Applying a retrofit and low-carbon technology archetype approach to buildings in Scotland

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Outcomes from the workshop series organised by the School of Engineering and the Centre for Future Infrastructure, at the University of Edinburgh

Workshop series between August and November 2023

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Contents

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Executive summary

During August, September and November 2023, three workshops were organised to discuss the coordinated delivery of the archetype approach in Scottish domestic, non-domestic and historic buildings. It considered the challenges in the rollout of retrofit energy efficiency interventions and the use of low-carbon heating. A series of case studies and talks discussed issues around energy transmission and distribution, the retrofit skills gap, the importance of data retrieval, testing and existing case studies. Discussions surfaced around the opportunities of digital tools and monitoring equipment, fabric-first approaches with a technology-balanced approach to achieve a balanced approach of good energy efficiency, low-carbon heat, occupant thermal comfort, and sharing energy between other building types and owners.

There was broad agreement at each workshop on the need for a coordinated archetype approach to enable the pace and scale of delivery of Scottish Government net-zero targets and to bring buildings up to an optimum level of thermal performance. Therefore the outputs of these workshops provided context and industry-relevant considerations for rolling out the archetype approach. It also allows for the creation of a technical board which oversees the initial actions of a Scottish archetype approach and can evaluate the rollout of guidance to undertake retrofit interventions relevant to each archetype.

The culmination of these workshops will be to create a website and database as a tool to access retrofit examples and case studies showcasing the before and after conditions of the buildings. This information would be available to all stakeholders and building owners/ occupiers to learn from exemplar projects that have applied retrofit interventions and there is evidence of its success and approaches. Data gathering of these case studies will help to show the impact of such work and also provide a series of best practice details suitable for different archetypes and technology solutions. A tool to select and suggest the best retrofit intervention with varying options for low-carbon heating can indicate energy and carbon reductions against the cost and other constraints such as required decanting and special planning/ building control restrictions.

The outcomes of these discussions hope to inform and agree on the best characterisation of domestic and non-domestic buildings with and without a significant historical location and classification. However, the approach and methods need to be available and easily interpreted by all levels of building users and stakeholders such as tenants, landlords, local authorities, conservation bodies, and government.

Each workshop concluded with many actions and recommendations, however, the following 3 should be prioritised:

1. Implement a **robust system of coded archetypes** for Scottish buildings that considers their historical context and condition. A similar approach is needed to select an appropriate low-carbon heating technology aligning with Local Heat and Energy Efficiency Strategies (LHEES) and Heat Network Zone designation areas.
2. Create publicly accessible **pattern books** and guides based on the archetypes providing “evidence-based tested retrofit solutions” considering different alternatives and existing conditions and occupancy types.
3. Integrate the archetype approach to a **UK national building database** which can host a repository of all building types used to track the condition of buildings, and identify typologies, known risks, occupancy and energy efficiency levels that align with net zero targets.

1.0 Introduction

This workshop series emerges from the need to develop transformative archetypes and low-carbon heating approaches that deliver a clear, concise and technically rigorous method of intervention to improve and conserve existing built heritage. It also seeks to support the development of archetype approaches for Scotland's net-zero carbon targets by lowering the operational energy of existing built heritage, applying low-carbon retrofit materials, improving mass retrofit delivery and skills pathways, enabling existing homes and buildings to become comfortable underpinning more improved health and living conditions for occupiers.

Held at the Edinburgh Climate Change Institute (ECCI) from August to November 2023, the workshops were attended by participants from varying backgrounds and expertise offering an opportunity to develop deep understanding and discussion over the topic. It was attended by distinguished representatives from city non-domestic partners[1], the housing and construction industry, local and central government, heritage professionals, conservation and architectural sectors and most importantly by residents and users of Scottish buildings.

The three workshops were:

1. Scottish *domestic* buildings Archetype and low-carbon heating approach on the 23rd of August 2023,
2. Scottish *non-domestic* buildings Archetype and low-carbon heating approach on the 22nd of September 2023,
3. Scottish *conservation and heritage buildings* archetype and low-carbon heating approach on the 24th of November 2023.

The workshops focused on the Scottish context and round table discussions highlighting the issues behind retrofitting buildings for better energy efficiency, comfort and carbon compliance. Existing retrofit methods can sometimes fail to consider the unique characteristics of some buildings, leading to ineffective one-size-fits-all solutions or simply not providing sufficient clear guidance for homeowners and existing trades/ contractors, which often end up applying conventional but inadequate retrofit methods and materials which leads to unintended consequences such as ongoing cost, health, building structure failure and fuel poverty of its occupiers. Recognising this, discussions focused on developing a Scottish approach by analysing the potential for building retrofit archetypes.

The workshops delved into domestic, non-domestic and historically significant buildings, identifying dominant typologies and suitable low-carbon heating solutions for each. The aim was to develop a pathway to enable future archetypal pattern books for successful retrofits, ensuring consistent improvement in building performance, occupant comfort, and low-carbon intensity.

