQ/Ventilation

The dwellings remained below 1,000ppm CO2 for the monitoring period, and there was no evidence from this monitoring of the MVHR systems being switched off or otherwise failing.

Interstitial condensation risks in timber

At this stage there are no obvious concerns about presence of interstitial moisture in the construction. This will require on-going monitoring as conditions may change over time, and with more adverse weather conditions.

Overall performance

From a technical perspective, based on the data available to date, the Niddrie Rd retrofit appeared to be very successful in providing dwellings that are very low energy, comfortable, healthy, with high degrees of occupant satisfaction.

Further work

The project will continue to gather data over the coming year, to evaluate ongoing performance. We will attempt to gain access to the 8th flat.

We aim to enable energy monitoring integration with the smart meters which will allow more detailed and remote access to data. This will also be collated in the environmental sensing data portal which will allow more detailed analysis.

We will complete the installation of the Heat Pump space and water heating consumption, which will provide more detailed and accurate data on actual heat pump consumption and water use.

We will undertake the installation of the sub monitoring of the MVHR and WWHR systems. This will enable a more accurate measurement of the efficiency and effectiveness of these system.

We will also undertake a more detailed and granular analysis of overall energy consumption and environmental performance to identify areas of further investigation and identify any mitigation measures that may be necessary. Part of this will be to provide feedback to the occupants and landlord about performance and identify any issues that require modification.

5. Post-occupancy evaluation

Introduction and context

This chapter describes the user-focused post-occupancy evaluation (POE) that commenced following the completion and handover of 107 Niddrie Road to Southside Housing Association and its residents in late summer 2022. The chapter begins by introducing POE, before describing the research design, preliminary results and the next stages of the research.

Post-occupancy evaluation in practice

POE involves returning to a newly completed or recently refurbished building soon after its completion to assess its performance using a structured methodology (Jiang et al., 2022; Menezes et al., 2012). In a widely cited exploration of POE in UK architecture practice, Hay et al. (2018, p. 698) offer a two-part definition, stating that it is:

> *…the process of ascertaining the quality and standards of design and construction (including space planning, resource consumption, internal environmental quality, maintenance and occupancy costs, user comfort, satisfaction and outcomes); and the continual learning and dissemination of POE knowledge in order to shape future architectural projects and practices.*

POE can thus take various forms, including the "[a]ssessment of building performance, investigation of relationships between occupant behaviour and building resource use, [and] optimisation of the indoor environment for occupants" (Jiang et al., 2022, p. 1). As a result, a range of assessment methods are used to conduct POE. These commonly include quantitative surveys with residents and other building users alongside the technical monitoring of building performance. This means that POE is a particularly useful tool for "exploring cause-effect relationships between technical features of a building and user experiences and needs" (Maslova and Burgess, 2023, p. 278). It has faced criticism, however, for being too technical and lacking "qualitative depth" (ibid.). There thus remains considerable scope to develop further forms of POE that valorise the intangible aspects of the lived experiences of buildings and the wider neighbourhoods in which they are situated (Serin et al., 2018; Hay et al., 2018).

Despite the critical role that POE can play in creating feedback loops and encouraging learning about how to design future buildings, it is not used consistently in UK design and development practice (Hay et al., 2018; Stevenson, 2019). A 2020 survey by the widely respected industry magazine, Architects' Journal, found that only 4% of UK architectural practices always undertake POE and 22% frequently conduct it (Watson, 2021). Part of the problem is that designers and developers tend to quickly move on to the next project rather than dwelling on the ones they have recently completed. There is also a widely held perception that POE is both a costly and complex endeavour (RIBA et al., 2017). In their 2020 report, Post Occupancy Evaluation: An Essential Tool to Improve the Built Environment, the RIBA argue that, in fact, the cost burden of POE tends to be minimal and only adds between 0.1% and 0.25% to a typical project (RIBA, 2020). Moreover, it offers invaluable information for future projects because the feedback "provides an opportunity to learn from mistakes, improve the predicted energy usage of a building and create better designs and better buildings" (p. 17). POE is thus a key component of the RIBA's Plan of Works industry manual (RIBA, 2020).

Post-occupancy evaluation methodology

POE is particularly valuable for building retrofit projects, such as 107 Niddrie Road, because new residents are likely moving into a highly energy efficient building for the first time and probably have limited understanding of the new and emerging technologies being tested in their dwelling (Chiu et al., 2014; Stevenson, 2019). User-focused POE was therefore included as an integral component of the wider building retrofit project and is being conducted by the

University of Glasgow alongside a technical building monitoring programme led by the University of Strathclyde.

Research aims

The aim of the POE exercise at 107 Niddrie Road was to collect data on the comfort and wider lived experience of the residents' new tenemental homes. However, the research team also wanted to gather the residents' views on living in the Strathbungo/Govanhill neighbourhood. This decision was made to ensure that the research was not strictly limited to the environmental sustainability of the building envelope, but also encompassed the social and economic conditions of the wider area. From an urban resilience and sustainability perspective these concerns are just as important as those pertaining to the building (Dixon and Eames, 2013) – not least in the context of the Scottish Government's new National Planning Framework 4 (NPF4), which has introduced the concept of '20-minute neighbourhoods' into the wider planning and housing policy landscape for the first time (Scottish Government, 2022).

