Defining and identifying complex-to-decarbonise homes and retrofit solutions

Annex C – case studies

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Annex introduction

This annex accompanies the main report ‘Defining and identifying complex-to-decarbonise homes and retrofit solutions’. This annex sets out summaries for the ten case studies that have been developed for this research, which include identification of the relevant complex-to-decarbonise (CTD) attributes and how these were addressed by the project. The summaries set out the measures employed, their impacts and any lessons learned. Each case study also provides insights for the identification of CTD homes, and participant recommendations for CTD Identification Framework use cases.

The annex uses the terminology complex-to-decarbonise (CTD) homes to describe homes which have been identified as those with one, or a combination of, certain physical, locational, occupant demographic, or behavioural attributes that prevent the effective decarbonisation of that home until they are addressed. These attributes may constrain the design and delivery of measures to improve energy efficiency, decarbonise heating, and realise occupant benefits (e.g., increased comfort and affordability of domestic heat and energy). These effects may be amplified by one or a combination of numerous system-level factors including financial (e.g., feasibility and affordability of measures), economic (e.g., supply chain and materials availability), and/or organisational capacity and capability (e.g., workforce skills).

Readers should note that the case studies have been anonymised, and as such identifiable information has been changed. Stock images have been sourced for each case study and are for illustrative purposes only. These images represent similar archetypes and external property characteristics that are relevant to the case study's CTD attributes. In some cases, these images do not reflect all property characteristics, where closer matches were not available. For example, the age and style of the case study property may differ to the image used. We encourage readers to refer to the property characteristic information provided at the top of each case study in combination with the illustrative images.

Case Study 1: Traditional building demonstrator with thermal upgrades

Property characteristic	Information
Date property built	1850s.
Number and type	One neo-gothic style lodge.
Walls	Mass masonry walls, with coursed snecked ashlar.
Traditional or heritage features	Gabled style, with an L-shaped plan (with modern extension). Lath and plaster internally.
Other notable features or aesthetics	Diamond flues and curvilinear barge boarding.
Heating type	Condensing boiler, with localised electrical heating in addition.
Tenure	Property in care.
Location	City in Scotland.
EPC and SAP before & after	Before: EPC F, with SAP rating 35. After: EPC C, with SAP rating 71.

Illustrative property image:

Similar archetype image used for illustrative purposes only.

Work elements	Information
Project overview	The lodge is a listed building and used as a visitor centre. Its comparable scale to a domestic dwelling made it well suited for showcasing a range of thermal upgrade measures that have been tested on previous domestic projects, which strike a balance between building conservation and energy efficiency. The property did not have any previous measures installed and was unimproved in energy efficiency, enabling the organisation to follow a whole house retrofit approach. The overall aim for the organisation was for the property to act as an exemplar to demonstrate best practice for energy efficiency retrofit of traditional domestic buildings.
Time	The pre-intervention monitoring and design work started in 2015. Works were completed in July 2017. Monitoring of the building resumed in February 2018 and carried out until late 2019. Additional works were carried out in 2021 and there is currently a programme of works to replace the boiler and introduce a renewable heating system from 2023.
Cost and funding	The retrofit work cost approximately £40,000, (alongside other non-retrofit work), noting that prices have significantly increased since then. A further £2,500 was spent later to add insulation to small ceiling areas that had been omitted before. The team tried not to do any unnecessary works, as they wanted it to be replicable.
CTD attributes	**Physical**: Generally speaking, there can be a challenge with wall insulation where the gap behind the wall linings can be quite thin (38mm is quite standard) or where decorative features, such as wall panelling exist, which can be limiting. Insulating coomb[1] ceilings can also be challenging, especially where there is limited access to the loft areas, meaning ceiling hatches have to be enlarged to give more space and improve safe working access into these areas. For this project, such physical challenges were mitigated as the team has developed good knowledge through their 15-year experience in retrofitting traditional buildings. **Locational**: The lodge's location between places of national significance meant visual impact and disruption had to be mitigated. **Occupant, demographic and behavioural**: there were no occupants at the time of the works and office functions were moved out. **System-level**: The contractor needed assistance with the installation of the wood fibre insulation, as they had not used it before but were able to use it successfully. Finding the right contractor can be a key challenge, as experience of working with traditional buildings or the flexibility to follow the organisation's approach, is required. It was important that the team had the expertise in house to direct/supervise the work and could accommodate increases in cost. This can normally add significantly to the overall cost but was absorbed by the organisation.

[1] Coomb space is a term used in Scotland and refers to a room in the roof, shaped by the slope of the ceiling.

Work elements	Information
Design and measures: addressing CTD attributes	**Design**: Overall, a fabric first approach was adopted. **Insulation**: Cellulose fibre insulation was blown into the air gap behind the existing lath and plaster wall linings. Wood fibre board was used in between the rafters and slid into the coomb space. **Windows and doors**: Glass in existing casements was upgraded to slim profile double glazing and the windows were also draughtproofed. Aerogel blankets were added internally to the panels of the external doors to improve their thermal performance. The overall approach focused on: breathability in the choice of materials; minimising waste (reducing unnecessary replacements); returning some features to a more traditional aesthetic; and to deliver minimum changes to achieve maximum results for the SAP assessment. **Heating control and delivery**: A thermostat was installed to control the heating for localised infrared heating panels. These panels were initially fixed to the wall but following the first SAP assessment they were unmounted to be mobile and gain SAP points (as SAP does not favour secondary heating). The panels were subsequently moved to a different location, which was open to the public during Covid-19. The combi gas boiler was relatively new at the time of the works, so it was not replaced. However, for the second phase of works to decarbonise heating, the organisation has considered several options, most of which would entail lifting the floorboards again (thus causing significant fabric disruption) to replace pipe work there. Instead, they are installing a pilot data centre heating technology which will not result in any such disruption. This work is currently still underway. **Assessment**: The U-values of walls and roof elements were measured and BIM and laser scanning were conducted upfront. Measurements were also taken of the relative humidity and temperature, thermal imaging, hygrothermal testing and air pressure tests.
Delivery: addressing CTD attributes	**Regulations and guidance**: work followed best practice guidance for heritage buildings (Guide to Energy Retrofit of Traditional Buildings).[2] Various mandatory building and planning regulations were followed, including Listed Building Consent (LBC) regulations, Building Control and Scheduled Monument Consent legislation, meaning the local authority was consulted prior to the works. The organisation also checked with the local authority to ensure a Listed Building Consent application was not required for the works. PAS 2035: 2019 was not in effect at the time of the project, which completed in 2017. **Wider considerations**: This project treated the property, which was being used as a visitor centre, as a dwelling home in terms of its energy modelling and the optimal target condition, and to ensure it could provide a comfortable, warm and affordable home.

[2] https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=47c9f2eb-1ade-4a76-a775-add0008972f3

Work elements	Information
Impact and evaluation	**Energy efficiency and thermal performance**: The property was initially evaluated using a SAP assessment, which showed that its Energy Performance Certificate (EPC) rating improved by three bands. More extensive evaluation found that there were improvements to the building's thermal performance, comfort, and indoor air quality. Heritage fabric: Another successful impact was that there was no loss of historic fabric whilst and future risks to the fabric were minimised. **Moisture**: Extensive building fabric monitoring confirmed that careful intervention does not increase hygrothermal risk. Post-refurbishment there is a much lower relative humidity level improving the internal environment and the wall conditions. Testing on air leakage showed an improvement of 26% reduced to $11.25m^3/h/m^2$. **Impacts of specific measures**: The U-values show an improvement in thermal performance of the walls of around 36% (0.65 W/m^2K post improvement compared to 1.07 W/m^2K before the works). Monitoring showed that: mass masonry walls perform much better than estimated in standard energy modelling software; lime plaster also adds to the thermal performance; and where vapour and capillary active materials are used for insulation, internal humidity is controlled, and the roof is wind and watertight, moisture does not build up. Monitoring also provided a better understanding on the parameters of adding fitting roof insulation and the importance of maintenance, the use of vapour permeable insulation materials and ventilation in an energy retrofit. The property is now serving as a demonstrator for measures and best practices.
Best practices and lessons	This case study has identified the following best practices and lessons for listed buildings in particular: **Retrofitting older buildings**: The works have shown that a traditionally constructed listed building can be thermally upgraded in a sensitive and proportionate way, improving its performance, whilst respecting the existing historic fabric. During this work, the opportunity was taken to reinstate lost period detail which enhances the building's character and significance. As it is an accessible site, it has been effective in allowing stakeholders to view the measures and understand what can be done in other traditional buildings. **Selecting measures**: Traditional approaches to ventilation have been successful, and the building is still warm and comfortable, and moisture is controlled. Solid wall insulation has proved to be durable and effective, providing a significant improvement on the hygrothermal performance of the masonry walls post-insulation. This template of refurbishment or selection of measures may be adopted to many other traditional buildings of this type, to bring them up to the standards required under legislation.

Work elements	Information
Relevance and insights for CTD Identification Framework	**Identification**: This case study demonstrates fabric first approaches can be effectively employed to decarbonise listed buildings. *“What should be noted is that traditional buildings are unique and there should not be any “one size fits all” solutions…. For historic and traditional buildings there can be a bit of myth that they are HTT/HTD, when you do have the good base of materials and skills. For example, other modern and unimproved properties can be more difficult to retrofit and to achieve good indoor air solutions.”* *“The best thing we can do to reduce carbon emissions in construction is to reuse our existing buildings and make them more energy efficient.”* **Potential uses of the framework**: This case study highlights the role of knowledge sharing and approaching the retrofit of listed buildings with due care and understanding the risks and opportunities. *“Some of the key things to look for and address early is water ingress, and to consider ventilation in the right way for each building and its materials. There is a need to respect older buildings and how they have been built that way and why. As soon as you introduce insulation, you change the balance and the way the building was designed to work, so that needs care and attention. There are very good examples available, including this one, that demonstrate what you can do to retrofit different types of historic and heritage buildings in a sympathetic manner.”*

Case Study 2: Conservation Area flats with mixed tenure

Property characteristic	**Information**
Date property built	1960s.
Number and type	Twelve flats and two business units in a B-listed modernist development of three blocks of 1-2 bedroom-flats.
Walls	Cavities.
Traditional or heritage features	B-listing. Located in a World Heritage Site and in a Conservation Area.
Other notable features or aesthetics	Architectural features to be protected. A Housing Development within a post-war complex, designed by a prominent architect.
Heating type	Gas boiler.
Tenure	Mixed-tenure: private owner, private rented, social housing tenants, a short-term holiday let and commercial ground floor units (hospitality businesses).
Location	City in Scotland.
EPC and SAP before & after	Before: EPC D (9 units), EPC C (3), with SAP ratings 58 to 68. After: EPC C (4), EPC B (8), with SAP ratings 78 to 82.

