“Retrofit Social Housing Report– Better Homes Improve Lives”

Nottingham, June 2020

Foreword

Our homes are essential for a successful society. They provide shelter and a safe space from which all of us, individually and collectively, can take part. But those homes need to be fit for purpose. They need to be ready for the challenges we face over the coming decades.

Housing accounts for about 30% of the UK's energy demands and about 20% of UK greenhouse gas emission. We need dramatic improvements in our housing stock to meet the net-zero carbon emissions target by 2050. At the same time, large numbers of people are in fuel poverty, where adequately heating their homes uses so much of their income that they fall below the poverty line. Fuel poverty leads to poor health, low levels of economic activity, and for the young, poor life outcomes.

Upgrading our housing stock will reduce carbon emissions, cut costs and improve health and wellbeing all significant societal and economic benefits. The challenge has been developing routes to upgrade the wide range of housing types in the UK and driving down the costs to the point of economic viability.

Through participation in the REMOURBAN European project, Nottingham has tested different solutions to retrofitting homes to be more energy-efficient, less cold, and better places to live. The report follows over 450 homes, mostly social housing. It describes how they were upgraded, what difference it made to energy efficiency, and the impact it had on the households.

Nottingham has learned a lot about the practical difficulties that must be overcome, but also the real benefits gained. Making our homes fit for the future needs of society is a major challenge that cannot be ignored. The evidence, advice and suggestions in this report will help everyone responsible for our housing stock to find solutions that work for them.

Table of Contents

Executive Summary

The UK housing stock is old and inefficient. We need housing that is low-carbon, resilient to climate change, flexible and adaptable, suitable for all ages, and above all, desirable.

The most pressing need is to reduce energy demand and carbon emissions from our housing stock. There are two major reasons:

- The UK has set a target of net-zero carbon emissions by 2050, and our homes are responsible for 18% of UK greenhouse gas emissions. We need a pathway to net-zero for housing.
- Fuel poverty is a serious problem. Cold homes contribute to respiratory and circulation problems, as well as stress, anxiety and depression. Fuel poverty leads to five thousand excess winter deaths each year. This is a drain on the NHS and social care system and reduces economic activity.

80% of the homes we will use in 2050 already exist. That means we need a route to upgrading 27 million homes to net-zero. A national programme to deliver in volume, at speed and cost-effectively.

Technical solutions for retrofitting existing homes exist, but they are not being deployed widely enough or rapidly enough. The primary reasons are:

- Lack of demand.
- No clear and consistent Government policy driving retrofit.
- Current high costs of retrofitting.
- A lack of both capability and capacity throughout the supply chain.
- Difficulty in financing.

Social landlords look after 17% of the total UK housing stock and have a crucial role to play in achieving net-zero. They face some specific barriers:

- Risk - confidence in both the solutions and the providers.
- Business case - something that fits their strategic objectives, investment criteria and other priorities.
- Information and knowledge - access to independent and trusted advice, and the supply chain that can deliver.

Large-scale demonstrators, under realistic conditions, can provide essential evidence on what works and what doesn't work. Demonstrators undertaken by social landlords and local authorities give confidence to others in a similar situation.

Nottingham has recently completed an urban regeneration project as part of a larger European project, REMOURBAN. The Nottingham project treated 463 existing properties in the Sneinton area of the city, a place with multiple deprivations.

The project trialled four retrofit options across eight different building types to improve energy efficiency and reduce costs. These ranged from simple replacement of all lighting with low-energy LED systems, to wrapping the entire property in an efficient insulating layer and providing heat from ground source heat pumps and electricity from rooftop solar PV.

The energy savings from improving the building fabric ranged from 31% to 45%. Using ground source heat pumps pushed the savings up to 68%. The upgrades saved about 3GWh/year in energy and 550 t/year in CO_2(eq) emissions across the 463 properties. It was possible to achieve these savings while improving the lives of the occupants. There are real benefits over and above energy savings in better health and wellbeing, and the regeneration of residential areas.

The retrofits produced warmer and more comfortable homes and increased the occupants' sense of wellbeing. 86% reported an improvement in the quality of their home and 52% reported a significant improvement. Occupants described warmer homes, cheaper bills, enhanced health and wellbeing, increased space, improved natural light, better ventilation and air quality, and better-quality homes.

Key lessons from the project:

1. **The tenure of the properties has a big effect on the outcome.**
   - It is much easier to retrofit social housing than private housing. A retrofit programme will reach up to 95% of social rented homes. Only 20% to 45% of privately rented or owner-occupied properties will take up the chance of a deep retrofit, especially when required to invest their own money. For example, the 1900 homes were all private sector, requiring bespoke solutions for each property at a price acceptable to the owner.
   - Properties previously sold under 'right to buy' legislation can disrupt a retrofit programme. In the Courts, flats sold to leaseholders had to contribute to the retrofit costs and leaseholders objected strongly. Private owners of houses in the 2050 Homes terrace refused to take part in the upgrade. This affected the cost and quality of the work and the overall aesthetics.
2. **Getting the right energy supply model is critical.**
   - A private wire model, with battery storage between a 'block' meter and individual tenant meters, is the most flexible, allowing for grid balancing. However, it took a lot of time and effort to deliver. In the Courts a new electrical connection was installed for each block. Solar PV provided electricity to each home with batteries at the block level storing any surplus.
   - A private wire solution for the 2050 Homes, coupled with combined heat and electricity contracts, allowed the testing of novel energy supply plans.
   - Getting the best out of a deep retrofit programme requires careful exploration of alternative energy supply models; choosing an appropriate model for energy sources and stock types. We need to improve our capability in the design, delivery and management of community heating, and community electricity with battery storage.

3. **Monitoring performance in use is difficult.**
    - Choosing the sensor locations and setting up reliable monitoring is technically challenging.
    - Cost and privacy concerns are barriers to gaining owner and householder agreement.
    - Ensuring reliable performance data over a sufficient period is both technically and managerially difficult.
4. **Excellent project management skills are essential for these complex programmes.**
5. **There are benefits to alternative procurement approaches.**
    - Procurement for the 2050 Homes used competitive dialogue. This OJEU compliant scheme allowed the development of a fixed price guaranteed outcome contract. Suppliers worked with the client to generate alternative design proposals. It was an iterative process that gave both client and supplier more confidence in feasibility, cost, performance and time scale
6. **The Grenfell Tower fire had an unexpected impact.**
    - After the Grenfell Tower fire, the design of the Courts refurbishment had to change. The architects specified an alternative cladding system which was more expensive, but custom manufactured to fit the buildings. Faster installation compensated for part of the delay caused by the redesign.
7. **There were benefits to the city, owners, occupiers and the supply chain.**
    - The city gained important information about routes to net-zero, and significant improvements in the appearance and vitality of a poorer part of the city.
    - Property owners saw significant improvements in the energy efficiency, desirability and value of the homes.
    - Those living in the properties saw improvements in comfort, cost and wellbeing.
    - The project enabled smaller SMEs to develop new products and services and to learn valuable lessons about this growing market.

1. Introduction

Nottingham has recently completed an urban regeneration demonstrator programme which focused on retrofitting existing properties and using district heating to reduce carbon emissions and improve wellbeing. This report describes the drivers for the programme, how they carried the programme out, the outcomes and benefits, and the lessons learned. It contains evidence and advice for other local authorities and social landlords developing regeneration projects.

1.1. The Need to Retrofit the Existing Housing Stock

The UK housing stock is old and inefficient. We need housing that is low-carbon, resilient to climate change, flexible and adaptable, suitable for all ages, and above all, desirable.

The most pressing need is to reduce energy demand and carbon emissions from our housing stock. There are two major reasons:

- The UK has set a target of net-zero carbon emissions by 2050[1]. Our homes use about 30% of the U.K.'s total energy demand[2] and are responsible for 18% of the greenhouse gas emissions[3]. We must have a pathway to net-zero for housing, and with 80% of the homes we will use in 2050 already built, that means retrofitting the existing stock.
- Fuel poverty is a serious problem. In England alone, 11% of households are in fuel poverty (2.5 million)[4]. There were 50,100 excess winter deaths in England and Wales in 2018[5], with 10% attributed to fuel poverty[6]. Cold homes are a burden on the NHS with a direct cost of £848 million per year[7]; more when you factor in cold-related issues such as excess moisture and mould. Cold homes contribute to respiratory and circulatory problems as well as stress, anxiety and depression in both adults and children[8].