It is important that sustainability is not just considered in terms of environmental sustainability measured through technical solutions, but also that socio-economic dimensions of sustainability are assessed (Carter, 2018). This perspective underpins discussions around the just transition and promoting the idea that environmental sustainability can and should reduce socio-economic inequalities (Bell, 2020). In the context of the cost of living crisis, particularly around energy poverty, 107 Niddrie Road might demonstrate the role that retrofitting can play in reducing energy bills in the social rented sector and for those tenants who may be most vulnerable to fluctuations in energy costs. From a neighbourhood perspective too, the socio-economic aspects of sustainability can be seen in access to public transport, local amenities, the quality and safety of active travel routes, provision of greenspaces, recycling facilities and more. Considering this, the research team were also keen to compare residents' lived experience of 107 Niddrie Road against their previous home and neighbourhood to understand the extent to which their lives were impacted by the move to 107 Niddrie Road.

Research design

The research team decided to use a survey questionnaire with quantitative (closed) questions on 107 Niddrie Road and the wider neighbourhood, alongside qualitative (open) questions that sought to probe further into the residents' lived experiences. Numerous POE templates are available online, so rather than 'reinvent the wheel', the research team decided to undertake a scoping study and identify a survey that best suited the context. From this exercise, a POE template developed by the Old Oak and Park Royal Development Corporation (OPDC) in London (OPDC, 2018) was identified. Published in 2018 to draw long-term lessons from a large-scale urban regeneration project in West London, the template was based upon a robust evidence base derived from organisations including the UK Green Building Council (UKGBC) and the Zero Carbon Hub, among others. It contains a mixture of building- and neighbourhood-focused questions and uses closed questions on a Likert scale around fourteen themes: temperature, controls, lighting, energy, water, design, air quality, noise, safety and security, waste, transport, public areas, public amenities, and identity and community. The OPDC template can be viewed online here.

In consultation with the wider Niddrie Road research team, the survey questions were adapted to suit the context of a single building in an established neighbourhood, rather than the new buildings within a masterplanned community that were the focus of the OPDC. These adjustments consolidated the number of themes to six and added an open question for each theme to allow residents to reflect about their lived experiences in more detail. The consolidated themes were: thermal comfort and air quality (temperature, energy use, air quality, controls); design and ease of use of home and controls (design, space and layout, lighting); sensory aspects (noise, safety and security); water and waste (water, waste); transportation and accessibility (public transport and traffic, cycling); and community and neighbourhood (public areas and green space, public amenities, identity and community). A copy of the POE survey is provided at the end of the chapter in Appendix 1.

To gather the additional information that the research team wanted to collect on the residents' previous home and neighbourhood a simple 'pre-occupancy' semi-structured interview template was also produced that asked residents to reflect on their previous neighbourhood and its amenities, the energy they used in their previous home, their expectations about their new neighbourhood and moving into a flat in a retrofitted building, and their views on climate change. A copy of this semi-structured interview template is provided at the end of the chapter in Appendix 2.

Ethics and data collection

Following POE research best practice, the research team decided to conduct the POE twice per annum over two years to capture the evolving lived experiences of the new residents and to ensure that data on energy use and thermal comfort could be captured during both the winter and summer months (Trofimova et al., 2021). The decision was therefore taken to undertake the initial pre-occupancy interview and a 'first round' of the POE survey soon after the residents moved into 107 Niddrie Road between January and March 2023. This allowed the research team to capture the residents' views on moving from their previous dwelling and neighbourhood into the retrofitted building and the Strathbungo/Govanhill area, as well as their initial lived experiences during the winter months. A subsequent round of the POE survey will be conducted soon after the publication of this report between September and November 2023 to capture residents' lived experience during the summer months and, in 2024, a final round of surveys in the winter and summer will be conducted before the results are written up and published by CaCHE.

Considerable care has been taken by the research team to ensure the ethical integrity of the research. The research team were conscious that a POE survey required residents to give up their free time over a period of two years to complete the survey and, in so doing, provide data on their private, home life. Moreover, the POE survey was not the only imposition on their home life by the wider research team because the flats in 107 Niddrie Road were also being monitored by a team at the University of Strathclyde for a similar duration. To ensure good research practice, the team worked closely with Southside Housing Association to provide the new residents with as much information as possible about the proposed research and why they were being invited to take part. This information was initially provided to the residents on a Participant Information Sheet via their housing association contact. If the resident agreed to participate the Participant Information Sheet was shared with them a second time, this time via email or in person.