The proposed approach has been developed previously in some aspects, however, the methods developed do not realise the regional differences in prevailing building types, materials employed and some methods of construction[2]. In Scotland, some buildings present a unique challenge for achieving a sympathetic and correct retrofit, and this is particularly the case with historical buildings. Some retrofit solutions fail to align with the existing conditions

[1] See section 6 of this document of organisations that attended – explames include the NHS, City of Edinburgh Council, Edinburgh Leisure, Glasgow and Edinburgh Museums, Crown Court, etc.

[2] Such as the National Retrofit Hub which favours a English and Welsh building typology approach, different to the context in Scotland where tenement flats prevail with constrained spaces and use of single stone (sandstone & granite) - https://nationalretrofithub.org.uk/

of the building, and solutions are applied uniformly without considering the existing materials, context, occupancy and building-specific conditions. To this cause the proposal is to group buildings by age, 'as-built material' methods, and usage patterns, creating distinct categories with specific challenges and opportunities.

Another driver to developing this approach is to use the guidance produced per archetypes to bridge the gaps in data available to make decisions on the refurbishment and interventions needed for our buildings. Currently, there are two sets of data sets available that make it difficult to provide solutions to many similar building typologies. There is a lot of high-level energy performance data obtained from large compliance-based calculations such as the Home Analytics UK housing stock data in combination with the Portfolio Energy Analysis Tool (PEAT) analysis method [3]. On the other hand, bespoke pilot studies applying individual component thermal retrofits and other larger interventions have emerged developed by architects, contractors, government (Historic Environment Scotland, National Trust for Scotland), associations and individual building owners, showcasing innovation, material trials or whole building approaches documented as case studies with individual data. However, many of these case studies aren't compiled in a way that can be used as direct guidance by homeowners and contractors as much of the literature is technically written. An approach using archetypes could merge the two data sources (individual case studies and larger compliance data sets) to provide guidance and solutions to clustered or individual buildings considering similar methods of construction with a selection of solutions to variances. Archetypes can emerge to provide guidance to deliver diverse tailored building retrofit solutions which accommodate the specific building. This in turn will help develop skills pathways and the scale of work required.

These workshops set the stage for a nuanced and effective approach to retrofitting Scotland's diverse building stock, preparing for a sustainable and net-zero carbon future.

2.0 Workshop 1 – Domestic Buildings

2.1. Introduction

Current efforts to improve the energy efficiency of Scotland's homes are impeded by a lack of clear, centralised guidance sufficiently tailored to specific building types. The scale of the ongoing and future retrofit tasks across the existing homes is significant with circa 2.7 million homes and a split of 24% RSL and 76% private homes. While successful projects exist, easily replicable solutions and technically sound "pattern books" remain intangible for housing organisations, public sector housing managers homeowners and contractors alike. Creating such a pattern book of replicable clear and concise retrofit methods will help deliver the Heat in Building and Local Heat and Energy Efficiency Strategy targets which are important in reaching net zero by 2040.

Moving forward, pilot projects showcasing whole-building approaches are crucial. These projects should move beyond the singular focus on heat pumps and address not just building envelope energy efficiency, but also climate adaptation and resilience, improved indoor air quality and adequately implement a full spectrum of low-carbon heating options. By learning

[3] The Portfolio Energy Analysis Tool (PEAT) method merges data from Home Analytics into recommended packaged retrofit measures based on the energy efficiency levels and inefficiencies in performance it identifies. It aligns with compliance software (SAP) to propose changes and interventions needed which lower energy use. This method is a large-scale approach and lacks detail which doesn't deliver at the speed and cost required. https://energysavingtrust.org.uk/service/home-analytics/

from these exemplars and treating buildings as holistic systems, Scotland has the potential to lay the groundwork for a successful and sustainable retrofitting future.

2.2. Workshop speakers

Stuart Walker, Net Zero Manager at Scottish Power Energy Networks (SPEN), opened the session by pressing the key question: do we have enough capacity in our energy transmission and distribution systems to handle the demands of a low-carbon future? He outlined the size and complexity of the task ahead with regards to new and replacement electricity energy infrastructure as gas is switched to electrical-based low-carbon energy systems. In addition, he outlined how an archetype approach could facilitate improved planning for future electrical infrastructure needs, modelling of energy demand reduction in blocks and streetscapes of homes and the ‘joined-up’ systems thinking of buildings, communities and infrastructure needs.

The second talk was delivered by Graeme Bruce, the Director of Asset management and sustainability at Link Group Ltd. His talk was titled: The Housing Association Perspective – challenges and Opportunities – Next Steps, based on a social housing viewpoint across Scotland. Graeme outlined the critical need for knowledge sharing of solutions as they are being developed, the opportunity pan-Scotland of applying retrofit solutions on key building archetypes and the oncoming regulatory and policy landscape for housing associations and local authorities (RSLs).