Space and water heating accounts for about three-quarters of domestic energy consumption. The primary fuel is gas, which needs to be eliminated from our energy ecosystem. Not only does it create carbon emissions, but it contributes to air pollution. For example, in 2010, about one-third of central London's nitrogen oxide pollution came from domestic use of gas[9].

We also have an ageing population. By 2030, 20% of the UK population will be 65 or over[10]. Our housing stock is not ready for our future citizens to have healthy and fulfilled lives[11].

Dealing with climate change and meeting the needs of our future population means that retrofitting our existing housing stock to very high levels of performance is essential. With current and projected rates of new-build, a very high proportion of our existing stock will continue in use for many years. Twenty-seven million homes will need to be upgraded, and that implies a national programme that can deliver in volume, at speed and cost-effectively.

We also cannot switch to electrical heating and decarbonise the grid. Winter demand for heat energy is six times the demand for electricity. No projected growth in the electricity grid can deliver that capacity. We must cut domestic heating demand as far as possible, and then decarbonise what remains. That means our homes must become much more energy efficient.

1.2. Available Solutions

The age and inefficiency of our housing stock are well known. Many projects, from individual properties to large demonstrators, have trialled different approaches to retrofitting homes for greater energy efficiency.

There is a wide range of approaches, systems, materials and components available both in prototype and on the market.

There are databases of projects[12,13], reports[14,15,16,17,18,19] and specialist groups[20,21,22,23] covering specific strategies, designs and implementations.

What all these projects showed is that we can retrofit domestic properties to the required standard. The technologies are there, and the solutions are there. There may be all kinds of practical and economic limitations, but net-zero is achievable. Innovation is required in components, construction methods and business models to make deep retrofit a more practical proposition.

From the many demonstrator projects reported, key success factors have been identified[17]:

- A clear policy lead.
- Public sector subsidy, or access to low-cost finance.
- A whole-house approach to retrofit.
- Aggregation of properties into larger projects.
- A single, trusted point of contact for owners and tenants that will stay with them throughout the retrofit process.
- A good consumer proposition.
- A long-term strategy

Of these, a whole-house approach to retrofit is particularly important. The goal is to drive the heating demand is close to zero as possible and then supply the residual need from zero-carbon sources. We cannot do this with incremental improvements, such as more efficient boilers. Individual, point solutions to specific efficiency problems can create a situation where installations must be expensively removed and replaced later on the journey to net-zero.

A whole-house plan is required to avoid regretted investments. One approach is the concept of a Building Renovation Passport[24]. This is a document outlining a step-by-step renovation roadmap for a specific building over a long time, potentially 15 to 20 years. It maps a clear pathway to the final goal. It recognises that it may not be possible or practical to do a complete retrofit in one go, but avoids technological dead ends.

1.3. Barriers to Widespread Adoption

Although deep retrofit solutions have been widely demonstrated, take-up is poor. Retrofit is largely stuck at the demonstrator and experiment stage and has not yet become mainstream. Acceleration of retrofit is essential to meet society's needs, and that means tackling the barriers to widespread adoption.

1.3.1. General Barriers

The key barriers affecting the whole retrofit market have been widely reviewed and discussed[16,17,18,19,25]. They are:

- **Lack of demand**

  Retrofit for energy efficiency is not attractive enough to homeowners, landlords or tenants.

  All buyers worry about the risks. They are not confident that the promised benefits will arrive, and worry about poor quality installation, defective equipment and uncontrolled costs.

- **No clear and consistent Government policy driving retrofit**

  Government is not demanding deep retrofit of existing homes as part of the journey to net-zero. It is not being given priority.

  Experience of changing Government policies, such as the Code for Sustainable Homes and the Green Deal, makes both buyers and sellers reluctant to commit.

- **Current high costs of retrofitting**

  With only a few properties undergoing deep retrofit, cost per unit is still high. This makes it difficult for an owner to create an economic case to invest.

  A small number of retrofitted homes mean no economies of scale; keeping costs high and suppressing demand.

- **A lack of both capability and capacity throughout the supply chain**

  Buyers lack the knowledge and understanding to specify, select and manage retrofit projects.

  There is a skills gap throughout the construction sector, but specifically in the new technologies required for deep retrofits.

  There are few integrators; businesses that can design and deliver successful retrofits.

- **Difficulty in financing**

  There is a lack of low-cost financing in the UK to stimulate this market.

Retrofit programmes have not been packaged to be attractive to large investors. They compare poorly in risk and return with more established green infrastructure projects such as wind farms.

1.3.2. Barriers Specific to Social Landlords

Social landlords face additional challenges specific to their sector.

A recent report[26] interviewed 40 social landlords and eight retrofit suppliers to discuss the barriers they faced.

- Maintenance work and improvement work are usually separate budgets, often with framework agreements for delivery. These silos make it difficult to coordinate activities and make the most effective use of the combined budget.
- Both social landlords and suppliers have limited knowledge about retrofit for energy efficiency.
- Thermal retrofit can be a low priority for social landlords compared to other activities such as meeting Decent Homes standards or replacing and upgrading kitchens and bathrooms.
- There is a conflict between funding for new homes and for retrofitting existing homes, with new homes often the higher priority.
- Some social landlords do not have accurate enough stock condition information to model the value of retrofit programmes.
- Improving the performance of the building is seen as more expensive than conventional maintenance and improvements.
- Many social landlords feel that they have already carried out the easy upgrades for energy efficiency and now need to move on to more demanding solutions such as external wall insulation. They see this as expensive, complicated, and difficult to integrate into work programmes.

At a retrofit workshop[27] in 2019 buyers, including social landlords, were asked what must change if they are to invest in deep retrofit. The top five challenges:

- Confidence – buyers need to know that there is a solution for their specific properties, that it can be delivered and is robust. They need to trust both the solutions and providers.
- A good business case – something they can take to their board that fits their strategic objectives and their investment criteria.
- Information and knowledge – buyers feel that there is a lack of independent and trusted advice on retrofit options and methods. They feel confused. They also need access to a supply chain that understands what they want to do and has the skills to advise and deliver.
- Policy and regulation – social landlords already struggle to deliver current legal requirements. Unless Government is prepared to mandate retrofitting for energy

efficiency and liveability, it is unlikely to make it to the top of social landlords' priorities.

- A better offer from suppliers – buyers are disappointed with the solutions on offer. They are not tailored to their needs, both strategically and operationally. Retrofit needs to be fast and hassle-free.

The Nottingham City Demonstrator shows how to overcome some of these barriers, delivering practical and beneficial retrofits.

2. Nottingham City Demonstrator Project

The Nottingham City Demonstrator is part of a larger European project, REMOURBAN[28]. This involved five cities and 22 partners pioneering novel approaches to sustainable urban regeneration. The project ran for five years 2015 – 2019 with a total budget of €24m.

The Nottingham City Demonstrator focused on the energy theme within the project, targeting novel approaches to delivering sustainable urban regeneration through low-energy and low-carbon districts. The project used market-ready technologies to show what is possible with the solutions already available.

The Nottingham project partners were Nottingham City Council (NCC)[29], Nottingham City Homes (NCH)[30], Nottingham Trent University (NTU)[31], and Nottingham Energy Partnership (NEP)[32].

2.1. Nottingham City Context

Nottingham is a historic city in the East Midlands 130 miles north of London. It is a compact city with an official population of 305,750. The wider urban area has a population of 729,977, making it the ninth-largest in the UK.

Nottingham City already has a 2020 Energy and carbon strategy with priority areas of energy saving, energy generation and transport. The plan set specific targets for a variety of energy efficiency technologies. The Nottingham City Demonstrator closely aligned with these strategies, and also supported the Derby, Derbyshire, Nottingham and Nottinghamshire (D2N2) Local Enterprise Partnership Low Carbon Plan; focusing on housing retrofit and district heating.