Illustrative property image:

Similar archetype image used for illustrative purposes only.

Work elements	Information
Project overview	These mixed tenure flats were in both a World Heritage Site and in a conservation area of significant importance. The organisation aimed to develop a demonstrator site as a case study of best practice – to demonstrate that a sensitive balance can be struck between conversation and energy efficiency in a CTD treat property, and to develop an integrated delivery model that would demonstrate best practice and could be replicated in other historic building of different periods (pre 1919 in particular) and where mixed tenure exists.
Time	The preparatory work started in December 2017, which included community engagement, match funding, financial and tender processes and the design stage. The site works then started in March 2020 (then paused due to Covid) and were completed in March 2021.
Cost and funding	The total project cost was £1,115,000. Energy efficiency measures were funded by: Scottish government (approximately 33% of the total cost) and SP Energy Networks Green Economy Fund., The organisation's conservation Funding Programme Grant was also used for the wider conservation works with owner contributions (about 30% of the upfront costs and the remaining 70% covered by Conservation Funding Programme Grant). The Conservation Funding Programme Grant was then repaid based on tenure type e.g., for domestic properties, it is repaid when the property is sold or transferred. Overall, the work cost between £63,000 to £94,000 per property depending on the amount of work to be carried out in the property itself and the apportionment of the costs of communal works between each property.
CTD attributes	**Physical**: There was potential thermal bridging (given the 1960s design using concrete and modern architecture detailing) and mould and damp issues, whilst the building was not a symmetrical design which can cause issues. The homes had single glazing windows, with twenty different types across the units, and the homes had no existing insulation. Existing issues or original design flaws had to be investigated and addressed e.g., water ingress, current damp and mould, thermal bridging, and cracks. **Locational**: Location in World Heritage Site and a Conservation Area. There were also limits to scaffolding use during the local festival period. **Occupant, demographic and behavioural**: These were significant challenges for these homes. Tenements are facing additional, inherent legal/organisational barriers when undertaking repair and improvement schemes, which created coordination challenges for the project with decision making, apportionment of costs, payment processes and other legal aspects. The current legislation and the absence of an entity at the start of the project to manage the common areas, shared services, and maintenance of the enactment exacerbated these coordination challenges and added to the complexity of such projects.

Work elements	Information
	The mixed-tenure and mixed-use nature of the flats was also a challenge. Expectations and disruption differed according to resident type, the use of the flats and commercial units. These differences can affect the willingness to proceed with a project and generate resistance at times. The organisation felt that the heating system would also have been difficult to solve with the current technology and given the mixed occupancy challenge. A communal heating system involving an air source heat pump was considered but not developed further due to challenges associated with additional capital and high running costs, joint maintenance, joint ownership and potential buy-in from all flat owners. **System-level**: There can be a need to train and upskill the delivery supply chain as there is limited care or knowledge for working with such properties and their complexities – to understand the issues affecting the performance of these buildings and their heritage significance that must be preserved.
Design and measures: addressing CTD attributes	**Design**: This was a fabric first and 'whole-building' approach. **Surveying**: There was detailed surveying and checking in advance of project design to understand the property and spot any water ingress. This process included: dynamic simulation modelling and detailed ventilation calculations with an academic partner; air tightness tests to understand how the building was performing; producing a conservation statement before the start of the design phase, which identified elements of heritage significance which needed to be preserved; borescopes inspect cavity wall conditions, giving confidence that measures would not have created water ingress or damage the stone elements of the wall; hygrothermal risk assessments survey; and an academic partner monitored the ventilation with different options, such as decentralised MEV or MVHR, and how it performs in this building. The surveying found condensation and moulds issues, driven by the presence of significant thermal bridging due the original design of the building and in there being no insulation with single glazing windows, which lead to cold surfaces, alongside a lack of proper ventilation in the flats. The air tightness tests also helped identify that air from the outside was circulating in the cavity through a stack effect – leading to the outer wall of the cavity wall being bypassed and the inner wall being cooled by external fresh air. These issues led to technical solutions being proposed, as the measures listed below and explained in the delivery section further below. **Measures included**: New windows, ventilation (MVHR), lighting, render and roof repairs, cavity wall repairs and insulation, more efficient boilers, loft insulation and flat roof repairs and insulation. A key element was helping tenants to coordinate and make agreements and take work forward. This involved many stakeholders and took time, as detailed below.

Work elements	Information
	Decarbonising heat: Low carbon heating was considered, such as a communal heating system/renewable, but it was deemed too complex for this property given the project's timeframe, the costs and the complexity to deploy it, given the mixed-tenure and mixed-use (dwellings and commercial) nature of this property). **Remedials**: Some repairs were required to the construction, the concrete elements, with the render, the cavity wall, and the roof. **Windows**: Some units had double glazing but with inappropriate window pattern/material (uPVC which is banned in conservation areas) from previous replacements. The windows were replaced with a unified scheme that reinstated the original design consistently across the whole building.
Delivery: addressing CTD attributes	**Regulations and guidance**: Scottish building regulations needed to be adhered to for making the replacements and upgrades. The project did not follow PAS 2035 but followed similar principles. For example, the decision of the material to use for IWI was well considered in ensuring the right product guarantee and certification. **Protecting the heritage and aesthetic value of the building**: A first step in the project was to produce a conservation statement by a conservation accredited architect. It identified the heritage (historical, social, architectural) significance of the building and the related elements that needed protecting. This helped define what changes to the building were acceptable that did not affect its heritage significance. **Addressing general thermal bridges & mould issues**: MVHR was a suitable solution as the building is not traditionally constructed but the walls are made of cement render that do not breathe. Double glazed windows and insulation (attic and cavity wall) were also very important, though the window reveals were not insulated as the MVHR system and the cavity wall insulation were considered enough to avoid any condensation risk there. Additional investigations were undertaken to ensure the technical solutions were well designed and delivered, including: • A condition survey of the cavity wall (externally), where cracks in the outer wall could have increased the risk of water ingress from wind-driven rain after the installation of the cavity wall insulation, if not repaired. • Borescope surveys to assess the internal condition of the cavity, to check the width, cleanliness (no debris such as mortar) and presence of water ingress. This indicated a lack of wall ties in the cavity wall in some areas. • Assessment of the hygrothermal behaviour of the cavity walls, interstitial condensation risks (for the materials that form the wall) and the impact of the proposed insulation strategies for the building. These helped confirm the suitability of the cavity wall insulation and the necessity to install a MVHR to manage moisture within the flats.

Work elements	Information
	Resident engagement: 23 meetings were held over the three years, which began before the design phase. The mix of tenure was complicated, and the group needed the heritage organisation to coordinate and facilitate communication and decision-making. An owner association was created with all residents included, as a vehicle to support the project. Further, residents didn't pay anything until the end of the design stage and tender process, so they did not financially commit to the project before the costs and benefits and how it would work could be communicated first. Residents stayed in situ and the works were done carefully to minimise disruption and the cavity wall insulation was not too intrusive which facilitated the process.
Impact and evaluation	**Energy efficiency and thermal performance**: A range of in-situ technical tests were used for air tightness and data collection of heat demands, energy use, temperature, and humidity, alongside occupier feedback through interviews. These showed relative improvements in thermal and heat performance and indoor comfort. **Pre-installation modelling**: Dynamic simulation modelling in advance was used, to give a good handle on what the energy use savings, carbon reductions and bill reductions could be. However, this assessment was estimated and lacked baseline information. The property has also served as a demonstrator for measures and sharing learning on the facilitation and installation. **Post-installation improvements**: Other measures of success were: • The reduction of mould and damp issues. • Improved home comfort. • Futureproofing the energy efficiency improvement and performance of the building fabric through fabric repairs. • Improvement of the heritage/aesthetic of the building and reinstatement of heritage value (e.g., original painting scheme, windows scheme and repair to concrete elements). • Addressing safety risks from concrete spalling and ongoing issues such as water ingress and mould issues.
Best practices and lessons	This case study has identified the following best practices and lessons for mixed-tenure and multi-occupancy whole house tenement retrofit in Scotland in particular, and for across CTD home types: **Monitoring and evaluation approach**: This was valuable as a demonstrator project, to test approaches, measures and feasibility and create a replicable delivery model. M&E was needed alongside education and sharing knowledge. The actual baselines should be clear and used to calculate/measure actual performance changes.

Work elements	Information
	Co-benefits: Where possible, other benefits should be added to the retrofit offer such as home condition and look/conservation improvements, renovation, and health improvements. Transparent **planning**: There was a need for a consistent and focussed project management skills/processes (for the client and the facilitator), with resilience and ability organise a group of residents/owners. Doing the pre-engagement and design work first to help develop understanding and buy-in was critical to get residents on-board and then willing to contribute for once funding could be started to be used to start work stages. **Expertise and skills**: There is a key role of skilled construction professionals and the design team, who assess the risk of proposed interventions and can help avoid inappropriate interventions. This is even more the case in historic buildings where considerations should be given their heritage significance and how they were designed to perform, whether based on the use of traditional materials or not (the latter for this case study). **Low carbon heating**: Decarbonising heat was too complex, on top of the project delivered and time was needed to deliver a proper feasibility study given the important implications to residents' home comfort and energy bills. **Guidance**: There is lacking evidence and guidance on the roadmaps to affordability and sequencing measures in a way that does not jeopardise the integrity of the building or the health of the residents. There is still a lack of understanding of a sequenced approach (embracing a whole building approach but delivering the measures in different points in time) as there is a big focus on whole building retrofit carried out at once – not everyone is in a position to do this– both technically and financially.
Relevance and insights for CTD Identification Framework	**Identification**: This example demonstrates that fabric first approaches can be effectively employed to decarbonise historic buildings that are listed and/or located in conservation area and with mixed-tenure. However, decarbonising heat will enable the full decarbonisation of historic buildings as improvement to their fabric is limited to an extent. This example surfaces a range of occupant and behavioural attributes. **Potential uses of the framework**: This case study highlights the need to understand an individual home's requirements, as well as to share knowledge on what works, and the importance of data to offer baselines. *"One of the common issues when planning energy retrofit at a city/region scale is in not having a detailed comprehensive understanding of the existing housing stock in this given area– common characteristics, such as dimensions, building layout, design, construction materials, challenges, priorities to improve efficiency … then you can really struggle to prioritise and to define the most efficient and replicable approach. It does also matter how many of each type you have. Knowing what you are working with is really key, though there are information and statistics gaps."*