Prof. Sean Smith from the University of Edinburgh outlined the Zero Emission Social Housing Taskforce (ZEST) [4] work he and many RSLs were involved with which aimed to propel Scotland's social housing sector towards net-zero with practical recommendations prioritising fabric-first improvements and a "whole house" approach. He proposed a robust system of coded archetypes based on house type, wall material, and other key specifications. This system is reminiscent of the acoustic "Robust Details" work he co-developed with the newbuild housing industry and government, starting from some key archetype solutions for masonry, timber and steel frame homes. These initial 12 construction proposals developed over time providing 65+ solutions and have now been adopted and built in 1.6 million homes across the UK. This led to enhanced building performance, common approaches for construction, supporting skills, site management and waste reduction. Using a coded approach for each new build archetype allowed for future tracking, monitoring and site visits for tests and inspections, supporting a continuous improvement cycle. The pattern books are provided online and free to access.

Finally, Dr Julio Bros-Williamson from the University of Edinburgh School of Engineering gave a talk on the technical aspects required, based on testing, benchmarks and models. He highlighted the importance of leveraging existing knowledge and best practices in retrofitting social housing. Recognising the wealth of existing case studies, he emphasises the need to consolidate findings and identify knowledge gaps, a challenge the archetype pattern book approach could aim to address.

[4] Smith S, (2021), https://www.gov.scot/publications/developing-net-zero-technical-solutions-for-scotlands-future-mass-retrofit-housing-programme/

Figure 1: Workshop 1 partners involved and wide participation during round table debates.

2.3. Round table discussions

The first round table discussions addressed the following set of questions:

1. **What challenges do you foresee in applying the archetypes approach?**
2. **What other archetypes should be discussed?**

The round tables discussions *based on the challenges* focused on the need to take into account individual contexts in addition to the archetypes by considering:

- Local conditions: Different climates (e.g. east or west coast of Scotland) can impact optimal insulation levels to avoid damp issues.
- Infrastructure limitations: Grid capacity and local electricity generation influence choices such as heat pumps vs. heat networks.
- Community dynamics: Rural communities with shared resources might benefit from similar decarbonisation methods despite differing building types.
- Occupancy patterns: Ventilation needs vary based on the number of occupants and their lifestyle (cooking, laundry, etc.).
- Past modifications: Existing upgrades not reflected in archetypes can affect recommended retrofits.
- Maintenance schedules: Aligning renovations with planned repairs maximises efficiency and cost-effectiveness.

These factors all highlight the importance of a context-sensitive approach to retrofitting. One-size-fits-all solutions rarely work; understanding the specific circumstances of each building and its surroundings is essential for successful and sustainable decarbonisation. **However, where many buildings have similar build and user characteristics there is potential for common retrofit approaches.**

The second round table discussions addressed the following set of questions:

1. **What evidence do we have on retrofit guidance and is it enough, is it replicable and concise enough?**
2. **How can low carbon heating methods be implemented into this approach?**

Discussions revolved around the challenges of hosting data and how the quality and proficiency of those who conducted the previous retrofit works need to be contemplated when extracting data from past projects as guidance.

While a wealth of data exists, compiling it for the archetype framework is a significant task. This process will not only bridge knowledge gaps but also reveal missing or inconsistent information, allowing for targeted data collection efforts. Past studies might also be outdated, necessitating updates for current relevance. Additionally, rural areas often suffer from data deficits, requiring specific attention.

2.4. Key actions and considerations

Applying domestic archetypes and retrofit interventions:

1. **Prioritise "no-regrets" solutions, specifically fabric interventions:** Insulation in homes offers significant energy savings (up to 80%) regardless of future low-carbon heat technology choices, leading to lower long-term costs, occupant thermal comfort and non-dependent fuel source indoor conditions (thermal mass, balanced temperature, controlled humidity). The proposed guidance needs to be the most appropriate fabric intervention for each archetype to avoid condensation, mould and dampness.
2. **Leverage the archetype approach:** By categorising homes based on shared characteristics, housing associations can tailor retrofit plans and resource allocation more effectively. This streamlines decision-making and potentially reduces costs by identifying common solutions for similar building types.
3. **Develop and implement a robust system of coded archetypes for housing retrofits:** This system would categorise domestic buildings based on key characteristics like method of construction, wall materials and construction details. Additional guidance could provided on other components and variances amongst them; roof type, ground floor type etc. This approach would streamline retrofitting efforts by leveraging existing knowledge and enabling efficient planning and specifying of solutions.
4. **Create publicly accessible pattern books based on the archetypes:** These user-friendly guides would provide “evidence-based tested retrofit solutions” (before and after) for different construction home archetypes. This would significantly improve accessibility and empower both homeowners and contractors to confidently undertake effective retrofits, even with limited prior expertise.