2.2. Selection of Demonstrator Area

The project selected Sneinton, to the east of Nottingham city centre, for the demonstrator for four reasons:

- It is a deprived inner-city area. Indices of Multiple Deprivation show that all parts of Sneinton fall within the 10%-15% most deprived neighbourhoods in the UK.
- Compared to the Nottingham average, it has higher levels of inequality, lower household income, higher levels of unemployment, higher proportions of residents living in fuel poverty, and poorer health.
- Nottingham has invested in a significant extension to its district heating network. Sneinton is close to its periphery, allowing expansion of district heating as part of the project.
- There is a wide range of property types from one-bedroom flats to 3-bedroom terraced houses, and homes from the 1900s to the 1970s. 65% are social housing, owned by Nottingham City Council and managed by Nottingham City Homes. The properties cover several designs, materials and construction methods, including many classified as hard to treat.

Sneinton offered an excellent chance to demonstrate real benefits, both for energy savings and improved occupant wellbeing.

Within the demonstrator area there are 999 properties. Removing all homes with cavity walls and some privately owned properties where the project expected low take up, reduced the total to 802.

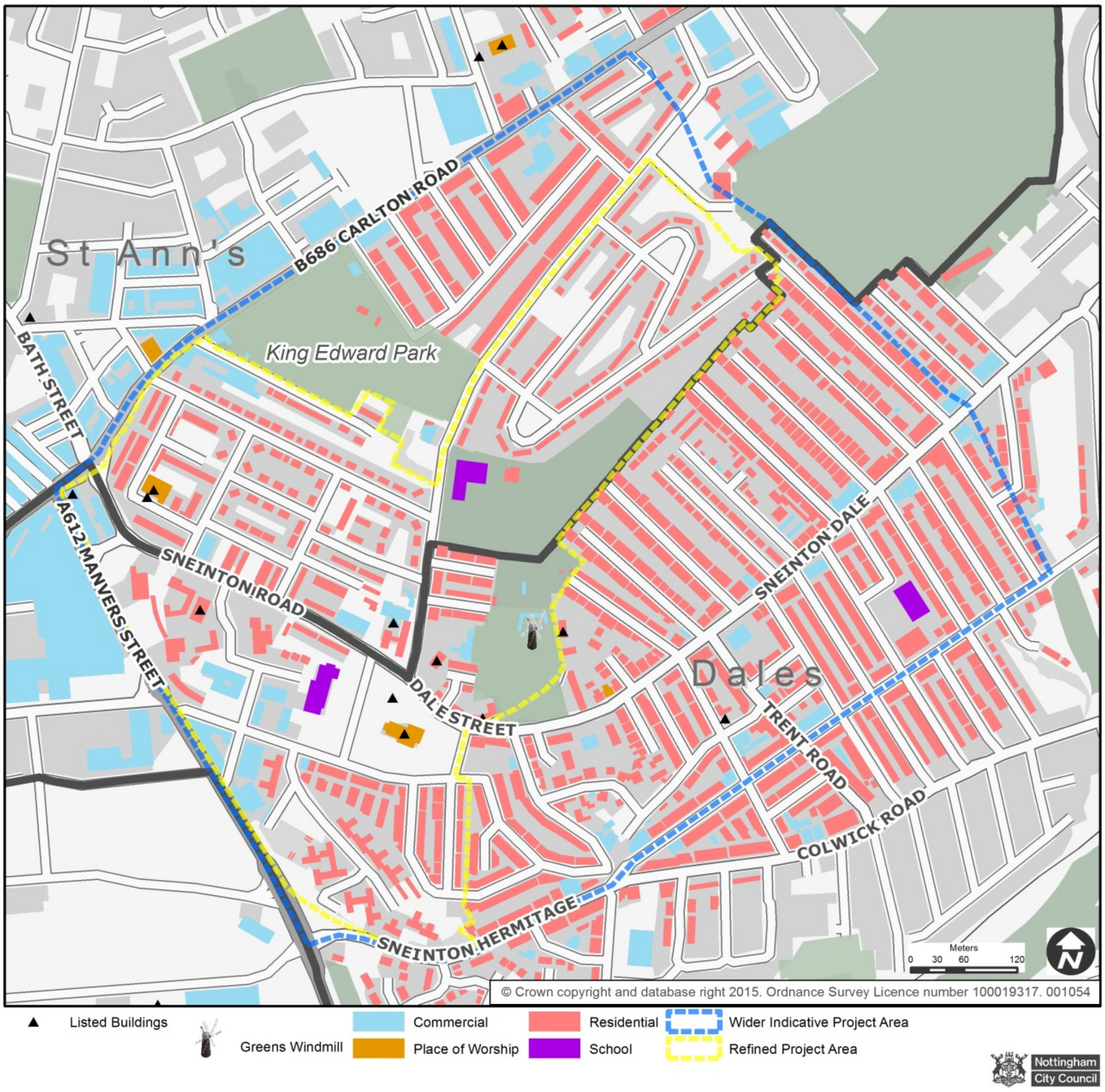


Figure 1: Map of the REMOURBAN Study Area in Nottingham

The 802 properties divide into nine archetypes listed in Table 1.

Table 1: Properties by Type in the REMOURBAN Area

Archetype	Description	No. in Sneinton	No. in Study
A	Houses, Brick 1900s	36	24
B	Houses, Brick 1930s	165	147
C	Bungalows, William Moss Cross Wall	21	21
D	Flats, Timber Frame Cross Wall	12	12
E	Flats, Wimpey No Fines Concrete panels	141	141
F	Houses, William Moss Cross Wall	51	16
G	Maisonettes & Flats, System-Built Low-Rise	94	94
H	Flats, System-Built High-Rise	270	0
I	Houses, Solid Wall Cross Wall System-Build	12	8
Total		**802**	**463**

The project eliminated system-built high-rise flats from the scope because of the limited resources available. 87% of the remaining 532 properties were included in the demonstrator, preserving the stock diversity.

Archetype A: House - Solid Wall Brick 1900s

Archetype B: House - Solid Wall Brick 1930s

Archetype E: Flat - Solid Wall Concrete

Archetype F2: House - William Moss 3 Bed

Archetype C2: Flat - William Moss 1 Bed

Archetype G: Maisonette - Concrete 2 bed

Archetype D: Flats

Archetype H: High-Rise Flats

Archetype I: Terraced House

Figure 2: Examples of the Different Building Archetypes

2.3. A Sliding Scale of Retrofit Strategies

The project used a series of four retrofit interventions of increasing complexity; allocated across the different archetypes.

Intervention	Description
1	Switching all lighting to low-energy LED's
2	Low-energy lighting plus external wall insulation, plus room-in-roof insulation for appropriate buildings
3	Low-energy lighting plus external wall insulation plus low-temperature district heating
4	Low-energy lighting plus external wall insulation plus replacement roof, windows and doors, plus solar PV and ground source heat pumps

2.4. Procurement

A key to the successful delivery of the demonstrator was the use of Competitive Dialogue[33] in the procurement process.

Competitive Dialogue is an alternative public sector procurement process for particularly complex contracts where:

- The client cannot define the technical means to meet their requirements.
- The client cannot define the legal or financial makeup of the project.
- Conventional public sector procurement would not be effective.

It works where the client can state what they want to achieve, but cannot specify a solution. After initial short-listing, suppliers work with the client to generate alternative design proposals. It is an iterative process that gives both client and supplier more confidence in feasibility, cost, performance and time scale for a specific solution.

At the end of the dialogue, suppliers submit tenders in the usual way, but both sides have much more clarity and understanding of the proposal. It brings the full expertise of the supplier into play in deciding how to meet the client objectives.

With limited internal expertise, Nottingham found that competitive dialogue helped them to find novel but practical solutions to their challenges.

For example, Nottingham City Homes used the competitive dialogue process for the ten 2050 Homes (intervention 4). Procurement was based on a fixed price and a specified outcome for energy performance. To assess bids, they split the points 70% for quality, 20% operations and maintenance, and 10% income generation.

Involving the tenants was a key part of the process. This included allowing the bidders to interview tenants and visit their homes, but also getting a wish-list of improvements from the tenants and feeding it into the specification. The knowledge of the tenants was essential to a good outcome, and their involvement recruited them into the project.

2.5. Citizen Engagement

Bringing the tenants into the project was essential to the project success. By making them participants, rather than having the retrofits ‘done to them’, the project team gathered valuable and detailed local knowledge, and respected their own ambitions and desires[34].