Work elements	Information
	"The barriers need to be well understood, for what is blocking x and why. And to have practical guidance and case studies to show how these have been overcome – there is a lack of detailed case studies publicly available." *"The industry could do better at sharing knowledge and what works where. There is a need for feedback on how people do certain measures well and ideally a library to support others and to reduce the need to re-invent the wheels. This helps others to compare their approach and project to elsewhere and understand if and where they can do better to improve performance. Key information items are baselines, costs, performance, and how people combine solutions."*

Case Study 3: 1930s semi-detached whole house retrofit

Property characteristic	Information
Date property built	1930s.
Number and type	One semi-detached, 3-bedroom, with small, 2-storey extension with a flat roof and timber-frame to rear of the property.
Walls	Cavity Wall (with earlier cavities, which were narrow).
Traditional or heritage features	Some period features e.g., bay windows, brick effect.
Other notable features or aesthetics	Mock Tudor gable.
Heating type	Combi boiler and two gas fires, on mains gas.
Tenure	Social housing.
Location	A village in the West Midlands.
EPC and SAP before & after	Before: EPC D, with SAP rating 67. After: EPC B, with SAP rating 83.

Illustrative property image:

Similar archetype image used for illustrative purposes only.

Work elements	Information
Project overview	This is a Social Housing Decarbonisation Fund (SHDF) project with a 1930s semi-detached home of solid wall and early cavity construction. This property was void and was selected as a future proof property to demonstrate how to sequence works with fabric first and whole house approach. There were no pre-existing energy efficiency measures in place.
Time	The project lasted 18 months, following the SHDF timeline. Works were completed December 2022. The cost per home was approximately £55,000. This was mostly from SHDF funding, with some top-up by the provider to deliver retrofit and meet needs beyond EPC C.
Cost and funding	The cost per home was approximately £55,000. This was mostly from SHDF funding, with some top-up by the provider to deliver retrofit and meet needs beyond EPC C.
CTD attributes	**Physical**: Bay windows made the external wall insulation (EWI) more technically difficult for the detailing. Further upfront assessment revealed remedial work was needed, including challenging elements such as the loft set-up and the roof condition. Loft hatches had to be removed and continual insulation ensured. Additional scaffolding needs increased health and safety requirements. Property deterioration and roof condition meant re-roofing was required. This included additional roof braces and the removal of chimneys. These remedials and complexities were in addition to what was found from the initial basic information and increased the work requirements for the property through SHDF. Overall, the scope of the job increased as the work continued and more design detailing, remedial works and installation needed deeper consideration. A significant amount of internal remedial work was required following installation of the measures that the provider planned for. This was seen as a good learning curve for the team and wider programme. **Locational**: The streetscape with different houses meant the provider required full planning permission to do the work. Design changes were needed to ensure they incorporated and retained certain features on the front elevation including the property's brick effect. **Occupant, demographic and behavioural**: N/A. **System-level**: Materials and skills shortage in the supply chain was a major challenge for the provider and contractors involved. Certified labour with the appropriate PAS certified skills were in short supply. For example, for EWI, no one organisation had enough qualified staff to deliver, therefore four different contractors were used. A contractor also had to be sourced from significant miles away in Wales for the airbrick rendering.

Work elements	Information
Design and measures: addressing CTD attributes	**Design**: The project followed PAS 2035 with retrofit assessment, coordination, and design. The 3-bedroom home was modelled for six occupants and a heating strategy developed to support the design of measures and enable decision-making. The project employed a fabric first and 'no-regrets' approach. **Surveying**: A greater number of detailed surveys were needed upfront, beyond what was specified for PAS 2035 assessment. This included structural engineering reports, Level 3 RICS surveys, borescope surveys, and wall tests to see how strong the structure was to hold EWI weight. This meant CTD attributes could be picked up and responded but this led to reactive rather than planned delivery. Structural engineering reports were undertaken to identify issues that could prevent the use of Solar PV (Photovoltaic) measures, as well as the need for insulation in the extension's flat roof. **Measures included**: EWI, internal wall insulation (IWI), Solar PV, air source heat pump (ASHP) with water tank, loft insulation (400ml), flat roof insulation, windows and door replacement (to U-Value 1.2), door undercuts and trickle vents for windows, air bricks for the suspended timber floor, mechanical ventilation and eaves and ridge ventilation. Key points of these measures are detailed below. Additionally, remedials included structural repairs, brickwork stitching, roof bracing and damp proofing. **Front and back of the property**: At the front of the house, internal wall insulation (IWI) was used, given the need to retain its features, whilst at the back of the house external wall insulation (EWI) was installed. **Windows**: PAS 2035 was followed such that the windows, including those with archways, were moved out into the EWI. The sills ended up further out in depth due to the internal remedials. The windows were replaced with those with higher U-value specification. A very specific profile was used for their fit, and they required careful installation to ensure this fit. The project team designed a solution which provided a continuous tightness barrier between the window and opening, and ensure the windows were issued with guarantees. This required significant liaison and review with different bodies to ensure it was fit for purpose. The social housing provider was involved in this and fed into the technical specification. **Underfloor insulation**: There were challenges in installing underfloor EWI below ground due access and depth of clearance requirements, given the suspended timber floor and air bricks. The project team fed this back and led to change of the SHDF approach requirements. There were also issues with the positioning of the vents for the underfloor insulation, and the requirements for ventilation and air flow, as the property's vent positions created difficulties. In future, the team are considering a suspended timber floor, as they could not get the supplier to do it here. Therefore, at this stage the underfloor ventilation system was improved with air bricks.

Work elements	Information
Delivery: addressing CTD attributes	**Regulations and guidance**: PAS 2035 Risk Pathway C was followed. The provider followed a sequence of data capture of the dwelling assessments and passed information on to the retrofit designer, who could then install the right measures and materials in the right sequence. Where there were interactions between junctions, the right design details are there to mitigate any unintended consequences, like damp, mould, and condensation. **Resident engagement**: For the wider SHDF programme beyond this home, the provider developed a robust customer engagement plan tailored to residents. This was focused on streamlining customer communications, such as reducing the number of contact points, to support clarity and consistency. Communication consisted of webinars, phone calls and face to face engagement, according to residents' preferences. The social housing provider delivered post-work support and formal handover through detailed house walk-throughs with residents and home guides. The provider also shared information about warranties relating to the works: e.g., how to avoid damaging new measures, including pin-point thermal bridging and causing water ingress due to fixings in the EWI. The purpose of this was to be open and honest upfront.
Impact and evaluation	**Monitoring and evaluation approach**: Per PAS 2035 guidance, 12-months of technical monitoring with customer and satisfaction surveys were undertaken. **Energy efficiency and thermal performance**: The property reached EPC B, and led to a significant reduction in heat demand (102.4 kWh/m2 (reduced from 113.4 kWh/m2) **Carbon reduction**: The carbon reduction was 3.194 tonnes. The house has very successfully retained its features whilst reaching a very high level of performance and structural soundness: it is well future proofed and is ready for its medium-term plan.
Best practices and lessons	This case study has identified best practices and lessons for properties of similar age, wall type (e.g., early cavities), and features (e.g., bay windows) in particular, and for across CTD home types: **Upfront property assessment**: The project shows the importance of understanding properties from the outset and undertaking necessary additional surveys and assessments. With the CTD elements, the provider approached design and delivery with care and close attention to PAS 2035. **Tailored resident engagement**: The tailored and resident-centred engagement approach used for the wider SHDF programme by the provider was a key factor for success and to ensure homes meet resident needs and are looked after well into the long-term, and to help navigate a difficult user through work disruption with transparent communication.

Work elements	Information
Relevance and insights for CTD Identification Framework	Identification: This case study clearly demonstrates the physical attribute of previous work and past maintenance, where a lack of good upfront data was a challenge and more detailed surveys identified further remedial work needs. Potential uses of the framework: This example identifies some uses of a framework in guiding organisations on what to check for and better understanding a stock of housing upfront. “Having that form of guidance that is broken down by property age, archetype, with some key bullet points on what to look for.” “Another use case is in whether that property is right for the program that an organisation wants to do. So having a property list with a good amount of reserves that are actually project ready is very useful. “No house is of course the same – and unless you get out on site and physically look at your properties you won’t know if there’s any variations or specific details. Though if you’ve got an overarching framework that can provide a checklist on properties that can be useful!”

Case Study 4: Pre-fabricated home retrofit with resident decanting

Property characteristic	Information
Date property built	1950s.
Number and type	Eleven 3-bedroom semi-detached houses. Reema prefabricated homes.
Walls	Concrete panel with hollow voids.
Traditional or heritage features	N/A.
Other notable features or aesthetics	N/A.
Heating type	Gas or storage heating – some had fossil fuel gas focal point fires.
Tenure	Social.
Location	Town in South East England.
EPC and SAP before & after	Before: EPC D (6 homes) and EPC E (5), with SAP rating unknown. After: EPC B (10), and EPC A (1), with SAP rating unknown.

Illustrative property image:

Similar archetype image used for illustrative purposes only.