5. **Apply a context-sensitive approach:** Recognising that one-size-fits-all solutions don't always work, this action emphasises considering individual contexts like local conditions, infrastructure limitations, community dynamics, occupancy patterns, past modifications and maintenance schedules.
6. **"Coupled actions" and holistic planning:** Combining planned repairs with retrofitting upgrades maximises efficiency and cost-effectiveness. This holistic approach considers both immediate needs and long-term vision of retrofitting efforts.
7. **Going beyond archetypes and U-values:** Factors like heating source, location context, climate change resilience/ adaptation, individual building data and AI-powered analysis can provide tailored recommendations and optimise carbon savings within the archetype framework.
8. **User-centric solutions and actionable steps:** Recognising diverse user needs, for creating two-tiered guidance, detailed technical manuals for contractors and concise homeowner guides outlining achievable steps with limited budgets. This makes the archetype system more accessible and encourages wider adoption.
9. **Bridge the data divide for archetypes:** Utilise existing data on optimal solutions for building types, materials and energy use to inform Scotland's archetype framework. Leverage coding systems to categorise buildings based on shared characteristics, address performance and build data gaps in rural areas. The coding should prioritise replicability, variability and available materials.
10. **Address the skills gap for retrofitting:** Implement robust training programs which could be archetype-specific for retrofit coordinators and contractors to bridge the gap between building science expertise and archetype solutions. Balance speed with quality control through standardised assessments and rigorous inspections. Focus on measurable elements like thermal performance, indoor air quality and material selection to avoid issues like condensation build-up. In more recent discussions with some attendees the ability to couple the development of skills training knowledge on new retrofit solutions coming forward, with a recognised training provider, could enhance and accelerate future delivery of such solutions (rather than waiting for a considerable time after the retrofit pilots kick start skills or training packages thus reducing delays to pan-Scotland roll-out fo such solutions).
11. **Introduce Scottish Government funding for retrofit skills pilots:** It was recently proposed by Smith (2024) that government, industry and/or public bodies could co-join funding for 1) retrofit R&D and 2) skills training funding within the same early pilots, rather than individual or at least reduce the timescales between each for successful pilots, given the time pressures of delivery and help optimise productivity towards scaling up such retrofit solutions.

Low-carbon heating and using archetype solutions to select the best technology:

1. **Massive infrastructure expansion:** Up to sixfold increase in network capacity within the next 20 years. This requires an unprecedented acceleration compared to the historical pace of grid development.
2. **Modernisation and smart grid management:** Urgent need to modernise ageing infrastructure and implement smarter technologies and protocols to manage the complex and dynamic demands of a diverse, low-carbon grid. This includes investments in grid resilience to mitigate disruption risks.
3. **Prioritise holistic energy supply strategies over individual solutions:**
    - Focus on either ambitious carbon reduction through district heating networks or tailored solutions like heat pumps, based on each building's potential.

- Utilise Local Authorities' LHEES (Low Carbon Heat Energy Efficiency Strategies) as the groundwork for preparing homes for future network integration and broader solutions and allowing wider energy systems to recognise how this impacts future heat decarbonisation such as the Ofgem Regional Energy Strategic Planners (RESPs) scheme[5].

4. **Develop a user-centric interface for choosing effective heating options:**
    - Provide easy-to-navigate information and guidance for homeowners, contractors, and landlords.
    - Clearly outline tailored solutions for buildings unsuitable for district heating, including heat pumps and other emerging technologies.
    - Empower stakeholders to make informed decisions about low-carbon heating options that align with their individual needs and building characteristics.

3. Workshop 2 – Non-domestic Buildings

3.1. Introduction

The archetype approach for non-domestic buildings shares similar challenges and approaches will seem similar to those discussed in the domestic buildings workshop. However, the data available is by far less detailed than that of domestic buildings given the variation of building uses in different industries from public and educational buildings to commercial, industrial and office buildings across Scottish towns and cities.

Despite this lack of knowledge, buildings can still be split into recognisable archetypes based on the materials of original construction (MOC), the methodology employed and some common denominators such as roof types, floor construction and window types. The domestic archetype approaches are in many ways transferrable to the approaches needed to retrofit non-domestic buildings, however, may differ on the scale and type of occupancy or activity in such buildings.

The workshop around non-domestic buildings brought building managers and experts as well as policy and new technological advances in data and user engagement. Questions addressed similar points discussed in the domestic archetypes workshop, however, turned more around the balance between fabric and low-carbon heating interventions and their suitability at a larger scale. Despite this, policy changes on the energy and building performance of existing buildings will push building owners and landlords to comply with certain standards and will require clarity in the mechanisms and details to retrofit their building stock. To do this, heat networks will require scalable solutions by adopting anchor loads facilitated by non-domestic buildings around towns and cities, primary examples are university campus buildings or industrial high-energy load buildings.

3.2. Workshop speakers

This workshop and speakers aimed to identify a building archetype approach and generate a pattern book for landlords and managers to turn successful retrofit projects into actionable replicable guides for extending the operational life and in some cases argue for the re-use of Scotland's non-domestic building stock. This guidance needs to encompass both single and multi-state scenarios, offering best practices tailored to diverse building types.