Contact started early in the project, continued throughout the design, tendering, implementation processes, and through monitoring and feedback continues to this day.

The key features of the citizen engagement process for the 2050 Homes included:

- Supporting materials to explain the works; artist impressions of the homes, direct mail, energy assessments.
- Individual household visits to introduce the project and undertake energy consumption research.
- Chip Shop Supper – very early in the project to get the tenant group together to discuss the project and options.
- Involvement in procurement and contracting. Tenants had a lot of contact with the bidding process; this meant the dialogue happened at a much earlier stage when the tenants had a greater opportunity to influence the final proposals.
- An event to announce the contractor and plans – celebrating the ‘start’ of the work.
- Garden Party with neighbouring housing development also involved in a REMOURBAN retrofit programme to discuss the wider plans for their shared spaces.
- Regular coffee mornings – an ongoing opportunity to get together.
- Constant information sharing during the construction phase so that tenants knew what was happening.
- A good handover process, so tenants understand how their new homes work and how to get the best out of them.
- Regular monitoring of building performance and tenant satisfaction to learn from in use experience and to keep tenants supported and engaged.

Figure 3: Citizen Engagement Activities in the Nottingham Project

After the retrofits, the occupants continued their involvement throughout the evaluation period. Through surveys and interviews, the project collected data on satisfaction, comfort and problems. This practical experience is being fed into the next phase of regeneration in Nottingham.

2.6. Retrofit in Action

2.6.1. Intervention 1 - Low-energy lighting

The simplest intervention was only replacing all existing lighting with low-energy LEDs. Applied to all retrofits. This was the only intervention used on most of Archetype C and all of Archetype D and I.

No cost data collected for this intervention. Assessed energy savings assumed conversion from 25% low-energy to 100% low-energy lighting.

2.6.2. Intervention 2 - Solid wall insulation

Many properties in Sneinton have solid wall construction (brick and concrete, or cross wall with uninsulated timber frame and cladding). These are classified as hard to treat.

An uninsulated masonry external wall 225 mm thick will achieve a U-value of approximately 2.1 W/m^2K. External wall insulation will reduce that to 0.30 W/m^2K, an improvement of over 80%. This is a highly effective intervention with an expected lifetime of 36 years, and an expected energy saving of 20% to 30%.

Standard external wall insulation was applied to Archetype B (1930s brick built properties) and Archetype E (Wimpey flats).

Sneinton also has many 1900s brick-built houses with intricate Victorian style architectural features including dormers and bay windows (Archetype A). Besides solid wall insulation these were fitted with ‘room-in-roof’ insulation at higher levels, down the sloping soffits and between vertical dormer stud walls. The result is a continuous layer of insulation that maximises the space for living in storage. This both improves the thermal efficiency of the property and creates a comfortable living area from a space that overheats in summer and is cold in winter.

Archetype B: Solid Brick 1930s

Figure 4: Solid Wall Insulation Example – Before and After

2.6.3. Intervention 3 - Solid wall insulation plus low-temperature district heating (LTDH)

Nottingham has the largest district heating network in the UK. The Nottingham district energy network has 68 km insulated pipework carrying pressurised hot water around Nottingham City Centre and a residential suburb to the north of the city. This is used to satisfy the space and hot water heating requirements of approximately 4900 dwellings and over a hundred commercial premises.

The district heating system uses combined heat and power plant supplied by steam from a waste incineration facility processing around hundred 70,000 tons of municipal waste per annum. Gas boilers provide backup, but these are only operational 5% to 10% of the time. As well as generating hot water, the plant produces 60 GWh of electricity annually.

Adjacent to the existing heat network are a series of low-rise maisonette Courts (Archetype E). Upgrading these with external wall insulation and new windows and doors means a much lower energy demand for heating. This allows the installation of a low-temperature district heating system that takes the cool return flow from the central district heating scheme and extracts useful energy. The system takes water in at 60 C to 65 C, abstracts the heat and returns it at about 35 C. As well as providing heating for the four blocks; a high-efficiency plate heat exchanger converts mains cold water into instantaneous hot water for each property.

Because it operates at a lower temperature, costs are reduced, heat losses in the system are lower and efficiency higher. The system successfully provides low-carbon space and water heating to a significant number of properties, taking advantage of heat which would otherwise go to waste.

Figure 5: Layout of the Courts and Path of the District Heating Link

Figure 6: Solid Wall Insulation and District Heating – Before and After

Partially enclosing the balcony of the upper storey of each maisonette created a small extension increasing the size of the main bedroom.

In addition, solar PV was installed on refurbished roofs. Each block has a separate grid electrical connection feeding a private wire into each flat. This makes is much each to make effective use of the rooftop PV, using battery storage at the block level to store excess electricity and to smooth demand. This is a scaleable solution for grid balancing that can be copied elsewhere.

2.6.4. Intervention 4 - 2050 Homes

The most demanding part of the project was to carry out a deep retrofit of ten properties to the net-zero 2050 goal. Homes that emit net-zero carbon for space and water heating.

The test cases were seven out of a terrace of nine three-bedroom houses of Archetype F, and three bungalows from Archetype C. The houses are uninsulated and built with a combination of unfilled concrete cavity walls and timber panelling. They are also of an unusual design that exposes the floor of living areas to the outside. As a result, they are very cold.

Figure 7: Terraced 3-Bedroom Homes Before Retrofit

The target was to get as close as reasonably possible to the EnerPHit standard[35]; a modification of the full Passivhaus approach to make refurbishment and retrofit more practical.

The retrofits used the Energiesprong[36] methodology to speed the refurbishment, minimise occupant disruption and guarantee performance.

An external 'wrapping' of insulation dramatically reduced the heat loss. The wrapping consisted of new insulating cladding panels, new insulated roof with integrated solar PV, triple-glazed windows and new doors. As far as possible these new components were fabricated off-site ready for quick installation. Treatment to improve airtightness and control ventilation completed the work on the fabric.

Heat for the complex came from a single ground source heat pump using deep boreholes. The heat pump, together with a thermal store and battery storage for the rooftop PV, occupied an energy module at one end of the terrace.

The 2050 Homes are fitted with a private wire system from the energy module to individual flats, allowing for effective use of the PV and grid balancing. The 2050 Homes have a 'mono energy solution' covering both heat and electricity. This allows the use of spare electricity for heat pumps or immersion heaters, driving further increases in efficiency.

Three of the potential properties were not included in the study because they were in private ownership. This allows direct comparison between the performance of retrofitted and un-retrofitted properties.

Figure 8: Terraced 3-Bedroom Homes and Bungalows After Retrofit

2.6.5. Cost of retrofit

The average cost for each combination of building archetype and intervention are given in Table 2. These are still relatively high as this was a demonstrator project using relatively low numbers of properties and incurring additional costs as prototypes.

Table 2: Costs of Retrofit

Type	Intervention	No.	Cost for Type	Cost per unit
A	2 - External wall insulation plus room-in-roof	24	£205,200	£8,550
B	2 – External wall insulation	147	£735,296	£5,002
E	2 – External wall insulation	141	£837,912	£5,943
F2	4 – Deep retrofit	7	£408,585	£58,369
G	3 – External wall insulation, plus new windows, plus low temp district heating	94	£826,108	£8,788
C2	4 – Deep retrofit	3	£126,165	£42,055
	Total	**416**	**£3,139,266**	**£7,546**

2.7. Monitoring Performance

Monitoring of actual performance in use is an essential part of the demonstrator project. Sensors for temperature, relative humidity, and electricity and gas consumption were installed in 41 properties covering all archetypes except those which received only a low-energy lighting upgrade.

A collection module received data from the sensors using low-power radio signals and transmitted the results to a central monitoring station over 3G/4G mobile phone connections.

Table 3 Frequency of Data Collection for Different Parameters.