Work elements	Information
Project overview	A set of semi-detached early 1950s pre-fabrication Reema homes where 11 were retrofitted by a social housing landlord. The landlord offered to carry out the work for the three private homes in this set but they did not want/were unable to participate. The homes already had 150mm of loft insulation and double glazing, but not all were in good condition.
Time	The project started in 2009 and lasted 12 months, completing in 2010.
Cost and funding	The works cost approximately £30-40,000per home for the retrofit element. This was largely funded by social housing landlord, with some EU ERDF funding including for skills, ECO funding for solid wall insulation, PV Clear Skies funding for solar.
CTD attributes	**Physical**: These were pre-fabrication properties which were non-standard builds without wall insulation or traditional cavity, effectively making them solid wall. The walls were large panelised concrete frames which were hollow, with some metal reinforcing which had rusted in places, and corner posts. Panel joins were visible between floors, mid front and rear elevations and in the gable end walls. There were also outbuildings with low quality structures that needed rebuilding. It was necessary for a structural engineer to survey the homes for defects prior to retrofitting. **Locational**: N/A. **Occupant, demographic and behavioural**: The homes were expensive for residents to heat, and there were some instances of mould and damp. Residents also needed to be decanted (moved from their homes) during the work, which needed careful management and led to time delays and increased costs. **System-level**: There was also some delay with using the in-house workforce of the housing association as skills capacity building for the external wall insulation system was needed.
Design and measures: addressing CTD attributes	**Design**: The project used a fabric first approach, driven by the 60% carbon reduction target (as was in place at the time with the Climate Change Act). **Surveying**: A clear specification was developed from unit drawings using SAP and energy modelling. The project pre-dated the introduction of PAS 2035. However, tests on air permeability and thermal imaging were taken both pre- and post-retrofit. The pre-tests identified areas of existing construction where additional focus needed to be placed during retrofit to uphold the desired performance e.g., exposed intermediate floors where there was no existing plaster, these were parge coated to reduce air leakage. The project team also undertook SAP energy modelling for all the retrofit plans, choosing the measures and the size of the PV, the thickness of the insulation etc. to deliver on that that target.

Work elements	Information
	The different measures are detailed below. **EWI**: 100mm of insulation was used then a two-coat render system. The rigid insulation was made up of two layers of 50mm extruded polystyrene. The principle of 'doing it right first time' was used and meant it worthwhile for the EWI to go above the minimum 50mm of the Building Regulations Part L. The two layers also enabled the joints to be staggered, which took more time but was considered beneficial to the property. Careful detailing of the EWI at window and door reveals was required to limit thermal bridging. Thin 25mm insulation boards were used to achieve this. **Solar PV**: This was fitted without difficulty into the 11 properties. Six units additionally had solar thermal as well as using a diverter into an immersion in the water cylinder wasn't available at the time. **Ground floor insulation**: This was also undertaken in the show home unit using Aerogel given its performance to thickness ratio which was required due to the finished height of the floor which could not be raised without significant extra work and disruption. Given the difficulties with the ground floors, elsewhere perimeter insulation was provided as a compromise. **Loft insulation**: this was improved by increasing to 300mm thickness mineral fibre. Cross ventilation to the loft space was also introduced. **Through wall single room mechanical ventilation with heat recovery (MVHR)**: this was installed in bathrooms and kitchens with humidistat control.
Delivery: addressing CTD attributes	**Workforce skills**: The existing direct workforce of the housing association was trained in new measures, including in EWI and undertook most of the elements including the installation of new windows. Some elements were sub-contracted including Solar PV. **Resident engagement**: Engagement through the project was important. Several community consultation meetings took place to explain the benefits of retrofit, allay fears and build buy-in for the project. The ground floor of one of the REEMA units was used as a drop-in for residents with the contractor's site office on the first-floor level. These proved successful in winning trust, which was particularly important where the works pose a significant upheaval for families due to the decanting of residents, which needed to be done sensitively. The landlord had already retrofitted a pair of REEMA units on a nearby estate and these were used as temporary accommodation for the decanted residents as these were similar to residents' homes.
Impact and evaluation	**Carbon reduction**: The properties achieved a 70-79% carbon reduction against baseline emissions (above the 60% target). **Bill reduction**: Bills were monitored for a 12-month period, with 40-50% reductions sustained for some residents. **Resident satisfaction**: Resident satisfaction, where all residents were satisfied on returning to a house that was like a new home, with its aesthetic also improved. More generally, the retrofit and upgrade works improved the useful life of these pre-fabrication properties.

Work elements	Information
	Monitoring and evaluation approach: There are limitations recognised here as today a more advanced monitoring plan would be followed and would include elements such as air quality, temperature, and humidity. **Limitations of the retrofit**: The homes remained on gas where in hindsight they would have been suitable for heat pumps – this was due to previous difficulties deploying heat pumps. Heat pumps were also overruled partly on cost grounds.
Best practices and lessons	This case study has identified the following best practices and lessons for homes with non-standard structures in particular, and for across CTD home types: **Collaborative work**: When there is wider home maintenance and capital work due, it is valuable to consider efficiencies e.g., when scaffolding for re-roofing work is going to be used then it is also a clear opportunity to do solar PV at the same time. There is benefit of doing more mass retrofit at the same time, to lower unit costs. It is also important to only do insulation once and complete it in one go, so ensuring properties are in good order before starting work is a key success factor. This means that homes are in a good state of repair, for example not requiring concrete repairs or similar maintenance interventions to the existing precast concrete external wall units to maintain structural integrity. **Resident engagement**: The resident engagement was tailored and was also within a wider street-based retrofit approach. The landlord provided a dedicated community officer based in the drop-in unit to support tenants with questions and to communicate benefits such as predicted improvement in EPCs, expected bill reductions and comfort improvements. The first home completed became a show home, forming both an effective resident engagement activity and opportunity to share lessons and successes with local stakeholders. Ensuring residents had choice and control over elements such as the style of kitchen units, wall tiles and flooring was also a success factor to support their buy-in to the process. Decanting and engagement time was a significant cost, estimated at a 10-20% addition above what was anticipated.
Relevance and insights for CTD Identification Framework	**Identification**: these homes reflect a specific archetype and construction challenges. Social attributes of CTD were also present, with significant disruption and hassle for a demographic including some vulnerable residents. Both of these drove higher costs and needed careful attention. **Potential uses of the framework**: This case study identified a need for the framework to be flexible in use for both individual home differences and inherent risks for a type of home, as well as the reflecting wider stakeholder needs. *"With the system builds, it is important to understand that no two are the same in such a framework, they can all be a bit different. When looking at IWI and EWI there are many different wall types. Overall, homes might be best understood by what is different about them and what should therefore be looked at and considered."*

Work elements	Information
	"A framework should also reflect the needs and challenges of stakeholders and suppliers, such as the hassle factors, how to best engage and what the specific material needs are." *"It could support a risk assessment in setting out the inherent risks for a property type, similar to what the PAS retrofit designer role does. But that does allow for a range of responses from simple drawings to detailed specifications that really cover the detail."*

Case Study 5: Resident centred response to failed retrofit

Property characteristic	**Information**
Date property built	1900s.
Number and type	22 terraced, two storey homes, typically 3-4 bedrooms.
Walls	The walls had previously had EWI installed but to very poor quality. This resulted in trapped water between the EWI and brick walls that resulted in significant damp and wetness.
Traditional or heritage features	Some stone features.
Other notable features or aesthetics	Some homes that had extensions without local authority planning approval and some had rooms in loft.
Heating type	Gas central heating.
Tenure	Mostly owner occupied, 60-70%, with some private rented sector.
Location	City in North West England.
EPC and SAP before & after	Before: EPC E (4 homes), EPC D (15), ECP C (3), with SAP rating unknown. After: EPC E (4), EPC D (15), ECP C (3), with SAP rating unknown (same as before).

Illustrative property image:

Similar archetype image used for illustrative purposes only.

Work elements	Information
Project overview	Work was undertaken to repair previous and failed retrofit work from 2012-2013 for a series of homes. Much of this was EWI that was badly impacted by poor workmanship, fast delivery, lack of quality assurance and care, and poor detailing. This resulted in trapped water between the EWI and brick walls that led to significant damp and wetness in the properties.
Time	Phase 1 addressed 22 homes and there is a potential Phase 2 for around the same number of homes.
Cost and funding	The organisation began work with the community in February 2020, works stated in May 2022 for Phase 1 and this ended in February 2023 for the 22 properties.
CTD attributes	**Physical**: Previously EWI had been poorly installed; this was badly impacted by poor workmanship, fast delivery, lack of quality assurance and care, and poor detailing. This led to highly significant property damage inside and out through damp and wetness, as explained below. The homes typically had narrow cavity walls that had been previously injected with cavity wall insulation. Cavity wall insulation should not have been installed due to the properties having such thin cavity walls, as the insulation didn't spread correctly and created thermal bridging. This thermal bridging accelerated the damage that EWI has done to the properties; water became trapped between the EWI in the first layer of bricks, so it seeped into the cavity walls, destroying the insulation and damaging walls. The water then seeped into the internal brick layer, and residents started to clearly see the damage to their properties. Further, the homes had very old electrical systems and asbestos, adding health and safety concerns that needed resolving by repairing these elements. There were also poor maintenance records for the properties, and high ancillary costs to return the fabric to its original condition and install measures. **Locational**: N/A. **Occupant, demographic and behavioural**: The physical CTD attributes caused health and wellbeing issues amongst residents, driving a need to intervene for resident welfare. Community trust was very low due to their poor experiences from the recent works. A deep engagement campaign including information to build trust was developed. There were high occupancy rates, including multi-generational families, making it more difficult to select the right measures such as ventilation, while ensuring work could be done with residents in situ. The residents also often had low incomes and limited financial capability to pay for works.

Work elements	Information
	The works for private rented homes had to be coordinated with the tenants, under the permission of the landlord, which in some cases created communication challenges. Even though it was a small pool, some properties still fell through the cracks as residents were hard to reach, such as those who found it hard to trust the contact being made. **System-level**: The original contractor had ceased trading, and it was challenging to identify a source of funding to address the issues. Further, repair works are not central to PAS 2035 guidance.
Design and measures: addressing CTD attributes	**External wall insulation**: EWI removed and replaced with a new EWI system, which interacted correctly with roof insulation and ventilation measures. Though two homes did refuse the new EWI. **Remedial works**: Remedial works included a damp-proof course for every property, in line with the EWI system warranty requirements. **Structural repairs**: • **Windows**: these were replaced, if the resident agreed, to increase the passive ventilation openings and to include trickle vents. • **Ventilation**: both windows with turnkey hands or mechanical ventilation were used. Mechanical heat recovery ventilation was highly complex in some properties because of the ducting that is needed. When this was not possible, fans with humidity sensors were used. For example, some homes did not have room in the walls for ventilation or the electrical system to feasibly accommodate MEV. • **Boiler replacements**: this was to ensure the flu was extended properly to connect to EWI.
Delivery: addressing CTD attributes	**Regulations and guidance**: This type of repair work and circumstances was not well or specifically considered in the policy environment and regulations such as PAS 2035, which does not apply to “like-for-like” replacement of damaged elements but could be followed in principle. The team would also have needed planning permission to remove the EWI where homes had stone features. **Advice**: Residents were supplied with humidity sensors to use in their homes, alongside an advice leaflet on how to reduce moisture build up from condensation. This was delivered by a community liaison employee. A good practice guidance package that outlined the warranties and guarantees for the works, with detailed information on where to access help if anything goes wrong, and how to claim in that event. This recognises that information provided such as with PAS 2035 can be very long and burdensome on residents, making it inaccessible. **Resident engagement**: Engagement used trusted local leaders and community groups to share information about the work. These channels were used to receive feedback and understand resident’s needs, so the works better met residents’ needs, and to improve processes and communication. Community groups utilised included religious groups, community-based businesses, and a community hub.