As part of the ethical evaluation of the proposed research, the research team decided that, where possible, the POE survey would be conducted in-person, rather than by a mail drop. This decision was taken with the hope that it would allow the research team to develop a rapport with the residents and to support those who might have trouble with English language comprehension to complete the qualitative questions. Furthermore, the research team decided to conduct the interviews in pairs with the intent that one of the two researchers could take notes while the other conversed with the resident while, at the same time, ensuring that both the resident and the interviewers were comfortable – this was deemed to be especially important because the interviews could take place in the residents' homes. Ethical approval for the research was secured by the UK Collaborative Centre for Housing Evidence, as part of its wider amended umbrella ethics approval status from the University of Glasgow's College of Social Science Research Ethics Committee.

For the first phase of the research, conducted during the winter of 2023, the research team used multiple methods to contact the new residents of 107 Niddrie Road, including email, phone and text message. If a resident did not respond, a reminder was sent approximately once a week for a maximum of three weeks – the intent being not to overburden residents with requests. Those residents that did respond were invited to choose a preferred location for the interview. Of the eight residents of 107 Niddrie Road, three took part in the first phase of the evaluation. All three participants lived alone. Two were male and one was female. Two of the interviews were conducted in the residents' homes and one was conducted in a local coffee shop. The remaining residents either declined to be interviewed, did not answer our request for an interview or failed to show up at the time agreed. Challenges with English language communication, availability during working hours and some confusion about the difference between the POE survey and the parallel technical monitoring exercise being conducted by the University of Strathclyde hampered the initial data collection. Efforts will be made to increase the response rate in the latter phases of the research.

Preliminary results

As the POE of 107 Niddrie Road is still in its infancy the research team is not yet able to share conclusive findings and results. A comprehensive analysis of the data will be conducted in late 2024 and a report will be published by CaCHE in 2025. In the meantime, the following preliminary results are provided to offer an initial snapshot of the emerging findings under the thematic headings used in the POE survey.

Pre-occupancy and previous address

The three participants had all experienced challenges at their previous address and were very glad to move into 107 Niddrie Road. Condensation in their previous flat was a particular problem for one participant, who noted that they had to use towels to keep the windows dry, while two participants stated that they had to use extra bedding and clothing to sleep as their previous homes failed to retain sufficient heat to keep them warm – one also slept on the sofa in the lounge as the bedroom was so cold. The three participants also all reported challenges with the wider building and neighbourhood. Security concerns in communal areas, a lack of shops and facilities nearby, and disagreements with neighbourhoods were common challenges. Climate change was a cause of concern from all three participants. One noted that "it's got to be dealt with" and another referred to the retrofit project at 107 Niddrie Road as an "excellent scheme".

Thermal comfort and air quality

The three participants were satisfied with the temperature of their new home at 107 Niddrie Road and with the temperature of the building's common areas. Two of the participants – one of whom h a gas boiler and one of whom had a heat pump – noted that their house heated up very fast when the heating system was on, while one of the participants found that their heating system, powered by a heat pump, was relatively slow to heat up. All three participants noted that they were very concerned about the cost of energy. It is important to note, however, that at the time of the survey, the participants had yet to receive an energy bill as they had only recently moved in. This question was also posed during a period of escalating energy costs across the UK due to supply challenges and the War in Ukraine.

All three participants were very satisfied with the air quality and air movement within their home, although one participant noted that they opened windows to improve air flow. One participant also noted that they could smell cooking and cigarette odours within the building. Air quality in the wider neighbourhood was not a concern for two of the residents, but one complained that the air quality was worsened by traffic, particularly on nearby Pollokshaws Road.

Design and ease of use of home and controls

The three participants were generally satisfied with the design, space and layout of their flats and the building. One participant noted that the building "really pops out" and another stated that the common areas were kept very clean. Opinions about the size of the flats and availability of storage was more mixed. One stated that their one bed flat was "just about big enough" while another noted that the flat was smaller than their previous home and that storage was a challenge. The participant that lived on the ground floor was also concerned about privacy and had installed screens. All three participants felt that their flats were bright. The rear outdoor space of the building was noted for being well looked after and useful to hang laundry.

Two of the participants noted that they were struggling with the user guidance provided for the hot water, heating and cooling systems. One noted that it was a "bit technical" and another said that their dyslexia made it challenging to understand. However, another participant stated that when "there's problems with building, everyone helps each other out". The same participant went on to state that this was especially the case when there were energy or other technical issues.

Sensory aspects

Two of the participants did not have any concerns about noise levels in their home or the wider neighbourhood, but one participant felt that the ventilation and heating systems were a bit loud. In contrast to the feedback they provided about their previous address, all three participants stated that they felt safe in their homes and in the common areas of the building, although two participants highlighted an issue with the building front door not fully locking. One participant noted that this made them feel anxious about possible bike theft. All three participants stated that they felt safe in the wider neighbourhood.

Water and waste

The participants did not raise any concerns about water, with two noting that the water tasted good and that they got strong water pressure in the shower. Waste was a more pressing concern for the participants. Although the participants reported that the backcourt area – the communal outdoor space at the rear of the building – was generally clean and useful for hanging laundry, two participants noted that rats were a problem at night. This is a common challenge in the wider Strathbungo/Govanhill area (Keenan, 2023). All three participants noted that the guidance on what to recycle could be better and one was concerned there wasn't sufficient space in the communal bins.