[5] https://www.ofgem.gov.uk/publications/ofgem-green-lights-regional-energy-planning-roles-speed-net-zero-transition

Our first speaker Sally Semple a Senior Technical Advisor at The Scottish Government mentioned that Scotland's Heat in Building Strategy confirmed that it intends to introduce regulations by 2025 to require non-domestic owners to reduce demand for heat through energy efficiency improvements and install zero emissions heating supply, where feasibly possible.

The next speaker was Patrick Brown who is Head of Sustainable Construction Delivery at the City of Edinburgh Council. His talk painted a clear picture of both the opportunities and complexities of building retrofits. While Passivhaus EnerPhit methods and low-carbon heating, such as heat pumps, hold tremendous potential for energy efficiency, occupant comfort, and net-zero goals, the path is far from straightforward.

Talking about the role of digital data-driven solutions and management of buildings was the topic of the next speaker, Paul Dodds who is the Head of Infrastructure Technology at the Scottish Future Trust. He suggested that a digital approach to buildings is key to reducing energy demands in our built environment. From smart assets such as sensors and controls optimising building systems to city-wide data networks informing targeted interventions, digital solutions are key to reducing the energy footprint of existing buildings, particularly at the city scale.

Finally, it was the turn of Grant Ferguson who is the Director of Estates Net Zero & Carbon Leadership at The University of Edinburgh. His talk was on the challenge of meeting net-zero carbon in a complex university buildings estate scenario both in original construction type, uses and complexity of services for science, medical and engineering purposes across the educational estate.

His talk described the wide variety of challenges that colleges and universities (C&U) building estate needs to manage to meet climate and net-zero targets. To reach these targets, the University of Edinburgh has embraced an ambitious roadmap implementing:

- Prioritising energy reduction,
- Archetypes and Pattern Books,
- Low-Carbon Technology and Net-Zero Assessment,
- Striving for Net-Zero, finding the "Sweet Spot".

Figure 2: Speakers presented the challenges and innovation in the existing retrofit methods and the available low-carbon solutions.

Figure 3: Round table discussions debating the archetype approach applied in non-domestic buildings.

3.3. Round table discussions

The first round table discussions addressed the following set of questions:

1. **What are the distinctions between domestic and non-domestic approaches?**

- Can we apply the same thinking based on construction methods?
- Should occupancy and use be the archetype distinction?

The general approach by most who attended was that we should not get sidetracked by the challenges encountered by the domestic stock in Scotland. While existing domestic building improvement is crucial, focusing solely on it risks neglecting the opportunities and already dilapidated non-domestic buildings stock. Their differing physical characteristics, usage patterns, and even ownership structures require a distinct set of actions. It was recognised that there was a need to acknowledge the complexity and embrace tailored solutions. Instead of having several subcategories based on a variety of building features, priority should be given to having practical frameworks that capture the core component and its eventual preferred solution.

The second round table discussions addressed the following question:

2. What role do community heating systems play?

On a regional scale, within the Local Heat and Energy Efficiency Strategies (LHEES) developed by each Scottish local authority, there is a push to develop heat networks for specific zones by having Heat Network Zone designation areas. This was a widely discussed topic taking into account the proximity of existing heat sources or networks within those zones. However, notwithstanding the possibilities to interconnect with each region or large building estates, e.g. the Midlothian district heating network with the Easter Bush campus at the University of Edinburgh. The goal is to identify areas where these collective, low-carbon heating systems could offer the most efficient and sustainable solution, reducing reliance on individual building systems (boilers or CHP's) and contributing to managing the distribution of energy using a more focused carbon and economic viewpoint.

3.4. Key actions and considerations

Applying the archetype approach to non-domestic buildings

Creating clustered non-domestic archetypes for building retrofits demands careful consideration of key elements as highlighted in the following points:

1. **Prioritise data collection and knowledge sharing:** Address the lack of non-domestic building data by leveraging multiple methods like surveying, building scans, and collaboration with owners and users. This information is crucial for developing reliable archetypes and enforcing future regulations. Partnerships with The Scottish Energy Oficers Network (SEON) who have local authority benchmarks for their buildings[6].

2. **Develop building assessment capabilities:** Invest in technology and expertise to assess building conditions beyond energy data, including materials, construction methods and overall condition. This detailed understanding is essential for implementing safe and effective retrofitting measures.

3. **Age as a determining factor:** Pre- and post-1919 buildings often exhibit distinct construction methods and retrofitting challenges. Recognising this historical divide, however, requires acknowledging modifications have been made over time, as buildings rarely remain untouched by subsequent alterations. Access to the Historic Environment Scotland listed buildings data sets would encourage this action, however, it requires stock analysis against it.

4. **Implement building fabric characteristics:** The inherent material makeup of a building's walls, roof and ground floor significantly influences its thermal performance and suitability for specific retrofit interventions. Solutions will be dictated by identifying the construction type, e.g. presence of cavity walls, which can mean external wall insulation, while solid masonry dictates alternative approaches.