Parameter	Location (scale)	Pre-set frequency
Temperature (T in ºC)	Different living zones	10 min / 1hr
Relative Humidity (RH in %)	Different living zones	10 min / 1hr
Battery levels of T / RH sensors (in V)	Different living zones	1 hr
Electrical power (W)	Whole-house	10 sec
Electricity (kWh)	Whole-house	10 sec / 1hr
Daily Electricity use (kWh/d)	Whole-house	1 day
Gas (kWh)	Whole-house	1 hr

3. Outcomes

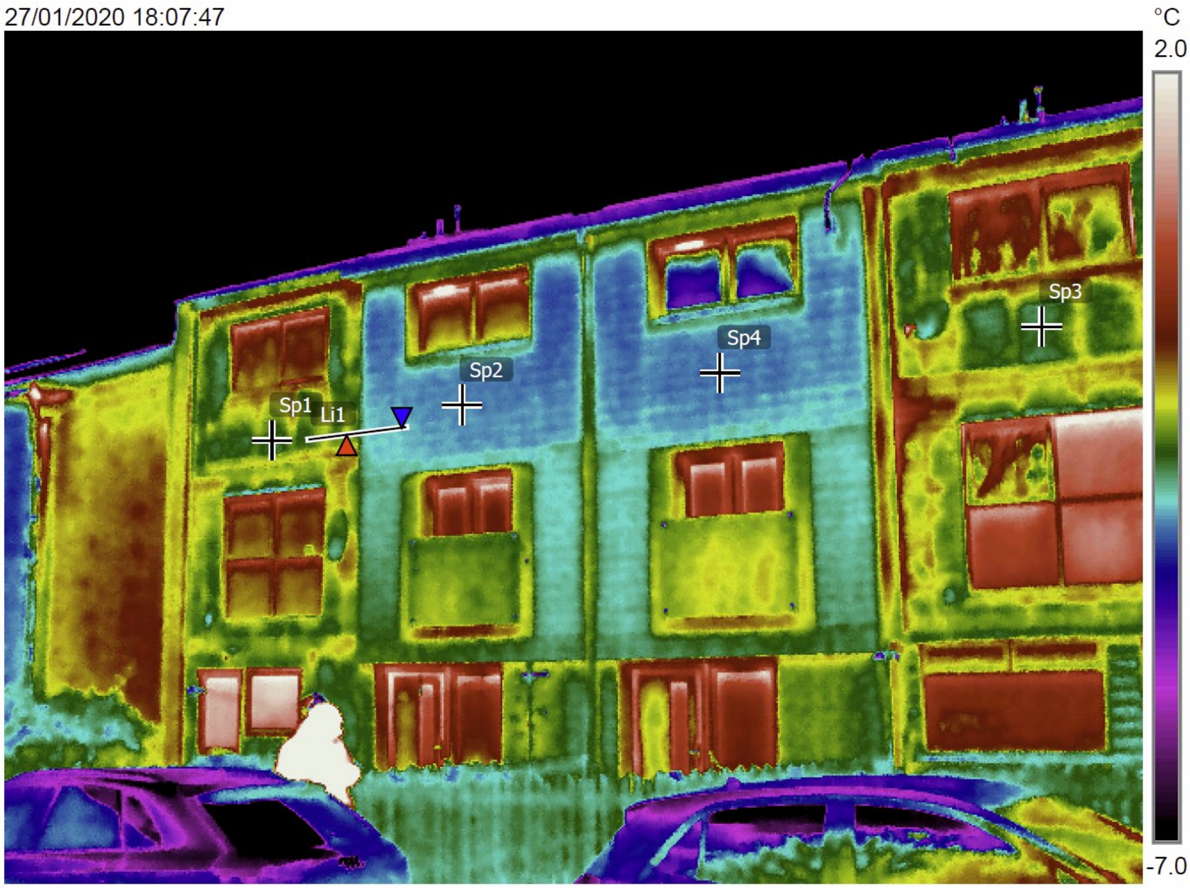


Figure 9: Impact of Retrofit on Heat Loss

The retrofits made a significant difference to the performance of the homes. Figure 9 shows a terraced row of 3-bedroom homes of Archetype F. The two middle properties were retrofitted, the two outer ones were not. The exterior temperatures are significantly lower for the retrofitted properties due to improved insulation.

3.1. Energy Savings

Energy savings after retrofit can be calculated using the International Performance Measurement and Verification Protocol (IPM&VM)[37]. This is a standard approach to assessing the impact of energy conservation measures used across all the REMOURBAN projects.

The problem is that energy savings cannot be directly measured because they are the absence of demand. You cannot do a direct before and after comparison for homes, because the very act of adding energy-saving measures changes the way people use the space. A common example is that those with cold homes will spend some of the fuel-saving from improved energy efficiency in keeping warmer.

The procedure for estimating energy savings used the following steps:

- For each of the monitored building archetypes, make a building physics energy model based on survey data and assumptions about usage patterns and occupancy.
- Compare the predicted electricity and heat demand with the actual data from the monitored properties.
- Adjust the model parameters with the weakest evidence until the simulation agrees with the real data.
- In the model, switched off the energy-saving measures and calculate what the demand would have been without the upgrades. This gives a pre-retrofit baseline with the same usage pattern.
- Apply the validated model to all buildings with the same archetype to get total predicted savings.

Table 4 shows the number of properties monitored for each archetype. There was no monitoring for properties that only received the LED upgrade. Instead, the calculated energy-saving was based on converting 75% of the typical lighting load to LEDs.

Table 4: Number of Properties Performance Monitored

Building Archetype	Numbers of dwellings
Archetype A: Solid Brick 1900s	4
Archetype B: Solid Brick 1930s	4
Archetype E: 'Wimpey No Fines' flats	9
Archetype G: LTDH served maisonette flats	14
Archetype F2: 2050 Homes (houses)	3
Archetype C2: 2050 Homes (bungalows)	7
Total	**41**

Figure 10 shows the validated model results for each archetype.