Transportation and accessibility

The three participants were pleased with the location of the building and its proximity to bus and rail links – Queen's Park railway station is located just behind 107 Niddrie Road and the bus routes on Pollokshaws Road are two minutes away. One of the participants did raise concerns about the variability of bus services and noted that there was no step-free access to the railway station. Another participant noted that "they walked everywhere". Car parking was not raised as a significant cause for concern by any of the participants and none of them were using a bicycle at the time of the survey. One participant did, however, note that there was not sufficient space to store a bicycle in the communal areas of the building, while another suggested that the wider area needed more on-street bicycle storage.

Community and neighbourhood

107 Niddrie Road is located a short walk from Queen's Park, one of the largest public open spaces in the Southside of Glasgow, as well as being a short walk from local shops and services. The three participants all noted that they were satisfied with the size and quality of the open spaces nearby but two lamented the fact that some of the open spaces were poorly maintained and the wider area was dirty. The participants were also generally satisfied with the local shops and services in the area. Two of the participants felt that a strong community spirit had developed within the building and one of the participants stated that there was also a nice community spirit in the wider area, especially among dog walkers.

Conclusions and next steps

While it is much too early to draw significant conclusions from the POE research underway at 107 Niddrie Road, the initial results suggest that the residents are enjoying a marked improvement in the thermal comfort of their living space compared to their previous address, but that they are still learning how best to use the heating and cooling controls in their new home. The evidence so far also shows that the location of 107 Niddrie Road, in a dense, mixed use urban area, allows residents to easily access public transport, open space and shops and services. This highlights the importance of understanding the lived experience of place in a holistic sense, both within and beyond the building envelope, and speaks to the wider need for future action-orientated retrofit research to consider these dynamics at the urban scale. As noted earlier in the chapter, the POE research will continue in 2023 and throughout 2024 before a more detailed analysis of the research data is conducted. A final report will be issued via the UK Collaborative Centre for Housing Evidence in 2025.

6.Conclusions: Outcomes, Key Benefits and Wider Lessons

Drawing together the work of the project and the emerging lessons from the parallel evaluation, what are the broader benefits we think will accrue from the Niddrie road project? We start by summarising each of the substantive elements of the evaluation.

Summary

The project evolved from a relatively undefined retrofit of a traditional tenement and a broad plan how to evaluate it when the bid to SFC was submitted, through a series of interactions between partners and a recognition of what can be done given, external factors and the realities of the built form and its condition became apparent. As a consequence, the evaluation of Niddrie Road took shape as a result of these constraints, the outcomes of the evaluability assessment and the real time decisions that were made. Chief among the factors shaping those decisions were (a) the agreed funding package, (b) the subset of retrofit components achieving planning permission (and consequences of those that did not like PV panels on roofs), (c) the condition of the property, and (d) the real time consequences for project delivery of the first three of the elements attenuated by the uncertainties and knock-on impacts of Covid-19 and lockdowns.

The critical decisions highlighted were:

- A focus on fabric first and EnerPHit which shaped the main components of the work undertaken (external and internal wall insulation; remodelling; airtightness; block level work; roof, floor and front external repairs, mechanical ventilation and wastewater heat recovery). Note that the choice of renewables was secondary to getting this energy demand reduction as a result of the fabric first work. The heat pumps decisions were driven by making the demonstrator project taken on an explicit renewables dimension, which in turn would be supported financially by the Scottish Government but was constrained by the planning permission achieved. Other valuable retrofit standards are available (also discussed below) and may involve an acceptable trade-off for landlords and owners: a lower cost but a retrofit that still achieves sufficient benefits, but does not require the same degree of external certificating constraints. One such example is the AECB methodology.[10] .
- The early decision to undertake a formal cost benefit analysis. Cost per unit were high but it was important to firstly identify the independent EnerPHit retrofit cost (£30,000-£40,000) and to recognise that a significant contingency is required in these sorts of projects because of the hidden costs of older buildings that do not emerge till the work is underway. On the other hand, the CBA properly accounts for the wider benefits of reduced carbon emissions which are substantial enough to tip appraisal decisions away from demolition and rebuilding and need to be factored into public policy decision on retrofit. The CBA is of practical value but a major undertaking in its own right
- The evaluation was characterised by a collegiate partnership working across the academic team, the housing association and the architect. This provided trust, facilitated sharing data and access throughout the project and was a good way (perhaps the only way) to manage the uncertainty of what was a complex process including the management of external factors outwith our control.
- A lesson learned concerned the airtightness testing decision. Future project management needs to ensure that such testing, clearly critical to reducing energy demand, must ensure that the ability to access and test the airtightness layer across the whole block is built into future contracts.
- There was also a wider sense that the sector, encompassing the built environment professionals and construction

10 See: https://aecb.net/the-aecb-carbonlite-standards/

sector, from the main contractor to sub-contractors – is at the early stages of embracing the skills, capacity and knowledge required to undertake this sort of work to scale. This is a classic market failure where there needs to be clear evidence of sufficient demand to incentivise investment in those skills, training and supply chains. Individual small-scale demonstrators are critical points of learning for the built environment professions but they will not shift the dial. The state, be it local or central government, needs to play a catalytic role to stimulate demand to encourage colleges, supply chains, to build the capacity required to bring efficiencies, lower costs and a more integrated response.