Work elements	Information
	Community insight panels were also used from the beginning and repeated every three to six months. The project team were physically present in the community whenever possible. Overall, the value of multiple methods of communication being made available to residents was recognised. As owner-occupiers, residents had the option to reject the measures, so it was important to provide detailed information to residents, such as the role of ventilation, and addressing concerns on heat loss and ventilation costs. For private rented residents the decision holder was the freeholder, though the project team kept tenants engaged to keep the process transparent. It was complex for residents to stay in situ. This led to time and cost impact, such as the need to work room by room and needing to clean up at the end of every day. Overall, all residents except two (due to particularly heavy works needed) stayed in situ. It was difficult to manage residents' expectations. Here, having an effective resident liaison officer was important, and being able to communicate with non-English speaking residents. There was also regular contact between the project team and residents to identify and respond quickly to minor issues or queries. There were some refusals and resident decision changes to be managed; two houses refused a new EWI system, a large number refused MEV due to the perception that it might leave their homes colder, and some refused passive ventilation with windows as they liked their current windows. In having a resident-centred approach, these adaptions were carefully managed.
Impact and evaluation	**Resident experiences**: the works significantly improved residents' home environment, comfort, and wellbeing, to deliver warm and safe homes. A key outcome from the work was to install ventilation in all homes where this was feasible. **Repairs**: The works halted the disrepair of the homes, addressed the damp and mould issues, and ultimately reversed the damage and restored the homes to a good and liveable condition. The project closely supported residents who had had severely negative past experiences with retrofit work. The organisation is undertaking a full social and technical evaluation, as a mixed methods approach over time and with dedicated social researchers. This is examining subjective fuel poverty, health impacts, energy affordability, air quality, and other factors, which will be reported in the next 12 months (as of June 2023). This includes smart devices to monitor remotely, indoor temperature and relative humidity readings.

Work elements	Information
Best practices and lessons	This case study has identified the following best practices and lessons for failed retrofits: **Resident-centred**: Residents' insights were fundamental to the project, and it was considered critical to meaningfully involve the residents in the programme. The contractor was chosen as they demonstrated significant experience with social housing tenants (though these were owner occupiers and private rented homes), to bring this experience forward in working with residents with heightened vulnerability where careful and bespoke engagement was needed. **Consumer protection**: This is an extreme example where the residents needed to be better informed and supported about warranties and their potential exemptions for this scheme and on the things that went wrong. The residents did not have the right mechanisms to protect themselves and the suppliers had avoided responsibility for the work failings. This is a risk that may need to be higher up the risk register for other projects. **Data limitations**: This project illustrates that EPC is not always a useful measure as it does not measure actual building performance. In this case, prior to the works it did not account for failed EWI and that the homes were now harder to heat. These clearly improved following the works to address the failed retrofit but are not reflected in the EPC rating, which remained unchanged after the works even though the homes' condition and performance was significantly improved.
Relevance and insights for CTD Identification Framework	**Identification**: This project demonstrates other elements and situations of CTD, with failed retrofit work, issues with resident vulnerability and protections. **Potential uses of the framework**: This case study identified a use for the framework to support those working with both residents and contractors, to be able to provide advice and to understand the project requirements and effective approaches for the home(s). *"It could be very useful. When we started this project, it was really hard to understand all the existing regulations around the processes, funding streams, how to dos and how to deliver this. And it took months if not maybe a year to just define all of this and understand it. So, a comprehensive document that gives an understandable step by step approach on best practice measures and essentials to go to would be welcomed. There were lots of consultants helping throughout the project, but each one of them wanted to push their agenda "* *"For example, there's no literature on the repair of failed retrofit schemes. There's a lot of different approaches ongoing in different projects, and it's often hard to understand what to follow and which direction to push your project to."*

Case Study 6: Victorian 'Eco Home' – whole house retrofit

Property characteristic	Information
Date property built	Early 1900s.
Number and type	One 4-bedroom end of terrace Victorian property.
Walls	Solid wall.
Traditional or heritage features	N/A.
Other notable features or aesthetics	Striking red-brick Victorian façade.
Heating type	Gas central heating.
Tenure	Void property at works, now social rented.
Location	London
EPC and SAP before & after	Before: EPC E, with SAP rating 51. After: EPC A, with SAP rating 92.

Illustrative property image:

Similar archetype image used for illustrative purposes only.

Work elements	Information
Project overview	This is a solid wall Victorian property in London, with a number of traditional and aesthetic original features to respect. The project was a whole house retrofit, to demonstrate an Eco home to the local council and its stakeholders and to test several measures and approaches for their effectiveness and feasibility. The property did not have existing energy efficiency measures except for thin loft insulation.
Time	The project planning started in May 2020. Work was undertaken from January 2021 to July 2021.
Cost and funding	Funding was provided by the local London borough council. The retrofit works included: £14,000 for the Solar PV and battery storage, £14,000 for the EWI, £10,200 for the ASHP and radiator, £2,100 for the underfloor insulation, and £1,000 for the loft insulation. Further non-retrofit work was also undertaken.
CTD attributes	**Physical**: A key objective for this property was to, where possible, maintain original features. This created a need to protect and keep work in line with other internal features and characteristics, for example the bannisters and ceiling roses were repaired. Some wider (non-retrofit specific) repairs were also needed and detailed surveying was important upfront to really understand the property and its features. **Locational**: The planning permission context for the exterior walls meant EWI could not be undertaken on the front, and this fed back to the design stage to consider IWI instead. IWI had potential issues with a careful approach needed to meet and seal it and as it can take away windowsills which residents can be resistant to. There were permitted development right (PDR) constraints to the heat pump in its noise levels and distance from the house boundary (not less than one metre). In addition, because the unit expels cold air, the unit had to be situated away from outdoor seating areas. There were also spatial challenges for where the battery storage could go. The loft was considered but it provided a fire hazard, and the transporting and maintenance access of the battery was important. **Occupant, demographic and behavioural**: Given the extent of changes, the maintenance of the house and the understanding of new energy and ventilation systems were important to ensure long-term benefits for residents and protect the condition of the house. **System-level**: N/A.

Work elements	Information
Design and measures: addressing CTD attributes	**Regulations and guidance**: This wasn't a PAS 2035 project, but the team were very conscious of the work's waste and in using natural products, respecting the original materials and permeability. **Design**: By not following PAS 2035, the project team had a little more freedom in the measures that the project team were able to choose, although the project was required to follow PDR for the ASHP. The project team developed an approach that ensured quality, such that PAS 2035 was less critical to follow than it might be for less experienced teams. **Surveying**: The fabric had to be improved to create optimal conditions for deploying a heat pump, where U-values were considered to ensure heat loss was reduced sufficiently and so the heat pump does not cost more and its size can be kept down. A partner was brought in to do some energy efficiency tests – air pressure, thermal testing, heat loss and fitting sensors in adjacent property to see heat transfer between the walls. **EWI**: the materials were 97% recyclable and renewable, and non-combustible. A render was applied to the boards, along with a mesh, to provide additional tensile strength and ensure the render was crack resistant. A decorative topcoat was then applied to complete the insulating process. **Underfloor insulation**: this was considered a difficult procedure due to floor depth and need to lift floorboards. Therefore, an innovative robotic device was designed to install underfloor insulation materials without disrupting the existing floor structure. The device sprayed expanding polyurethane foam on the underside of floorboards sealing any gaps and reducing draughts. A small air space was left between the foam and the floor to allow air circulation, to prevent mould and mildew, in line with building regulations. It was air-tested after completion to ensure the floorboards were properly sealed and insulated. Smart bricks were also used beneath the floorboards. **Mechanical ventilation heat recovery (MVHR)**: this system was installed as part of the retrofit to remove moisture and improve the circulation of fresh air. MVHR was also installed in 'wet areas', such as kitchens and bathrooms, to recover heat from water vapour and use it to keep the property warm. The system is automated so there is no need for occupant interaction. **Windows**: instead of replacing whole windows, window glass was replaced using low eco glass (as close to triple glazing as is currently possible) to retain the frames and coating. This balance was seen as the right approach to limit landfill waste. There is also lower cost and a sufficient efficiency benefit. **Solar PV panels**: solar edge optimisers were added to the system to ensure maximum panel efficiency. The inclusion of a battery allowed power to be stored for overnight use – any excess was sold back to the grid.

Work elements	Information
Delivery: addressing CTD attributes	**Ventilation**: The MVHR was the most effective ventilation to install, for removing moisture and improving air circulation. Given that installing the ductwork can be very intrusive, this installation was completed by lifting the floorboards to hide the ductwork there. As the home was void at the time this was completed without causing prohibitive levels of disruption. Ducting that went into the loft was also insulated. **Maintenance and use**: The base temperature was set to 21˚C during the day and 18˚C overnight. The controls used sensors to monitor internal and external temperatures to maintain the levels set. Residents were able to increase the temperature if they needed to, but the temperature reduced after three hours, ensuring that the temperature did not run high all the time. The heating and hot water cannot run at the same time, and hot water takes priority. **Resident engagement**: The residents (social rented tenants) who moved in following the work were given a briefing and engaged with the project team's engineer to understanding if there were any issues. The project team designed a booklet as a quick start guide to the house and its (efficient) use, which was shared after an interview with residents.
Impact and evaluation	**Energy efficiency and thermal performance**: Comparisons and analysis have been undertaken to compare the thermal performances between the original building and the design performance (increasing from EPC E with SAP rating 51 to A with SAP rating 91). Innovative monitoring devices have been fitted by the local council that monitor live internal temperature and system operations using AI machine learning. An 82% improved energy usage and a 64% improvement in running costs. Further, the annual heat demand is also estimated to fall from 17,219kWh to 7,995kWh per year. It is anticipated that the changes will reduce heat loss from 370W/m^2.K to 150W/m^2 K. **Carbon reduction**: the works led to a 81% reduction in CO_2 emissions.
Best practices and lessons	This case study has identified the following best practices and lessons for Victorian and solid-wall houses in particular, and for across CTD home types: **Knowledge sharing**: The project provided an experience for extensive learning and sharing with other suppliers to benefit, working as a home demonstrator that enabled engagement visits. Linking up and learning from others in industry for data analysis side was considered important. Knowledge and skill management was important given that all skillsets are utilised. This required effective coordination. **Technological updates**: Battery storage was considered a potential improvement for the future. The technology is improving, and batteries are getting better, so it is important to keep up to date on market changes as these may offer a storage solution for home projects in the future.