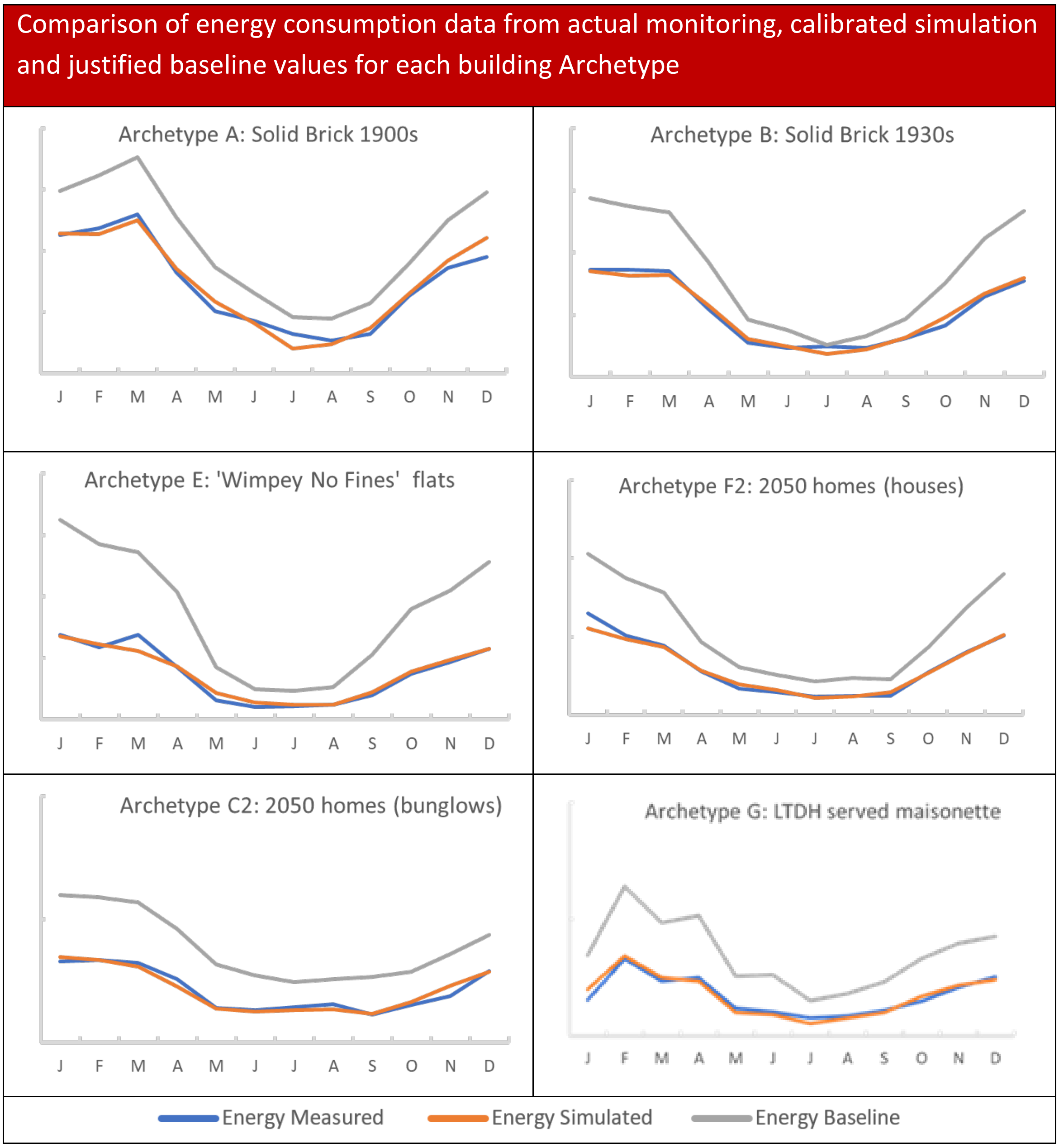


Figure 10: Validation of Models for Energy Saving in Different Archetypes

Table 5 shows the calculated energy-saving per home for each of the archetypes. Percentage energy savings range from 3.5% for low-energy lighting installation to more than 40% with an average across the whole estate of 39%.

Table 5: Predicted Energy and Carbon Emissions Savings

Building Archetype	Energy savings per home (kWh/yr)	% energy savings	Dwelling numbers	Archetype Energy savings (kWh/yr)	CO_2 Savings (kg CO_2e/yr)
Archetype A: Solid Brick 1900s	7,813.8	31%	24	187,531.2	38,309
Archetype B: Solid Brick 1930s	7,733.4	38%	147	1,136,809.8	232,228
Archetype E: 'Wimpey No Fines' flats	7,613	40%	141	1,073,433	219,281
Archetype G: LTDH served maisonette flats	5,538.7	42%	94	520,637.8	N/A
Archetype F2: 2050 Homes (houses)	8,207	55%	7	57,449	19,648
Archetype C2: 2050 Homes (bungalows)	6,151	58%	3	18,480	6,320
Archetypes C, D and I – LED only retrofit	497.5	3.5%	47	23,380.50	11,224
Total numbers of retrofitted homes and energy savings per year			**463**	**3,017,723.3**	**526,337**

The percentage energy savings come solely from improvements to the energy efficiency of the building envelope. In the case of the 2050 Homes, the savings are much greater as the heat pumps in use generate far more energy than they consume. The total savings for the 2050 Homes reach 68%.

The Low Temperature District Heating properties (Archetype G) also benefit from unused heat in the low-temperature return feed from the existing district heating system. It is difficult to calculate the additional energy savings as allocation of energy costs across different uses of the heat energy from the incinerator is not easy.

Savings in carbon emissions have been calculated based on the carbon intensity of energy from the latest Digest of UK Energy Statistics[38].

No carbon savings are quoted for the LTDH scheme as measuring and classifying emissions from waste incineration is controversial. Energy generating municipal solid waste incinerators in Europe released between 50 and 120 million tonnes of CO_2 in 2017[39]. None of these emissions are included in any trading scheme. Waste to energy plants may appear to be low-carbon, but in reality are often not.

3.2. Improvements in Wellbeing

The retrofits produced warmer and more comfortable homes. For quantitative assessment, the REMOURBAN project defined comfort as relative humidity and temperature within specified limits (table 6).

Table 6: Definition of a Comfortable Thermal Environment for the REMOURBAN Project

	Relative Humidity Thresholds	Dry Temperature
Winter	20%< RH < 80%	0.008·RH+18.917 < T < -0.011·RH+24.067
Spring/Autumn		-0.009·RH+19.750 < T < -0.019·RH+25.267
Summer		-0.009·RH+19.950 < T < -0.020·RH+25.500

The data from the monitored properties gave the percentage of time that each archetype had a ‘comfortable’ environment. Figure 11 shows the percentage of time where the environment was within the comfortable range for each archetype and for different seasons.

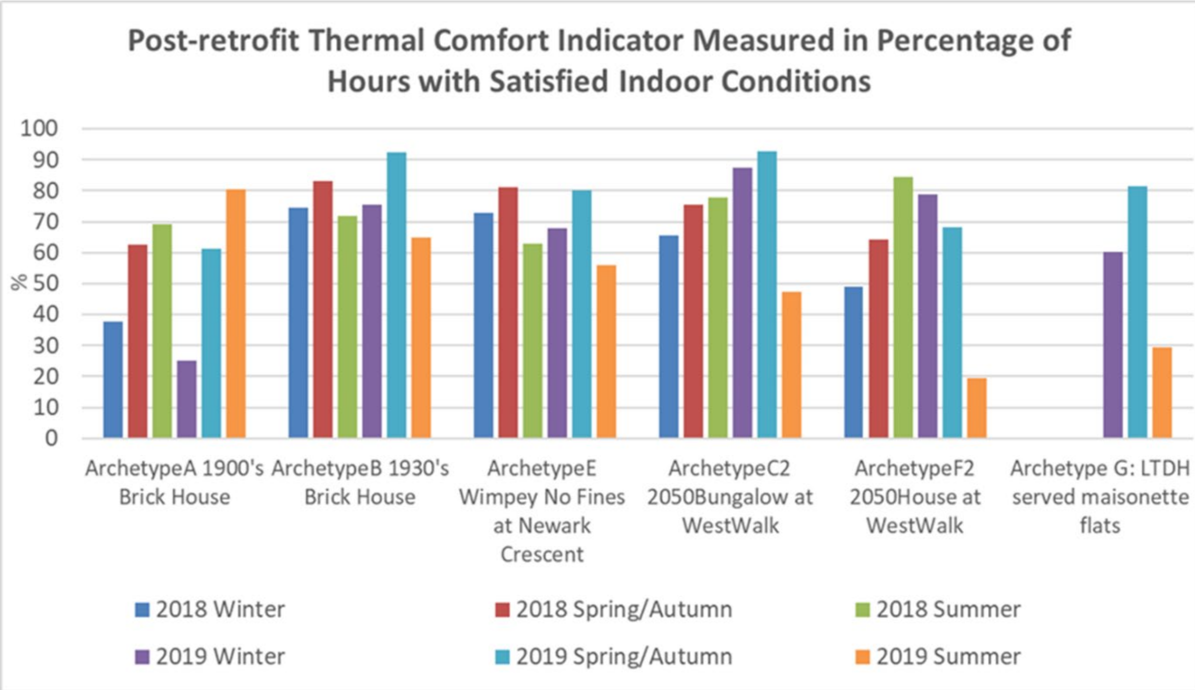


Figure 11: Percentage of Hours Properties Met Thermal Comfort Targets

Note:

- Due to changes in monitoring responsibility and methods for some homes during the project, the most reliable data sets are for Archetypes A, B and E.
- Data collection for Archetype G did not start until the end of 2018.
- It is not clear whether the lower percentage of comfortable hours in summer 2019 for Archetypes C2, F2 and G reflect the hotter summer or issues with sensor installation.

Overall, the monitored buildings showed a good level of comfort throughout the year. As expected, the 1900s solid wall brick houses showed the weakest performance in the winter.

3.2.1. Evidence from the Occupants

More important than the instrumental evidence is the experience of the occupants. What did it feel like to them?

31 residents completed post-retrofit surveys. 16 lived in Archetype G - solid wall insulation plus low-temperature district heating, 14 in Archetype B - 1930s brick construction with solid wall insulation, and one in Archetype E - flats with solid wall insulation.

3.2.2. Survey Results

The survey showed the retrofits significantly enhanced the residents’ quality of life, although there is less evidence that they saw significant improvements in their overall physical health and emotional wellbeing.