5. **Consider original and current building use:** As Patrick Brown's local authority data and case studies suggest, the function of a building can unveil patterns in energy consumption and potential upgrade needs. Grouping buildings by use type facilitates targeted solutions tailored to the specific demands of schools, offices, or leisure facilities.

6. **Relate building use to form factor for energy benchmarking:** The shape and size of a building, captured by parameters like floor area and aspect ratio, also influence heat loss and retrofit options. However, caution is required as sometimes this rule can provide wrong results in high-level analysis.

7. **Integrate a landlord context approach:** Grouping buildings under a common ownership or management structure, like local authority operational estates, can be advantageous for streamlined decision-making and resource allocation.

[6] J. Stinson, 'Scottish Public Sector Energy Benchmarking Tool (SPSEBT)', Zero Waste Scotland, Building Research Solutions, 2022. [Online]. Available: https://www.zerowastescotland.org.uk/content/scottish-public-sector-benchmarking-tool

8. **Balancing Technical and Practical Considerations:** The net-zero assessment should also consider a building's whole-life carbon trajectory, including construction, maintenance, replacements, and disposal. Collaboration is key, especially for buildings with limitations, where achieving net-zero might require different approaches than those applied to common building types.

Integration of low-carbon heating technology and methods

1. **Bridge the scale gap:** Develop methods to integrate site-specific building archetype data with regional LHEES planning. This could involve:

    - **Mapping archetype energy demand onto LHEES heat network zones:** Identify areas where **heat highways** can be the conduit between clusters of buildings with similar archetypes and existing or planned heat network infrastructure.
    - **Prioritise archetypes and LHEES zones for joint decarbonisation**: Focus interventions on areas where both individual building upgrades and heat network expansion offer optimal carbon and economic benefits.
    - **Develop tools for designers to assess heat network potential:** Create decision-support tools that help architects, engineers and heat network developers/operators evaluate a building's suitability for connection to a heat network based on its archetype and surrounding infrastructure.

2. **Support building archetypes with heat network considerations which inform heat network planning by:**

    - **Include proximity assessments to heat sources and network capacity in archetype profiles**: Provide designers with clear data on nearby infrastructure options to facilitate informed decisions.
    - **Model potential energy load contributions from different archetype clusters:** Estimate the cumulative heating and cooling demand of groups of buildings within a network zone to optimise system design.
    - **Develop archetypes specific to heat network integration:** Create dedicated archetypes most suited for district heating systems and other technologies, considering compatibility and efficiency.

3. **Adopt a collaborative knowledge-sharing approach: Encourage** communication and collaboration between stakeholders to drive effective integration.

    - Establish platforms, managed by the Scottish Government, for LHEES planners and building designers to share data and insights.
    - Promote best practices and pilot projects showcasing successful integration of archetypes and heat networks.
    - Invest in training and capacity building for building professionals on heat network considerations within design processes.

4. Workshop 3 – Historic buildings

4.1. Introduction

This final workshop of the 3-part Edinburgh series focused on the solutions to lower the carbon intensity of heritage and conservation buildings, blending the complexities of domestic and non-domestic cases. Addressing a sympathetic approach to historical buildings poses a great challenge given the limitations of space, listed status, conservation area location and the adequate skills and materials required. As in the other workshops, detailed and specific archetypes can enable considerations of the critical elements of a building, and then propose specific interventions that can be rolled out at scale across similar building types. This approach is gaining momentum with domestic housing associations and local authorities. However, in the context of heritage buildings, there are cases of neglect, poor maintenance, and difficulties of engagement between building owners and users, all especially exposed to the effects of climate change but lacking a clear approach to mitigate these effects.

4.2. Workshop speakers

The workshop was split into morning and afternoon sessions with two main speakers at the start of each. Round table discussion then addressed specific areas relevant to the speaker's challenges and new approaches.

First as speakers were Jane Robertson, Head of Conservation and Yann Grandgirard, Head of Climate Change for the Edinburgh World Heritage Trust (EWHT). They shared their systemic approaches to these challenges; striking the balance between maintenance and condition monitoring with retrofit work to maintain UNESCO site status. The EWHT is at the helm of conserving buildings in Edinburgh as buildings within the conservation area can apply for a repair grant focused on tenements and commercial shop fronts solutions on improving the public realm which leads to adaptations and resilience to climate change. They recognise the real threats to existing buildings, including those in a conservation area such as the EWHS including the physical impacts, impact on the use of buildings through disruption and loss of comfort and the role of inappropriate interventions which affect the originality of buildings but also make them less resilient.

Lila Angelaka, Senior Technical Officer at Historic Environment Scotland shared their practical issues and solutions to energy efficiency upgrades for traditional buildings in Scotland, including a refurbishment case study of Holyrood Park Lodge that had 3D laser scans, infrared thermography, and sympathetic historic improvements to the building.