Work elements	Information
Relevance and insights for CTD Identification Framework	**Identification**: This case study provides an example of measures and approaches that can reduce the CTD attributes of such a property with traditional and aesthetic features that could be protected and with underfloor insulation that could be undertaken with less disruption. **Potential uses of the framework**: This case study highlights the need for the framework to consider individual homes. Other uses include for upskilling and to support resident engagement. *“It is important to reflect that every home is bespoke, so it can’t just do a sweeping ‘everyone needs this’ and you have to look at what the biggest issues are with the house. There would be so many questions that you could go down a big tick list.”* *“There may be value in looking by types and then considering the use for an individual in their home who wants someone trusted to come and give them some options, with recommended surveys and tests and estimated costs following a trusted body. Given trust is such a barrier, this could be a key focus and value for such a framework.”* *“There could also be a key interaction to the need for upskilling the workforce here and to help address the cost and time pressures that can make some in the industry cut corners.”* *“It could be something that is filled out, not by the homeowner themselves but by a skilled person who can go through a tree diagram structure for the questions and resulting considerations. There is a key focus… to get the resident involved and to not exclude them in decision making and understand and support their home understanding and use. A framework could also be an opportunity to dispel some myths.”*

Case Study 7: Victorian owner occupier home in Conservation Area – deep retrofit

Property characteristic	Information
Date property built	Pre-1900.
Number and type	One 3-storey Victorian house in Conservation Area, mid-terrace, 3-bedroom house.
Walls	Solid wall.
Traditional or heritage features	Front wall and windows.
Other notable features or aesthetics	N/A.
Heating type	Gas boiler.
Tenure	Private owner occupier.
Location	London.
EPC and SAP before & after	Before: EPC D, with SAP rating 57. After: EPC A, with SAP rating 92.

Illustrative property image:

Similar archetype image used for illustrative purposes only.

Work elements	Information
Project overview	This was a deep retrofit project for a Victorian terraced home, undertaken in 2009, where the trigger point was the owner carrying out refurbishment and extension work. Retrofit was driven by the policy at the time for 80% reduction in carbon. It has since undergone ongoing monitoring and provided many lessons and best practice examples. The property did not have any existing energy efficiency measures.
Time	The organisation was appointed in 2008 and was on-site in 2009. The work was completed in early 2010 after nearly a year of site work, which this was five months more than expected.
Cost and funding	The work used private funding from the client, the homeowner, covering energy and retrofit works, repair works and the extensions. Whilst the total cost is confidential, the energy efficiency work cost around £60,000.
CTD attributes	**Physical**: At the time the heat pump market was not fully established, so heat pumps were not considered to be an appropriate solution. Other physical challenges included the new extensions, the L-shaped spatial dimensions, and the need for some remedial work to the back walls. **Locational**: Conservation Area issues created delays due to poor quality guidance on energy efficiency matters, such as heat loss form factors, and uncertainty on what would be permitted. These included a constraint on what could be done on the front elevation, especially with the sash windows (poor quality Georgian-style replicas with multi-pane arrangement). The extension required significant design time as the Conservation Area dictated that this would need to be a less compacted form, which would lead to greater heat loss. The owner was keen for solar thermal or PV on top of the extension’s roof and was initially granted permission for solar thermal. However, the resident then changed their preference to solar PV, as they could access grant funding, and there were technical difficulties associated with solar thermal at the time. The local authority tried to challenge this change to planning permission, but the case was dismissed by the appeal officer. This caused some delay. **Occupant, demographic and behavioural**: These were limited as the owner was well informed, patient, and motivated to try measures, and also had the access to finance to do so. **System-level**: Procuring some of the materials was a challenge. For example, triple glazing windows for the property rear could only be procured from Germany at the time, which created very long lead times. Since this project the supply chain has developed and some of these issues no longer exist. However, there remain issues with builders potentially making product substitutions where they have existing merchant accounts, and there is a limited ability to scale-up retrofit work with the current supply chain.

<table>
<tr><th>Work elements</th><th>Information</th></tr>
<tr><td>Design and measures: addressing CTD attributes</td><td> Design: At the time, the most important target was to reduce the space heat demand, with the Kyoto Protocol that was in place at the time, targeted a reduction in carbon emissions to 80%. Roof: The roof was rebuilt and replaced with an insulated flat roof. Front walls: The front walls were sensitive to the restrictions of the Conservation Area so they needed to have IWI applied. IWI was installed by creating a new wall on the inside that was disengaged from the wall outside and used a cavity, avoiding moisture problems and considering air tightness carefully. This was about 6 inches of wall insulation to deliver a 0.2-U value. In response to moisture concerns, they cut out the joists and re-hung them on steel beams, which was quite interventionist. Back walls: The back walls were in very bad condition due to poor original build quality, so were rebuilt as cavity walls, with light blockwork inside and 300ml glass wall insulation and later brick added outside. This left a 500ml thick wall on the back with triple glazing. Windows: These were replaced to double and triple glazing (where allowed), resulting in very modest heat leakage. Doors: An energy efficient front door was also installed. Ventilation: A heat recovery system (MHVR) was used, which was quite revolutionary at the time. Solar panels: Solar PV was installed. Air tightness: The home was progressed close to passive house air tightness. </td></tr>
<tr><td>Delivery: addressing CTD attributes</td><td> Surveying: The approach needed to resolve details and complexities with the work, and the first attempts took time and care. Upfront surveys ensured effective planning and precise work for the junctions and edges in particular. The project team invested in detailed building inspection and self-taught how to do energy modelling as this was an early adoption of such processes. Passive House principles: Passive house principles were followed, and technology was used for some elements, such as in the back solid walls (which needed rebuilding as cavity walls) and in ensuring excellent air tightness, close to passive house retrofit level. The approach was considered appropriate given the poor condition of the fabric and where remedial works were required. This was considered the most cost-effective approach. Protecting the heritage and aesthetic value of the building: An overarching principle was to leave the front of the house unaffected. This was due to the local conservation context and a shared objective to maintain the quality of the streetscape. </td></tr>
</table>

Work elements	Information
	It was also important that the roof extension was done in such a way that it couldn't be seen from the front of the house. The extension needed to follow masking and guidance on depth and height, where the design did not initially follow a prescribed solution, and this caused delays as it needed to go back and forth with planning permission. This took a year and various meetings with the head of planning and a case officer. **Resident engagement**: It was also important to communicate with the residents early on that elements may require adjustment before they worked optimally. This communication approach was offered early on for the residents, to help ensure a successful consumer journey and that they are satisfied at the end of the work.
Impact and evaluation	A series of tests and measures were designed and committed to over the project lifecycle and in several years of post-testing. The measures included air tightness, heat demand and energy use modelling, as well as customer satisfaction. Results include: **Carbon reduction**: The reduction in carbon emissions was estimated to be 80%. The estimation was complicated as it was an empty house before the work, so it lacked actual base case data and was modelled for having the home at 18-20 degrees. 13 years of energy consumption data demonstrates that the estimated carbon emission reductions continue to be achieved. The embodied carbon of the build was offset by 2017, and since then there has been a saving of around five tonnes of carbon per annum. **Energy efficiency and thermal performance**: Heat demand was reduced below the target to a predicted 25 kWh/sqm – and this is still performing well after 13 years of monitoring. The client has reported being very comfortable with reasonably consistent temperature and in not feeling they were being overly environmentally cautious. A very high level of air tightness was achieved, at 1.1m3/m2/year which is close to the passive house retrofit level. Subsequent air tightness tests over the monitoring period (13 years) have produced stable results and, though there has been some minimal reductions and increased leakiness, it remains at a very good level compared to most homes. The home still performs robustly and has not lost efficiency over time. The project's 13 years of monitoring demonstrate a very high consistency of performance.

Work elements	Information
Best practices and lessons	This case study has identified the following best practices and lessons for Victorian terraced houses in particular, and for across CTD home types: **The local planning context**: This was a significant challenge. It would have been helpful for Conservation Area guidance to incorporate local retrofit guides. **Whole house approaches**: Implementing this approach is key as thinking about the interactions very carefully and to document them is very important. This made the coordination easier, to focus on what was known and what was coming forward. **Time needs**: How much time is needed on site can be underestimated, where being local can help to be on site at least once a week helps for a sense of overall control. **Monitoring and evaluation**: There is a need to balance the resident and house outcomes in some circumstances, to a level that is comfortable and improved versus the level of investment and disruption. There's an important role of monitoring, which was completed and continued well here. Embodied carbon also needs to be more carefully watched and included.
Relevance and insights for CTD Identification Framework	**Identification**: This case study reflected CTD attributes with the property's layout and spatial features, as well as the Conservation Area constrains. These were incorporated in the design and delivery to effectively decarbonise the home. *"One of biggest areas to include would be on the simple geometric elements of a house e.g., a 'box house' or where the eaves overhang, so to identify where it is a bit more complicated and where things can get difficult quickly. Examples include bay windows creating challenges to EWI, extensions at back of houses, poorly considered roof extensions, and where there are cables outside of buildings or gas pipes impacting walls."* **Potential uses of the framework**: This case study identified the value of a CTD definition and framework, for understanding a stock of housing for different stakeholders. *"It would certainly be useful, there are more loose terms out there and not clear definitions. This would be useful and make things clearer for architects, social landlords and housing associations – to understand where their stock falls."*

Case Study 8: Bungalow with low carbon heating measures

Property characteristic	**Information**
Date property built	1960s.
Number and type	Two bungalows.
Walls	Cavity walls.
Traditional or heritage features	Suspended timber floor.
Other notable features or aesthetics	East/West facing properties.
Heating type	Electric storage heating – old version from 1990s with manual controls.
Tenure	Social housing.
Location	A small rural community in North West England.
EPC and SAP before & after	Before: EPC E (2), with SAP rating 54. After: EPC B (2), with SAP rating 85 and 87.