- 68% were satisfied with their retrofitted properties. 86% reported an improvement in the quality of their home and 52% reported a significant improvement.
- 66% reported their homes were warmer during winter, 62% reported an improvement in their overall comfort in winter and 34% a significant improvement.
- 86% were satisfied or very satisfied with the warmth of their properties during summer months.
- 86% reported the appearance of their homes improved, with 34% indicating a significant improvement.
- 58% indicated the retrofit had improved their sense of pride about living in their homes, with 51% reporting an improved sense of pride in their local area.
- 50% reported their energy bills were cheaper and 46% that they were about the same (despite suppliers raising prices since the retrofit).
- 65% were satisfied or very satisfied with the warmth of their homes and 69% with the overall comfort in winter. 66% reporting improvement and 34% a significant improvement in warmth during winter compared to before the retrofit.
- Occupants of the LTDH properties reported a valuable increase in usable space.
- Some occupants of SWI properties reported fewer coughs and colds.

Occupants of the 2050 properties noticed that their homes "felt larger". People in fuel poverty in poorly insulated homes tended to concentrate the living space into one or two rooms in winter that could be kept warm. The rest of the space being unusable in cold weather. The greatly improved insulation led to more even temperatures throughout the house for the same energy cost. The livable space expanded to fill the entire home.

3.2.3. Interview Results

Eight interviews were completed, two from Archetype B (solid wall insulation) and six with residents of Archetype G, the Courts (flats and maisonettes with insulation and low-temperature district heating).

Comments from residents show a broad range of positive impacts from the retrofits. Selected quotes for several themes, illustrate the benefits.

- **Warmer Homes**

Solid Wall Interviewee 1: "Before the refit I had the gas heater (front room) and the central heating on all day and night. The house was freezing. Now I have the heating on only 1 and ½ hours a day and it stays warm all night too. I'm much happier cause I can wear less layers of clothing. I don't have to wear a coat in the home anymore and I don't have to wear three layers of trousers. Now I can sit comfortably in my pyjamas watching tv which I do a lot because I'm retired".

Courts Interviewee 2: "In winter it's a lot warmer, definitely. It's improved in comfort too now it's got colder."

- **Cheaper Bills**

Solid Wall Interviewee 1: “It costs 10-15% less now each month. I used to use a gas heater (living room) and the central heating on and high all the time. Now I don’t use the gas heater when I’m in the living room and the central heating is on less too”.

- **Enhanced Health/Wellbeing**

Solid Wall Interviewee 1: “The cold didn’t help my arthritic knees. Going to the toilet/bathroom at night is so much easier. My body is so much more relaxed cause I’m not cold anymore. I’m free to walk around the whole home. I sleep better, before it was freezing but now it’s much warmer”.

- **Increased Space**

Courts Interviewee 1: “Above (in the main bedroom) we gained the extension, quite a substantial extension. So, if you rearrange your room it’s quite a bit of extra space”.

Courts Interviewee 2: “I’d say it’s improved a little bit cause there’s that little bit of extra space upstairs (in the main bedroom).”

- **Improved Natural Light**

Courts Interviewee 1: “I get a lot of natural light, this side of the flat (the living room); a lot. It’s a lot brighter upstairs because they’ve opened ‘this bit’ out as well so we got the same window that runs all the way up from the living room.”

Courts Interviewee 1: “Loads, we went for a patio door as leaseholders where normally (for social renters) you would just have a window (half brick wall and window)”.

- **Better Ventilation/Air Quality**

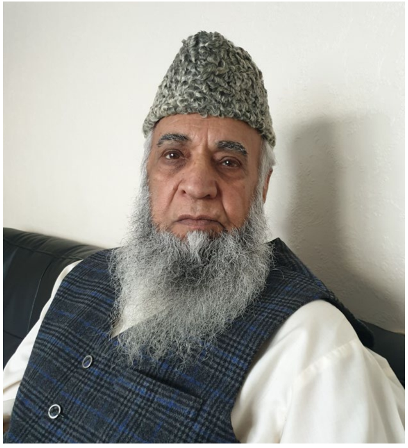
Courts Interviewee 1: “I had damp and mould in the bathroom before they made changes, because I didn’t have a fan in my bathroom and then when they removed the window, because I had a single pane window. I had a little fan and turned it on and off and kept the window open but moths were getting in. But when they had a new double-glazed window, they put in a fan. I’ve not seen any signs of mould since (they put in the new fan/double-glazed window/heating) so now it’s all OK. The damp and mould has definitely improved”.

Courts Interviewee 2: “The fans are good. The ventilation is better. In the bathroom we used to get mould. It was cold. The construction of the building is a slab with a flat roof now we have a pitched roof. But because we have cold on the outside, it used to get damp, but the ventilation is now better.”

- **Better Quality Homes**

Courts Interviewee 1: "Since the refit it's improved. I'm happy with the windows because before that we had single glazed windows. Windows wise it's great. The exterior of the

CASE STUDY: Mr Hussein, living in 1930s house with Solid Wall Insulation (type B)



Mr Hussein is an elderly, retired male who lives alone in his home. The solid wall insulation was completed 18 months prior to the interview. Mr Hussein described the benefits to him, his quality of life and wellbeing:

"Before the solid wall insulation, there was cold in the house, particularly the bedroom. It didn't help my knees" (Mr Hussein has arthritis). "If I got out of bed in the night, the bedroom was cold and I found it hard to get up and out of bed" (Mr Hussein has mobility difficulties and has to use a walking stick). "Going to the toilet or the bathroom at night is so much easier now."

"My body is so much more relaxed because I'm not cold anymore. I'm free to walk around the whole home which is warm. I sleep better, before it was freezing but now it's much warmer."

"Before the retrofit, I had the gas heater (in the front room) and the central heating on all day and central heating on all night. The house was freezing. Now I have the heating on only one and a half hours a day and it stays warm all night too. I'm much happier because I can wear less layers of clothing. I don't have to wear a coat (in the home) anymore in autumn, winter and I don't have to wear three layers of trousers. Now I can sit comfortably in my pyjamas watching tv which I do a lot " (Mr Hussein is retired). "Now its quicker to heat the house and it stays warm. 30 minutes to warm the home. It's not cold at night anymore and it's warm in the mornings too, when I come downstairs. The whole house is warmer."

"It costs 10-15% less now each month. I used to use a gas heater (in the living room) and the central heating on and high all the time. Now I don't use the gas heater when I'm in the living room and the central heating is on less too."

building is lovely, but this side (internal facing) they could have planned a bit better and made it a bit nicer. The outside looks a bit like a Holiday Inn hotel on the outskirts of London”.

3.2.4. Improvement in the local environment

The look and feel of an area are also vital in engendering a sense of community and wellbeing.

As shown in the images below, the retrofits have taken a tired and somewhat shabby part of Nottingham and given it a makeover. The properties look fresher, higher quality and more inviting.

Building Archetype	Pre-retrofit	Post-retrofit
Archetype F2: 2050 Homes (houses)		
Archetype G: LTDH served maisonette		
Archetype E: 'Wimpey No Fines' flats		
Archetype B: Solid Brick 1930s		

Figure 12: Improvement in Property Appearance After the Retrofit

3.3. Increased Property Values

Another impact of domestic retrofits is an increase in the capital value of the property. Improving the energy efficiency of homes tends to enhance their value. A 2013 study[40] reported a link between EPC ratings (as a proxy for real-world energy efficiency) and house prices.

Compared to EPC G rated properties:

- EPC F and E sold for a premium of 6%
- EPC D sold for a premium of 8%
- EPC C sold for a premium of 10%
- EPC B and A sold for a premium of 14%

This effect was seen directly in the Nottingham demonstrator. The 2050 Homes were valued before and after the retrofit and showed an average increase in value from £80,000 to £100,000. An increase in value of 25%, significantly larger than seen in the 2013 study.

The 2050 Homes also benefit from projected energy savings of £25,000 over 20 years at current energy prices.

4. Advice to Social Landlords

The Nottingham demonstration project has successfully retrofitted 463 homes saving 3GWh/yr in energy and approximately 550 tonnes CO_2(eq).

It has proved technically feasible to achieve these savings, whilst improving the lives of the occupants. There are real benefits over and above energy savings in better health and wellbeing, and in the regeneration of residential areas.

The energy and carbon savings can make a major contribution to reducing the environmental footprint of our homes.

During the project a lot has been learned about retrofitting the housing stock at scale. The following points will be of interest to any local authority or social landlord attempting a similar challenge[34].