Dr Frédéric Bosché shared the rationale, vision, and successes of the Historic Digital Survey (HDS), which involves ongoing digital scanning for unintrusive building fabric conditions (roofs and walls) used for repairs, tracking erosion, and monitoring maintenance of historic buildings such as Duff House and St. Mary’s Church. He mentioned some of the compounding challenges faced in most buildings with a lack of information and data caused by a lack of knowledge of the building type, its condition and appropriate maintenance. His proposal seeks to link the use of digitised building surveying supported by reality capture (3d lasers, photogrammetry and thermal imaging with digital tools in 3D models, BIM, digital twins and artificial intelligence.

Finally, there was a talk by Alasdair Gordon of Balfour Beatty and Iain Tinsdale of Bennetts Associates who shared their practical experience of the conservation and change of use done on the old Edinburgh Royal Infirmary building now hosting the University's Edinburgh Futures Institute. This presentation brought building conservation and preservation techniques, blended with new extensions and alternative building services.

Figure 4: Wide participation with 60+ professionals, policymakers, academics and community leaders

4.3. Round table discussions

These expert views and practical applications were punctuated by facilitated group discussions. The room had over 60 diverse stakeholders who debated a set of questions based on challenges and opportunities relevant to improving the performance of such buildings within the context of archetype approaches to retrofit interventions, climate change adaptation and resilience, low-carbon technologies and condition monitoring. The following is a summary of the discussions:

The first round table discussions addressed the following two questions:

1. What existing approaches to low-carbon retrofit and sustained energy performance are you applying to your Estate/ buildings? What role do the following play?

2. Based on the approaches mentioned, what challenges and opportunities do foresee in applying an archetype approach?

A second round table discussions addressed the following question:

1. What innovative methods have you applied (or heard of) to collect data on/monitor (a) the condition of your building(s) and (b) energy/ carbon performance - at scale and for various tenures?

1. Sympathetic Approaches to Retrofit Interventions

Retrofit interventions should consider not just the “whole house” system, but the wider context in which these systems exist. For example, complexities of property ownership, like multi-tenant leasing situations, and potential future scenarios of building use, should be kept in mind while approaching proactive retrofitting of buildings in conservation areas. The current and various states of building envelopes and the progress of upcoming low-carbon heating schemes should also be kept in mind. It is also helpful to consider buildings as clusters, making it easier to source diverse renewable/low-carbon heating sources and share any surplus energy. Case studies from the presenters provided valuable insights into successful approaches.

2. Citizen Participation and Community Empowerment

Maintenance and tracking the condition of heritage buildings ultimately lies in a complex stakeholder environment. Citizen participation and community engagement (including visitors) could be crucial to meeting these goals. There are existing shared repair methods, e.g. phone applications that involve the citizens by actively requesting direct data (energy, indoor conditions) or simple perceptions of thermal comfort, overheating and changes to their building during storms or heatwaves. These could be scaled up; diverse building users can take part by gathering data, potentially incentivised by novel citizen science methods and elements of gamification. This has the potential to intrinsically inform the rollout of required maintenance and condition monitoring of heritage buildings. Our discussion brought to the forefront the idea of incentivising neighbours to share best practice methods, motivate each other to be part of this process and create a network for sharing valuable information.

3. Challenges and Opportunities in Archetype Approaches

There was a lot of excitement about the archetype approach, discussed extensively during the workshop. This approach presents both challenges and opportunities. Challenges include the scale of building stock, resource allocation, and the availability of retrofit skilled workforce. Having a technically viable pattern book of retrofit methods by archetype has great potential to deal with buildings similar in their method of construction, age, and architectural features. Estates with buildings spread out in a city or region may not fully consider this, and over-generalisation may risk overlooking particularities of cultural significance. However, opportunities lie in mainstreaming “evidence-based” solutions, reducing installation costs, and quickly identifying and proactively instigating low-cost, high-return and no-regret retrofit opportunities. Another challenge identified was the format of available data on historic building performance which is often found as text-based information in reports and guidance technical documents. There needs to be a move towards linking the evidence and data from past trials and work, and the surveys and condition monitoring of historical/ conservation buildings.

4. Innovative Methods for Building Performance Data

The workshop explored innovative methods for ensuring sustained building condition and energy performance data at scale. Key themes included the use of point-cloud scanners, drones, robotics, and digital twins for efficient surveys and data collection. Attendees highlighted the importance of predictive maintenance, occupant engagement, and continuous monitoring through digital tools. There was a sense that the construction industry is behind industries like aerospace and engineering and that the use of a more data-driven and whole-system approach to maintenance and retrofit needs to be incentivised.

5. Ensuring Long-Term Performance

A crucial aspect to the success of this work is to ensure the long-term performance of retrofitted buildings. Suggestions ranged from sensors and building management systems (BMS) to track and control the condition of the building and to determine a baseline performance that meets carbon targets and energy sufficiency. Participants highlighted the importance of a stewardship approach as seen in other communities, mindset changes which may be incentivised by interventions like green leases. Involving communities in such schemes requires mindful engagement and investing in the development of skills and knowledge of the best options to retrofit specific archetypes – having an archetype pattern book of interventions will help to inform this process.