The cost benefit analysis (CBA) found that, in social net present value terms, the high-quality EnerPHit retrofit performs similarly to the less expensive, but also less energy efficient EESSH2 retrofit. The EnerPHit retrofit provides more benefits but is also more costly. We find, in general, that which retrofit option is better is highly sensitive to the assumptions used. Our results also 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. Although the costs are relatively high for Niddrie road, even when we decompose the different elements of the project and focus just on the retrofit, the benefits are considerable and far outweigh demolition and rebuilding. Adopting conventional government-approved methods to undertake the CBA, the evaluation strengthens the case for embedding carbon emissions costs and scenarios into appraisal of retrofit options for older housing stock like traditional tenements.

However, while the CBA shows than investment in retrofitting provides positive social value, this does not necessarily mean it will be viewed as financially beneficial by landlords or owner-occupiers. This is because some of the benefits, such as lower greenhouse gas emissions, are not completely captured by the homeowners (i.e. there are wider external benefits that do not accrue to residents or owners). Therefore, left to their own devices, owners may under-invest in retrofitting measures without further policy interventions on a regulatory or financial incentive basis. While we do not expect or assume that the good practice approach to CBA we have undertaken can be readily replicated, we are sure that above a minimum capital cost threshold for a project, the wider application of stripped-down robust models applying standardised assumptions and parameters, is perfectly possible and indeed important to the future of retrofit decision making and use of public funds.

Regarding the overall technical performance, energy consumption and targets, the overall performance, from a technical perspective, based on the data available to date, the Niddrie Rd retrofit appeared to be very successful in providing dwellings that are very low energy, comfortable, healthy, with high degrees of occupant satisfaction. It is, however, important to note that these are interim results to date and will not be verifiable until we have 12 months of data. It is also based on 6 out of the 8 properties. The monitoring period was also during a relatively mild winter, but a cool spring and in the context of the UK energy fuel crisis which may have constrained use. There are some issues which may be affecting energy use – for example one of the flats with heat pump heating has quite high electrical consumption which may be due to patterns of occupancy and electrical equipment used in the home.

The dwellings appear to be performing below the targeted levels of consumption, with estimated annual energy consumption for space 36.91 kWh/year for the gas flats and 4.89 kWh/year for the heat pump flats. From the 6 monitored combined flats and extrapolating to annual figures for the whole block suggests consumption of 20.90 kWh/m^{2}a.

This low energy use does not appear to have been at the expensive of thermal comfort, with good average indoor temperatures, generally within the Enerphit performance targets throughout this period. The dwelling also appeared to not have been unduly adversely affected by a period of very warm weather in the early summer. One dwelling is anomalous, but this is understood to be a comfort preference for this occupant. The dwellings internal air quality/ventilation remained below 1,000ppm CO_2 for the monitoring period, and there was no evidence from this monitoring of the MVHR systems being switched off or otherwise failing. At this stage there are no obvious concerns about presence of interstitial moisture in the construction. This will require on-going monitoring as conditions may change over time, and with more adverse weather conditions.

We also note that there were some initial technical problems and delayed maintenance completion with the heat pumps. We also note that there are clearly lessons to learn for more efficient and effective training in the use of different aspects of the 'kit' in the properties though as time went on there was also evidence of satisfaction with the homes and their warmth and affordability.

From the post-occupancy strand, initial findings suggest that the residents are enjoying a marked improvement in the thermal comfort of their living space compared to their previous address, but that they are still learning how best to use the heating and cooling controls in their new home. It was also too early to say anything definitive about their energy costs. The emerging evidence also shows location matters: a dense, mixed use urban area, allowing residents to easily access public transport, open space and shops and services. The post-occupancy evaluation highlights the need to understand the lived experience of place, both within and beyond the building envelope, and speaks to a requirement for not just retrofit research, but the design of action-orientated retrofit itself to consider these dynamics at the urban scale. This is just one of the ways in which the build project and the evaluation of the retrofit work complement and support one another.

Benefits and Lessons

We can stand back and highlight the main benefits of the retrofit work across seven specific headings.

1. Low Carbon Emissions. When compared to demolition and new-build, retrofitting buildings saves huge quantities of embodied energy and carbon. At Niddrie Road, we have achieved the best of both worlds; much reduced embodied carbon and much reduced operational energy into the future. How much depends on how occupants use their buildings, but it will be perfectly possible for them to remain comfortable on just somewhere between 5% and 20% of the typical pre-retrofit fuel bills.