Illustrative property image:

Similar archetype image used for illustrative purposes only.

Work elements	Information
Project overview	These were bungalows built in the 1960s with old heating systems, off-gas grid and isolated in a rural area. The project included heat pump and Solar PV installation on top of fabric measures installed using a previous funding award. Pre-existing measures included cavity wall insulation from ECO 3, roof replacements over five years old, loft insulation that was already Part L Compliant and windows which were double glazed.
Time	The Trust undertook Retrofit Assessment & Technical Surveys in June 2022, upon which identified underfloor insulation wasn't viable. Following a project change request, the Trust progressed with coordination on the installation of Air Source Heating and Solar PV, installation started early January and the two properties finished mid-February 2023
Cost and funding	The funding consisted of SHDF and Housing Trust capital expenditure (a 50: 50 split without VAT). The cost per home was £23,700 including all surveys and preliminaries. The solar cost approximately £6,000 - £7,5000, these were not the most aesthetically advanced versions on the market but were good value for money and provided more solar generation and space efficiency. The heat pump cost £12,000 - £12,500.
CTD attributes	**Physical**: The floors had a shallow void and this meant underfloor insulation could not be installed, even when innovation approaches were considered. This made the work harder to achieve the targeted EPC band C. The hot water cylinders were also necessarily located in the centre of the properties so pipe work had to be routed behind kitchen units. **Locational**: Compliance with noise requirements were an important consideration when siting the heat pump. There was a further need to be considerate to reduce disruption to the local community and wildlife. The rural and remote nature was a challenge in complying with the construction design and management, health and safety and to get suppliers to site. Further, the grid capacity was not initially understood, so early coordination with the district network operator (DNO) was needed to understand if the move from storage heaters (and other off-gas grid sources) to heat pumps in kWh demand could be accommodated. **Occupant, demographic and behavioural**: Through resident engagement, the Trust identified some residential characteristics that could make the homes CTD and that a clear information and an education piece was needed. For example, the residents had some resistance to heat pumps given negative coverage in the media and negative views of friends, family or neighbours concerning running costs and efficiency in particular. Further, working with a community that was used to solid fuel heating or older electric heaters was a challenge when moving to an electric heat pump system.

Work elements	Information
Design and measures: addressing CTD attributes	**Design**: The key consideration in the design was heat loss and correctly sizing the radiators and unit size. The project followed PAS 2035 with retrofit assessment, coordination, and design. **Hot water tank**: Pressurised cylinders were installed to enable operation of the heat pump. A challenge was that the cylinders were located in the centre of the properties, so pipe work had to be re-routed behind kitchen units, which added complexity. **ASHP**: in terms of noise limitations, this was mitigated with the use of a mono-block heat pump to a high reliability standard and one that fell below noise requirement levels. **Solar PV**: this was quite straightforward from a bungalow perspective, following earlier roofing work and with clay tiles on the roof, which solar can be fitted to quite easily.
Delivery: addressing CTD attributes	**Regulatory and guidance**: The project followed PAS 2035, as required. The Trust noted that they could have used the available PAS 2035 support more, but there was advantage to working through the project challenges themselves to learn, The Trust was able to begin work once it was established that they were able to install the measures under PDR, without impacts of any conservation areas. **Surveying**: The process began with pre-engagement to begin the PAS 2035 journey and undertake property surveys early on. They tried to capture all key information and surveying at once to reduce disruption to residents. **Remote location**: Given the remote location, the Trust worked to ensure the work complied with construction design and management, and health and safety. They put up local facilities and used an ‘Oasis Van’ for this purpose, including toilet facilities and welfare support on site for the team. Their main office was a few miles away which was helpful generally, but too far for the daily site support. **Resident engagement**: Resident resistance to heat pumps was overcome with tailored and effective engagement, this included communicating cost breakdowns and estimates with individual residents which generally overcome the reluctance to heat pumps. There was also clear communication with neighbours on what was happening, why and when to reduce resistance and disruption. The work timelines, as a result of upfront delays, meant making heating upgrades during the winter period with some of the coldest weeks of the year, with residents staying in situ. To mitigate for this, they rapidly removed the storage heaters and installed a heat pump over two days. They provided residents with clear information on this process and provided temporary heaters to make sure residents were comfortable. The Trust also prioritised wiring the hot water cylinder up to the immersion heater so there was at least hot water overnight.

Work elements	Information
	Handover processes: The Trust developed handover processes through the retrofit work, with a retrofit adviser-evaluator crossover role. This included going through with the residents how to use different installation elements and to get the most efficiency out to things. For moving from storage heaters to heat pumps, it was important to ensure residents were not at a disadvantage and understood the different tariffs and the Smart Export Guarantee.
Impact and evaluation	**Monitoring and evaluation approach**: This work followed the SHDF monitoring and evaluation process and reporting templates, monitoring for a year post-installation. Given the works completed in February 2023, this remains ongoing, and results are still emerging. The Trust has brought in a third party to conduct visits/phone calls to the homes with regards to their energy usage post installation, tariff review and Smart Export Guarantee enrolment following installation. This is part of the wider aim of addressing fuel poverty. **Energy efficiency and thermal performance**: The initial heat demand targets from funding were overly challenging for properties to get to 90 kWh per sqm or less. This was not specified per se in the Trust's bid, the home with a gable wall achieved 121 kWh/m2/yr and the mid terrace home achieved 108kWh/m2/yr. **Resident satisfaction**: The Trust is also using this period to keep in touch with residents and their satisfaction, which has been targeted at 95% satisfaction. This enables the Trust to see another winter of use to see how consumption and bills change.
Best practices and lessons	This case study has identified the following best practices and lessons for bungalow properties and those in rural and/or off-gas grid locations in particular, and for across CTD home types: **Fabric first approaches**: This project demonstrates the relationship between a fabric first approach and low carbon heating and solar installations thereafter for a remote CTD property. **Tailored resident engagement and planning**: The approach ensured residents remained in-situ and had their disruption minimised. Deep engagement is a key best practice emerging from this study. Having an engagement strategy upfront helps bring residents into the process effectively, to onboard them and ensure their buy in. **The importance of surveying**: Having clear and comprehensive data to understand the homes upfront is important as well especially for funding to know your properties upfront. Clarity on what is trying to be achieved here is also a key lesson. The Trust was able to go through each property to see where they had information and where it wasn't recorded to enable them to target their homes better.

Work elements	Information
	There is also a key financial impact in being able to plan surveys and retrofit work like any other component replacement such as kitchens, bathrooms, and roofs. This is about programming the work into wider refurbishment work as and focusing on the forward planning to make sure the skill set is there to understand the needs and do the required work.
Relevance and insights for CTD Identification Framework	**Identification**: These bungalows include physical, and locational, elements that can identify the home as being CTD. In this case study, a fabric first approach followed by installing low carbon heating has effectively decarbonised the home. **Potential uses of the framework**: This case study highlights useful ways the framework could use and present data to users and recognises its use to guide resident engagement and information. *"The framework could need to be quite broad and cover a lot of information. [We] would expect to see the physical difficulties you might find with a property to be included and there are checklists that you could use to see and check certain things such as whether the home is in a conservation area or is it listed and what type of construction it is e.g., non-traditional, solid wall. This could then follow for example; these measures may be particularly challenging to deliver. While these measures could be standardised and assumed to be deliverable to this home, the framework would be quite large to actually map those out, but it could give say a level of hard to treat and based on your rank or rating, it could present a hierarchy or an organogram of considerations [and risks] for possible measures."* *"From an engagement perspective and the customer side of things, a best practice sort of framework document could be useful. This could articulate how something was done elsewhere and what others have found. There are various forums out there that are doing that, but is may be something for the government to push forward and help coordinate."* *"This could be very useful, and it would enable a lot of people who don't have experience in delivering where to deliver and to help set good standards for residents ultimately."*

Case Study 9: High rise tower block external wall insulation

Property characteristic	**Information**
Date property built	1960s.
Number and type	Fifteen high rise tower blocks.
Walls	Cavity walls.
Traditional or heritage features	N/A.
Other notable features or aesthetics	N/A.
Heating type	Electric heating.
Tenure	Social housing.
Location	City in North East England.
EPC and SAP before & after	Before: EPC E and F (across the many units). After: EPC C and D (across the many units).

Illustrative property image:

Similar archetype image used for illustrative purposes only.

Work elements	**Information**
Project overview	This project worked with fifteen 1960s built high rise tower blocks of between 20 to 24 storeys. The properties had cavity walls and required extensive insulation. This project used innovation work developed for the ECO funding programme to deliver cavity wall insulation, without using external cladding, using qualified abseilers. The properties did not have any existing energy efficiency measures.
Time	This work was undertaken in between April and September 2021. For the properties here the cavity wall insulation took between 10 and 15 days to install, compared to a usual 3-6 months if external cladding is used. The work also involved surveys, which took a day to complete, and there were minor delays due to changes in weather to meet health and safety requirements for the abseiling work.
Cost and funding	The specific project cost is not available here. The project was fully funded by ECO3 Innovation funding, approved by Ofgem and BEIS. The approximate cost per block/flat varied dependent on the number of storeys but is significantly lower than using external cladding. This was due to lower material, machinery, site security and labour costs.
CTD attributes	**Physical**: These properties are CTD given their height and that the potential alternative measure of external cladding would be prohibitively expensive, given its extensive work time and scaffolding needs. For some of these blocks, the first one or two floors had wall insulation, originally installed using ladders or cherry pickers, but beyond that the cavities were left empty. **Locational**: N/A. **Occupant, demographic and behavioural**: These were all social housing tenant blocks. **System-level**: This project required very specific expertise for extensive insulation fitting at height, combining abseiling and cavity wall IWI.
Design and measures: addressing CTD attributes	**Design**: The ECO3 innovation work developed a product that was fire retardant for cavity walls, as a critical focus following the Grenfell tragedy, and the method of installing the cavity wall e.g., with abseiling. Significant research was needed to ensure the product was airtight and fire retardant. The product came with full manufacturer guarantee. It took two years to design the approach and ensure the product was ready for client sign-off. **Surveying**: The first project steps involved mapping the nature of the blocks as a desktop exercise to understand wall and heating types. Surveys were conducted by trained abseilers, including roof checks and borescope tests for each floor. Ventilation was also checked in each flat and improved in line with PAS 2035 guidance and standards. **Resident engagement**: The project team wrote to all residents early on to explain the works, share timelines and to update on progress. Residents were also invited to contact the organisation with queries by phone, through their website, by post or in-person when on-site.