4.1. Property Selection

Working out which properties are suitable for deep retrofit is a key part of any project. Positive reasons for selecting properties include:

- Identifying units that have substantial repairs and maintenance planned. For example, roof replacement or new heating systems.
- Policy drivers for upgrade. For example, meeting the Decent Homes Standard or tackling fuel poverty.
- The technical suitability of the units. As we have seen, 1900s single skin brick homes with Victorian details are more complicated to retrofit than most post-WW II properties. There may be also issues of access, services, property mix and the needs of the tenants.

Property selection requires a good knowledge of the stock condition and thorough surveys. Information should be collected on available housing budgets, current energy consumption patterns and personal circumstances of the tenants (are they vulnerable and what will the implications of the retrofit works be for them?).

4.2. Tenant Engagement

Engaging the tenants early, throughout the retrofit process, and through into a monitoring and evaluation phase is essential for success. Ways to improve engagement include:

- For each group of properties, try to identify a project champion from amongst the residents who can make sure that information flows. Someone they trust.
- Meet the residents on their territory. Use local community centres, pubs etc. Set up coffee mornings and fish and chip suppers.
- Make sure that any third parties brought into the discussions (designers, suppliers etc.) are listening to the tenants not talking at them. Their wishes must be listened to carefully, and if it is not possible to deliver them, then there must be a clear explanation why.

- The ‘look and feel’ of third parties must be appropriate. Suits and ties, tell instead of ask, us and them, can all breed frustration and resistance.
- Simplify technical details and make sure the tenants understand. It is your job to make everything clear to them.
- Ensure information flows throughout the project and manage expectations so the tenants are not disappointed.
- Engagement does not stop when the retrofit is completed. An ongoing relationship is needed to make sure the tenants get the best out of the refurbishment.

4.3. Procurement

Procurement for complex retrofit and regeneration projects is difficult. This does not lie within the comfort zone of either social landlords or suppliers. It is necessary to balance both cost and non-cost issues where there is no pre-defined outcome.

Cost Issues	**Non-Cost Issues**
Capital cost of retrofit	Design
Revenue costs – maintenance	Performance specification
Income – tenant costs	Monitoring – evidence of performance in use

Methods for successful procurement:

- Competitive dialogue was an effective way to engage with bidders during the procurement process. This allowed supplier expertise to be fully engaged in the design and delivery of the retrofits. It also allows the social landlord to specify the desired outcomes, but not how they should be delivered.
- However, competitive dialogue brings challenges:
    - It is a slower process as the contract specification is not finalised at the beginning of the process. This causes delays both in finalising the contract and in contractors starting work.
    - There is a potential for the project specification to drift in the discussions. This breaks the rules of the competitive dialogue process.
    - Risk needs to be balanced between buyers and suppliers in new ways.
    - In a performance based contracting process it needs to be clear precisely what is and what is not included. White goods, with their potential to significantly affect energy demand were an issue in Nottingham.
    - This means the interface between social landlord and contractor is particularly sensitive and must be clear.

4.4. Contracting

For complex retrofits targeting specific outcomes, standard contracts are probably not immediately applicable. Issues to consider include:

- Developing a performance measurement framework to resolve conflicts between supplier and social landlord.
- Make sure that the boundary between work done by the contractors and by the in-house team is clear. If the contractor has accountability for long-term performance of the retrofit, it will change the work done by the social landlords own staff.
- Ongoing engagement with tenants is important. They need advice and support in realising the benefits of the retrofit, and their experiences are important evidence of performance in use.
- It is better to take a standard contract and attach a schedule of amendments than to develop a bespoke contract. That will waste a great deal of time in detailed debates.

4.5. Monitoring and Evaluation

Being able to measure performance in use is a vital part of any deep retrofit programme. There are a number of issues with getting reliable data and delivering the best from a retrofit:

- Getting good quality baseline data prior to retrofit is often difficult, but developing some kind of baseline is essential to assess performance.
- Equipment for automated data acquisition and analysis is often expensive and temperamental.
- Engaging tenants is critical, especially where new energy service plans are involved. This is new for them as well and they need support. Good liaison helps.

4.6. Volume Needed to Reduce Costs

At the moment, the sorts of retrofits in the Nottingham demonstrator are hard to justify in strict cost-benefit terms. Nottingham were able to undertake this programme by pulling together budgets from multiple sources. Many of the interventions were either prototypes, or early scaleups. The technologies and methods have all been proved, but the suppliers and contractors have not gone very far down the price learning curve.

We know that prices will come down as volume increases. This has been true for nearly every technology in history. But the volume is needed. One possible approach is for social landlords to combine together to create larger retrofit and regeneration schemes. Larger schemes will achieve two things; a reduction in unit cost, and making retrofit projects more attractive to investors. This has been done very successfully for wind farms, and there is no reason why it cannot be done for domestic retrofit.

We hope that other projects will build on what has been learned in Nottingham and will add their own experiences, discoveries and experiences to the collective pool of knowledge.

5. References

[1] https://greengb.campaign.gov.uk/

[2] https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

[3] https://www.gov.uk/government/collections/provisional-uk-greenhouse-gas-emissions-national-statistics

[4] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/829006/Annual_Fuel_Poverty_Statistics_Report_2019__2017_data_.pdf

[5] https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/bulletins/excesswintermortalityinenglandandwales/2017to2018provisionaland2016to2017final

[6] "Getting the measure of fuel poverty: Final Report of the Fuel Poverty Review", J Hills, 2012

[7] "Good Housing: Better Health", The Academic - Practitioner Partnership, 2016

[8] "Chance of a Lifetime: the impact of bad housing on children's lives", Shelter, 2006

[9] "Lethal and Illegal: London's air pollution crisis", IPPR, 2016

[10] "Later Life in the UK 2019", AgeUK, 2019

[11] "Inquiry into decent and accessible homes for older people", All-Party Parliamentary Group on Ageing and Older People, 2019

[12] https://retrofit.innovateuk.org/

[13] https://www.lowenergybuildings.org.uk/

[14] https://www.changeworks.org.uk/case-studies

[15] https://es.catapult.org.uk/case-studies/smart-systems-and-heat/

[16] "Regeneration and Retrofit", UKGBC, 2017

[17] "Scaling Up Retrofit: 2050", The Institution of Engineering and Technology & Nottingham Trent University, 2018

[18] "UK Housing: Fit for the Future?", Committee on Climate Change, 2019

[19] "Reinventing Retrofit: how to scale up home energy efficiency in the UK, the Green Alliance, 2019

[20] https://www.passivhaustrust.org.uk/

[21] http://www.nef.org.uk/knowledge-hub/view/superhomes

[22] http://aecb.net/

[23] https://www.energiesprong.uk/

[24] "Building Renovation Passports: customised toadmaps towards deep renovation and better homes", Building Performance Institute Europe, 2016

[25] "Homes for the Future: project position paper", Connected Places Catapult, 2019

[26] "What are the Barriers to Retrofit in Social Housing" J Palmer, A Poku-Awuah, S Webb, BEIS, 2018

[27] "Retrofit: towards a sector-wide roadmap 2020", Connected Places Catapult, 2020

[28] https://www.remourban.eu

[29] https://www.nottinghamcity.gov.uk/

[30] https://www.nottinghamcityhomes.org.uk/

[31] https://www.ntu.ac.uk/
[32] https://nottenergy.com/
[33] “Competitive Dialogue in 2008: OGC/HMT joint guidance on using the procedure”, Office of Government Commerce, 2008
[34] “Transition Zero: Make Net Zero Retrofits for Houses a Mass Market Reality – Deliverable 6.3, Report on Prototyping Phase”, Energiesprong, 2018. http://transition-zero.eu/wp-content/uploads/2018/06/TransitionZero-D6.3-Report-on-prototypes_V03.pdf
[35] https://www.passivhaustrust.org.uk/UserFiles/File/2014/Guidance/EnerPHit%20pres%20Oct%202011.pdf
[36] https://www.energiesprong.uk/
[37] https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp
[38] https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2019

[39] “Waste Incineration getting away with CO2 emissions unscathed”, Zero Waste Europe, 2019

[40] “Final Project Report: An investigation of the effect of EPC ratings in house prices”, F Fuerst et al, DECC, 2013