A highly efficient building is no good, if the occupants don't know how to use it. The post-occupancy work suggests that there may still be work to be done to ensure that residents are in control of their environments though it was reassuring to see evidence that the tenants are working together to help each other make best use of their apartments. At Niddrie Road, an extensive system of both monitoring and tenant engagement should help to identify areas that need work and support the tenants and provide lessons for future projects so that residents make the most of their new energy efficient homes. This is another reason why post-occupancy work is so important for all future retrofit work.

2. Waste Water Heat Recovery. When the space heating demand is reduced by as much as it is at Niddrie Road, then the biggest component of most peoples' fuel bills are hot water costs. We designed wastewater heat recovery systems which use the heat from the water going down the shower or bath drain to pre-heat the cold water about to be used. In this way, we expect that costs (and carbon emissions) of hot water can be reduced by around 40%. The ongoing monitoring will test this assumption and will be reported later.

3.Thermal Comfort. The next major benefit for tenants will be that they can afford to live in comfort. In winter, it will not be expensive to keep the flats warm and in summer, it will be possible to keep the spaces cool. The Niddrie road retrofit project was completing when the cost of living crisis erupted across the UK with a focus on the spiralling cost of energy bills precipitating massive temporary government intervention. At the time of writing, we anticipate still historically very high average fuel bills and mass fuel poverty across the UK this coming winter. The high levels of airtightness and insulation (along with effective ventilation) radically reduce energy demand and visitors, including the research team, the housing association's staff and various comments from the residents indicate that the building is now highly adapted to require less heating and hence whether, prior to conclusive data evidence that we continue to monitor and collect, we can estimate just what the achieved fuel savings are compared to a nonretrofit benchmark. But we remain convinced that, at this time of crippling energy inflation, this will be a radical and significant improvement of the scale suggested above.

4. Controlled Humidity. Many homes in Scotland suffer from high levels of humidity, often in the form of condensation on cold surfaces. The air in Scotland is often damp and ventilation inadequate. Airtight buildings increase such risks. However, high performance MVHR has been used to constantly bring in fresh air and extract humid, spent air. Ducts are run to every room and so there is no risk of excess humidity building up. The risk is also reduced by an important part of the Passivhaus methodology, which is to eradicate all 'thermal bridges' which leak heat, but also provide the cold spots that lead to localised damp and mould – themselves critical issues for contemporary housing practice.

5. Safeguarding Heritage. Safeguarding our heritage is critical to a sustainable future if for no other reason than we couldn't possibly afford - in carbon terms - to demolish and re-build all of the country's homes. It is surely far better to protect the older homes and buildings that most people know and love, while ensuring that they consume a tiny fraction of the fuel that they currently do. Heritage issues were uppermost, with the street-facing facade carefully re-pointed in a traditional lime mortar, with damaged stone replaced with matching natural stone and other repairs made to restore the building close to its original condition.

6. Landlord benefits. The Niddrie Road project meets the original 2032 requirements of Social Landlords set out by Scottish Government, known as EESSH2 but these can be met with less rigorous alterations. The difference is that, at Niddrie Road, the practical consequences of the deeper net zero EnerPHit approach means that pressure on energy bills will be less, which in turn reduces pressure elsewhere on household budgets. This will likely lead to reduced arrears on rents, support tenancy sustainment and mean fewer empty or void flats.

7. Net Economic Benefits. We have seen that the project did cost a lot but also that the cumulative 30 years carbon savings and the net benefits make the project better value for money under all reasonable circumstances compared to demolition and new build. It is important that future decision making on deeper retrofit of our older buildings, including appraising different retrofit delivery and funding/subsidy options, takes proper account of these economic issues, especially embodied carbon.

We also need to recognize that there are positive externalities – the benefits of close to net zero housing apply more widely than just to the residents. This is a reason for the state to intervene in retrofit, but it is also an argument to think about providing finance and other helpful interventions to encourage owners to make that externality benefit possible. The related economic argument is that developing these programmes to a larger scale, increasing demand for retrofit, will in turn encourage supply chains: the virtuous circle of supporting the trades, installation, maintenance and manufacture of what retrofit entails – fabric first property investment, renewables and products like wastewater heat recovery and mechanical ventilation.

Final Reflections

First, even with ongoing monitoring and successive rounds of post occupancy evaluation still to come, we can be confident that the property is close to, if not meeting, the certificated EnerPHit standard. In terms of thermal comfort, health and financial benefits, significantly reduced energy demand and extending the life of a pre-1919 heritage building – the demonstration project has worked well. It has also provided lessons and learning for the wider tenement strategy, even if one such lesson might be to consider a wider range of near-Passivhaus alternative retrofit standards for specific situations.

Second, there are important qualifications about the transferability of findings from Niddrie road. This was an empty property wholly under the control of a social landlord aiming to fill a retrofitted empty property with social tenants. The reality is that most tenement blocks are mixed tenure with the management of different interests a critical

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UK COLLABORATIVE CENTRE FOR HOUSING EVIDENCE

APPENDIX ONE: Post-Occupancy Survey: Niddrie Road, Glasgow

The following survey is adapted from once has been developed by Old Oak and Park Royal Development Corporation (OPDC) in London/

We will be using the survey to gather feedback on what residents like the most and the least in their homes, the building they live in and the immediate neighbourhood.