Work elements	Information
Delivery: addressing CTD attributes	**Regulatory and guidance**: Working at Height and health and safety regulations informed the delivery of the work. This included a detailed Construction Phase Plan (CPP) before any work commenced. The work was fully compliant to PAS 2035 standards, and it met ECO3 standards. **Resident engagement**: A dedicated person was also always on site for residents to speak to. The organisation also worked closely with block caretakers who are known well by residents – with some caretakers also residing on the block. The caretakers were trained to understand and be able to explain the work. There was little resident resistance and much interest in the work itself. Site visits and demonstrations were also undertaken with key stakeholders, where seeing it happen is key part of the awareness building. **Installation**: There were few challenges in delivery once the method and product were approved as much pre-work and considerations had been made. The work was external, quick and there was nothing left overnight (e.g., scaffolding or work vans), which also differed to external cladding works
Impact and evaluation	**Energy efficiency and thermal performance**: The flats became more energy efficient, increasing to EPCs C and D (from E and F). Monitoring has been limited, although it is known that the properties heat up quicker and retain heat longer. **Resident satisfaction**: Immediate and short-term customer feedback and satisfaction were positive. Although there was not further monitoring of this, there have been no complaints or problems noted by the social housing provider since the work was carried out. It was recognised that there could be more done for M&E going forward. For example, running cost reduction depends on occupational behaviours and the level of heating by different residents, as is the case with other projects. **Carbon savings**: Assuming that properties are being heated to a comfortable level, annual carbon reduction across the 15 blocks was estimated at 1,422.5 tonnes per annum.
Best practices and lessons	This case study has identified the following best practices and lessons for high-rise blocks of flats in particular, and for across CTD home types: **Workforce skills**: This project used a majority local workforce, with a 50% commitment in the Social Value pact. The organisation trained local people, both cavity wall installers in abseiling and abseilers in cavity wall insulation. They found the former more effective to train, as they already had the technical skills, and this group found the training and experience very rewarding.

Work elements	Information
	Technological innovations: This new product and method can be applied to any height as long as there are cavity walls. As yet, it has not been applied in other areas. The organisation suspects this is due to perceived risks and caution with tower block properties. Awareness-building and demonstration will likely be important in future.
Relevance and insights for CTD Identification Framework	**Identification**: Often, tower blocks are considered for cavity wall insulation, and are clad from the outside at great expense. Further, new heating systems are often installed alone, meaning heat continues being lost due to the lack of insulation in the walls, leading to high energy usage and costs for residents. This project demonstrated that while high-rise or tower blocks of flats are CTD, they can be effectively retrofitted with the right insulation product and accompanying training, applying a more nuanced and innovative approach. This can reduce the level of complexity and address the CTD attributes of affordability and disruption in particular, as well as to reduce system-level barriers (product awareness and supply chain expertise). The outcomes of the work are also dependent on occupant behaviours in the home going forward, reflecting a CTD behavioural attribute. **Potential uses of the framework**: This case study highlights that the framework could be used for knowledge sharing and understanding of required project steps for CTD homes. *"A framework could also have a useful role in dissemination, of what works and of the solutions that are out in there – in a way that people and organisations could trust. "* *"A decision tree type of structure could work to help the decision flow given what is known about the property, its archetype, and the context – an 'if-then' focus for decisions and considerations".* *"It could also help suppliers who they need to speak with in the local councils for such work. Getting the message out there is extremely challenging."*

Case Study 10: Bungalow with fabric first measures and low carbon heating

Property characteristic	Information
Date property built	1950s.
Number and type	One semi-detached bungalow.
Walls	Cavity and solid.
Traditional or heritage features	N/A.
Other notable features or aesthetics	N/A.
Heating type	Electric boiler.
Tenure	Social.
Location	City in North West England.
EPC and SAP before & after	Before: EPC E, with SAP rating 39. After: EPC C, with SAP rating 72.

Illustrative property image:

Similar archetype image used for illustrative purposes only.

Work elements	Information
Project overview	A 1950s single story bungalow was retrofitted due to high-risk issues identified by the landlord when surveying the home for a new kitchen installation. There were multiple significant structural and social issues for this property, including highly vulnerable residents and damp issues posing a risk to their health and wellbeing. However, there was little information on the condition of the property, which had “flown under the radar”. The property did not have any energy efficiency measures that were working effectively. For example, windows were thought to be double glazed but poor quality, the IWI was poorly fitted and in need of repair, and there was limited ventilation that needed upgrade.
Time	The project began in 2022 and lasted three months.
Cost and funding	The total cost is unavailable, but it was funded by the housing association’s energy capital budget.
CTD attributes	**Physical**: There were visible and extensive damp and mould issues as damp-proof course (DPC) had failed. These were exacerbated by poor heating and insulation, posing significant risks to the residents. The damp and mould in the front porch also acted as a thermal bridge. Further, the roof was leaking and required additional works, and the cavity wall insulation was old and in need of repair. **Locational**: N/A. **Occupant, demographic and behavioural**: The elderly residents were hard to reach and vulnerable from living in unsafe conditions from damp and mould. They also lacked access to suitable information and support. These issues had not been raised previously and it was only on access the extent of poor housing condition was realised. Electric storage heaters that were not in use required replacing. **System-level**: A key challenge was the impact of supply chains, particularly for windows and doors which now take up to 12 weeks to deliver; and before COVID-19 were more readily available. This issue has in part been mitigated through better planning now across industry to ensure materials are available.
Design and measures: addressing CTD attributes	**Organisational approach**: The project was referred to the retrofit team who prioritised it and moved it up the list of works, engaging colleagues from across the housing association. The home was provided with priority attention and support due to circumstances of the property and residents. **Regulatory and guidance**: The PAS 2035 technical survey was undertaken and then repeated as required, to assess how different approaches could be deployed. Several interventions were deployed once the tenants were temporarily decanted. **Design**: The project took a fabric first approach, with alternations to insulation, windows and doors, damp proofing and structural repairs first.

Work elements	Information
	Following this, remedials were put into place to protect new measures, including porch and roof repairs, as a priority due to water and damp issues, where the fabric was sealed and then cavity extraction and refill. Finally, the new IWI, ventilation, Solar PV and ASHP were installed. Doors and windows were replaced later due to supply chain delays.
Delivery: addressing CTD attributes	**Regulatory and guidance**: PAS 2035 was followed with retrofit assessment and coordination. **Surveying**: This included assessment works, damp treatment and drying, and then time to tackle the fabric, to change windows and doors, as well as complete redecoration and updated bathroom and kitchen, as initially planned. The timescales were challenging and much work was required to coordinate and organise between different departments and other contractors. **Resident engagement**: A dedicated Resident Liaison Officer (RLO) and Housing Officer (HO) engaged the residents face-to-face over time. The HO was aware of the specific needs of the vulnerable residents, and the RLO provided energy efficiency advice. The residents had no initial knowledge about the processes involved in the works, and the solutions required for the property which meant they had to be decanted. The HO spent time to understand their needs including social and health needs, and ensure they were comfortable with the decanting process. This took considerable convincing and the benefits of decanting were communicated in person.
Impact and evaluation	**Monitoring and evaluation approach**: Full evaluation is still to be completed, including check-in with residents. So far, the project is viewed as a successful rapid intervention to tackle a significant and complex issue. The evaluation by the housing association will follow a standard process of 3, 6, and 12-month face-to-face visits with the occupants in which the RLO and HO will check on heating energy bills, and provide advice. **Resident satisfaction**: Resident satisfaction will be measured with surveys after the works. **Energy efficiency and thermal performance**: The property's EPC increased to C from E. The contractor will monitor resident air comfort, energy use, carbon savings, property resistance to flood and water, and enhancements to heritage/architectural quality of the property. At the time of interview this information was not available. This also takes account of the annual heating cycle, to get a full assessment of the property throughout all seasons.

Work elements	Information
	As the residents are vulnerable, the HO and RLO will more follow further guidance. For example, they will provide advice and guidance in using the new heating system (ASHP). They will also review and conduct regular meetings with tenants to check guidance is being followed.
Best practices and lessons	This case study has identified the following best practices and lessons for bungalows and projects involving highly vulnerable occupants in particular, and for across CTD home types: **Home assessments**: Having a process in place to be able to quickly prioritise homes that may need more care and complex works and move them up the work pipeline would have been beneficial. This was developed as a result of this project. **Data limitations**: EPC didn't support full understanding of the issues in the property and is only used to assess energy characteristics. In the future processes that take account of multiple data sets across several attributes should be used to fully assess the property and design/deploy measures. **Standardised approaches**: This is a good example of how PAS 2035 is most effective when used to tackle a complex property. However, PAS 2035 also caused some delays such as the administrative tasks and prescriptive approach it required. **Stakeholder engagement**: There was value in continued client and contractor communications and planning, and in having a clear interest in the needs of the end-user. There was also value in using trusted suppliers who are able to deliver rapidly and in a methodical manner. **Transparent planning**: Setting realistic timeframes for this project, particularly with decanting residents. Ensuring that project partners fully understood how long PAS 2035 takes to follow was also important. **Tailored resident engagement**: Resident liaison was also critical. It was important to follow up soon after the project is delivered to get compliance certificates from suppliers and ensure awareness. When this did not happen, resources were wasted, for example visiting devices which had been reported as broken, but which could be quickly remedied either through the warranty, or through engagement with the tenants. This was particularly relevant for the ASHP, where tenants didn't understand how to use it, changed settings, and then reported a fault.
Relevance and insights for CTD Identification Framework	**Identification**: This project shows the importance of homes not being left behind in decarbonisation, where other assessment and checks may be needed in the identification process. The length of time since refurbishment and lack of resident engagement (for social housing tenants) can proxy a potential CTD home in need.

Work elements	Information
	Potential uses of the framework: This case study highlighted the value in understanding attributes across a large stock of housing, and to avoid some homes being left behind. *“A framework of approaches would be useful: [we have a high number of] properties across the retrofit programme that require work. It’s not possible to know them individually, and for some of them we must go from best guess about what needs improving and when. A predictive model of where hard to treat properties might be in our stock data based would be useful to help understand where to pay attention, and where there could be some properties that slip through the net.”*

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