All questions are optional and we would be very grateful if you could take the time to complete as much as you can. The data from the survey will be collected by the University of Glasgow and will be processed and anonymised pursuant with the [add something about ethics]

[Names of researchers] from Urban Studies and the UK Collaborative Centre for Housing Evidence at the University of Glasgow are conducting the survey on behalf of the [Official name of project] project team.

Please email jamest.white@glasgow.ac.uk if you have any questions or comments about the survey.

(A) Introductory Questions

The name of the respondent:

The date of the survey:

How do you identify your gender? (tick)

Male	Female	Other	Prefer not to say

What is your age?

How many people including yourself live in your household?

Do you live with children? (tick)

Yes	No

On which floor(s) is your home?

Do you have heat pump or boiler in your home?

Heat pump	Boiler

How many hours are you at home (including sleeping) during a typical (weekday / weekend)?

Weekday	Weekend

(B) Thermal Comfort and Air Quality

Temperature

How would you describe temperatures in your home during...

		-3	-2	-1	0	+1	+2	+3		n/a
Winter?	Too Hot	☐	☐	☐	☐	☐	☐	☐	Too Cold	
Summer?	Too Hot	☐	☐	☐	☐	☐	☐	☐	Too Cold	

How would you describe temperatures in communal corridors during...

		-3	-2	-1	0	+1	+2	+3		n/a
Winter?	Too Hot	☐	☐	☐	☐	☐	☐	☐	Too Cold	
Summer?	Too Hot	☐	☐	☐	☐	☐	☐	☐	Too Cold	

Is your home slow or quick to heat up during winter?

	-3	-2	-1	0	+1	+2	+3		n/a
Slow	☐	☐	☐	☐	☐	☐	☐	Fast	

Is your home slow or quick to cool down during summer?

	-3	-2	-1	0	+1	+2	+3		n/a
Slow	☐	☐	☐	☐	☐	☐	☐	Fast	

Energy Use

Do you worry about your ...

		-3	-2	-1	0	+1	+2	+3		n/a
electricity bills?	Worry	☐	☐	☐	☐	☐	☐	☐	Do not worry	
heating bills?	Worry	☐	☐	☐	☐	☐	☐	☐	Do not worry	

Please share any further thoughts about Temperature and Energy Use in the box below

Air Quality

How satisfied are you with the air quality?

		-3	-2	-1	0	+1	+2	+3		n/a
In your home?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
In your neighbourhood?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

How satisfied are you with air movement within your home during…

		-3	-2	-1	0	+1	+2	+3		n/a
Winter?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
Summer?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

How satisfied are you with odours within your home during…

		-3	-2	-1	0	+1	+2	+3		n/a
Winter?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
Summer?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

Please share any further thoughts about Air Quality in the box below

UK COLLABORATIVE CENTRE FOR HOUSING EVIDENCE

(C) Design and Ease of Use of Home and Controls

Design, Space and Layout

How satisfied are you with the...

		-3	-2	-1	0	+1	+2	+3		n/a
appearance of the building?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
the view to the outside?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
cleanliness of common areas?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
size of your home?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
size of the rooms		☐	☐	☐	☐	☐	☐	☐		
internal layout of your home?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
amount of storage in your home?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
size of back court?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

Lighting

How satisfied are you with the...

		-3	-2	-1	0	+1	+2	+3		n/a
amount of lighting?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
brightness of lighting?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
amount of daylight?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

Are blinds/shutters effective or not effective in blocking out glare (direct daylight)?

	-3	-2	-1	0	+1	+2	+3		n/a
Effective	☐	☐	☐	☐	☐	☐	☐	Not effective	

Please share any further thoughts about Design of Your House in the box below

Controls

What controls you have in your home? (tick)

Lighting	Hot water	Heating	Cooling

How satisfied are you with the user guidance provided for your home?

	-3	-2	-1	0	+1	+2	+3		n/a
Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

How easy is it to use your controls for…

		-3	-2	-1	0	+1	+2	+3		n/a
Lighting?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
Hot water?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
Heating?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
Cooling?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

Please share any further thoughts about the Controls in the box below

UK COLLABORATIVE CENTRE FOR HOUSING EVIDENCE

Noise

How satisfied are you with the noise…

		-3	-2	-1	0	+1	+2	+3		n/a
levels in your home?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
from other rooms?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
from your neighbours?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
from traffic?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
from the trainline?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
from people outside?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
from ventilation system?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
from heating system?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
from other sources?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

Please share any further thoughts about Noise in the box below

Safety and Security

How satisfied are you with…

		-3	-2	-1	0	+1	+2	+3		n/a
how secure your windows & doors are?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
the level of security in your building?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

How safe do you feel in your home during

		-3	-2	-1	0	+1	+2	+3		n/a
the day?	Unsafe	☐	☐	☐	☐	☐	☐	☐	Safe	
the night?	Unsafe	☐	☐	☐	☐	☐	☐	☐	Safe	

How safe do you feel in common areas of the building

		-3	-2	-1	0	+1	+2	+3		n/a
the day?	Unsafe	☐	☐	☐	☐	☐	☐	☐	Safe	
the night?	Unsafe	☐	☐	☐	☐	☐	☐	☐	Safe	

How safe do you feel in the local area

		-3	-2	-1	0	+1	+2	+3		n/a
the day?	Unsafe	☐	☐	☐	☐	☐	☐	☐	Safe	
the night?	Unsafe	☐	☐	☐	☐	☐	☐	☐	Safe	

Please share any further thoughts about Safety and Security in the box below

(E) Water and Waste

Water

How satisfied are you with the...

		-3	-2	-1	0	+1	+2	+3		n/a
water pressure in your home?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
taste of drinking water?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
size of your bath/shower?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
recycled water system?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

Waste

How satisfied are you with...

		-3	-2	-1	0	+1	+2	+3		n/a
the amount of waste storage at home?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
how much you currently recycle?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
cleanliness of communal waste areas?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
access to communal waste areas?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
guidance on what can be recycled?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

Please share any further thoughts about Water and Waste in the box below

Public Transport and Traffic

How satisfied are you with…

		-3	-2	-1	0	+1	+2	+3		n/a
the frequency of buses in the local area?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
the frequency of trains in the local area?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
the walking distance to public transport?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
the amount of car parking spaces?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
the amount of traffic on the roads?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
car sharing schemes in the area?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

Cycling

How satisfied are you with the…

		-3	-2	-1	0	+1	+2	+3		n/a
number of cycle spaces in the building?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
number of on street cycle spaces?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
location and access to cycle spaces?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
number of public bicycles available?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

Do you feel safe when…

		-3	-2	-1	0	+1	+2	+3		n/a
your bike is left unattended?	Unsafe	☐	☐	☐	☐	☐	☐	☐	Safe	
cycling on the roads in the local area?	Unsafe	☐	☐	☐	☐	☐	☐	☐	Safe	

Please share any further thoughts about Transport (public transport, traffic and cycling) in the box below

(G) Community and Neighbourhood

Public areas and green space

How satisfied are you with...

		-3	-2	-1	0	+1	+2	+3		n/a
the size and quality of parks/open space?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
the walking distance to parks/open space?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
how well landscapes in the neighbourhood are maintained?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
number of water features?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
cleanliness of local area?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
variety of outdoor play areas?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

Public Amenities

How satisfied are you with the...

		-3	-2	-1	0	+1	+2	+3		n/a
educational facilities in the area?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
exercise facilities in the area?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
health facilities (e.g. GP, dentist, hospital)?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
community facilities in the area?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
variety of leisure facilities in the area?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
postal services in the area?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
variety of shops in the area?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
variety of healthy food outlets?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	
variety of restaurants in the area?	Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

Identity and community

Do you feel a weak or strong community spirit...

		-3	-2	-1	0	+1	+2	+3		n/a
in your building?	Weak	☐	☐	☐	☐	☐	☐	☐	Strong	
in your local area?	Weak	☐	☐	☐	☐	☐	☐	☐	Strong	

Do you think this area of Glasgow is affordable or unaffordable in terms of living costs?

	-3	-2	-1	0	+1	+2	+3		n/a
Unaffordable	☐	☐	☐	☐	☐	☐	☐	Affordable	

Do you think this area of Glasgow is affordable or unaffordable in terms of rents?

	-3	-2	-1	0	+1	+2	+3		n/a
Unaffordable	☐	☐	☐	☐	☐	☐	☐	Affordable	

How satisfied are you with the overall services of the local council?

	-3	-2	-1	0	+1	+2	+3		n/a
Unsatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

How satisfied are you with the communication you receive from the local council?

	-3	-2	-1	0	+1	+2	+3		n/a
Unsatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

How satisfied are you with the overall services of the housing association?

	-3	-2	-1	0	+1	+2	+3		n/a
Unsatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

How satisfied are you with the communication you receive from the housing association?

	-3	-2	-1	0	+1	+2	+3		n/a
Unsatisfied	☐	☐	☐	☐	☐	☐	☐	Satisfied	

Please share any further thoughts about Neighbourhood and Community in the box below

APPENDIX TWO: Pre-occupancy Interview

Pre-occupancy interviews used to understand tenants' attitudes, experiences and habits before moving into the flats and to allow meaningful comparisons to be drawn with 107 Niddrie Road.

Them and their History

1. Tell us about yourself?
2. What was your previous building like?
    a. Did it have much outside space and did you use it?
3. What was your previous neighbourhood like?
    a. Was their space for car parking and did you use it?

Energy Use

4. Thermal comfort in the previous dwelling: how did you make yourself comfortable?
    a. Managing draughts?
    b. Condensations?
    c. Clothing
    d. Location within your home
    e. Electric vs gas
    f. Expensive fixes: fan heaters
5. Was it expensive to heat your home?

Expectations and Intentions

6. What are your expectations of the new flat?
7. What do you think about your new neighbourhood?
8. How do you feel about climate change?