4.4. Key actions and considerations

Implementation of an archetype approach to preserve buildings

The key actions below can be applied to all building types, however, the important consideration is the condition and preservation of buildings considered historic, listed and in conservation areas.

1. Prioritise Building Use and User Behaviour:

- Focus on whole-building approaches: Address both building fabric and occupant behaviour for maximum impact.
- Promote community building usage: Utilise existing spaces like libraries and community centres as "warm banks" for energy efficiency.
- Address maintenance issues: Integrate grid upgrades with retrofitting plans to avoid future challenges.

2. Balance Operational vs. Embodied Carbon:

- Consider lifecycle impacts: Choose materials and solutions that minimise both operational (in-use) and embodied (production) carbon.
- Explore new and sustainable options: Support innovative materials like hemp insulation and recycled materials to scale up production and lower costs.

- Develop circular economy solutions: Encourage reuse and recycling of building materials for greater sustainability.

3. Address Traditional Building Challenges:

- Develop retrofit approaches for historic structures: Implement standardised methods like PAS 2035 and pilot projects for better guidance.
- Bridge the skills gap: Integrate historic building conservation into education programs to create a skilled workforce.
- Offer specialised funding for traditional buildings: Avoid excluding specific measures through targeted grants and support.

4. Enhance Coordination and Communication:

- Embrace archetype approaches: Develop standard retrofit plans for different building types based on location and needs.
- Prioritise resident and user buy-in: Ensure effective communication and address concerns to secure community support.
- Address factor failures: Identify and prevent potential issues in retrofit projects for smoother implementation.

5. Leverage Technology and Funding:

- Utilise automation and digitisation: Explore tools like scan-to-BIM and Lidar scanning for accurate building data and planning.
- Optimise capital planning: Allocate resources towards archetypes and prioritise future needs within existing buildings.
- Explore alternative funding models: Investigate "People Powered Retrofit" schemes and advocate for increased support for smaller domestic projects. People Powered Retrofit – beginning in Manchester and is now available through Changeworks.

On using new technology and approaches to building conservation & retrofit

1. Embrace Passivhaus Design and Tools:

- Utilise Passivhaus standards and tools throughout the planning and design stages, from individual flats to entire blocks.
- Set ambitious yet achievable energy targets, like 50 kWh/m^2, for both new build and retrofit projects.

Although adopting this standard demonstrates energy efficiency and can make a real difference in improving the operation of the building, issues arise over its practicality and delivery in a Scottish context, particularly at scale and under already constrained budgets.

2. Implement AI-powered Decision Making:

- Leverage software tools such as Trimble, Bentley and HES condition survey to analyse retrofit options across various scales and optimise resource allocation.
- Prioritise critical historic interventions by evaluating building readiness and identifying key areas for improvement, like breathability and detailing.
- Creating databases of the performance of all the archetypes, including condition, heritage status and specific variances to tackle when improving such buildings, all in a larger scale data set avoiding just text-based data.

3. Standardise Processes and Skills:

- Skills required for historic buildings will differ greatly from other buildings, therefore, the development of standardised retrofit approaches with core elements to improve quality, compliance, and skills development will be needed.
- Address the shortage of skilled professionals by establishing framework agreements with built-in training and workforce revitalisation programs.
- Streamline planning processes and help with tax incentives to reduce the cost of retrofit and make it a more cost-effective choice.

4. Foster Community Engagement and Participation:

- Invest in citizen participation models to inform initial retrofit strategies and avoid community resistance.
- Explore innovative community tagging and funding mechanisms to encourage active involvement in retrofitting efforts.
- Implement citizen science where data and condition surveys can be uploaded or simply discussed and accounted for.

5. Develop Dynamic Decision-making Tools:

- Create dynamic models that simulate the impact of different retrofit measures on energy performance and costs.
- Offer clear pathways from "do nothing" to deep retrofit, allowing tailored approaches and informed resource allocation.
- Integrate tools like SAP and Passivhaus models for early-stage decision-making and a holistic approach to building improvements.
- Adopt place-based planning strategies for heat decarbonisation such as LHEES
- There is a need to develop a **UK national building database** which can host a repository of all building types where the archetype approach is used to characterise buildings and to provide construction typologies, known risks, condition surveys and information of the requirements to reach energy efficiency levels that align with net zero performance.

5. Summary

As part of this workshop series, a prevailing objective was to explain the rationale and need for clustering building types leading to retrofit and low-carbon methods and technology. The objective is to provide validated and informative solutions to the existing built heritage which is available to all building users, owners and property portfolio managers.

The invited speakers and discussions first turned to the existing domestic buildings sector (non-historic) to identify the typologies and the ones that prevail in our Scottish towns and cities which are in desperate retrofit. A second workshop discussed buildings from the non-domestic realm with varying uses and energy requirements. Finally, a third workshop discussed the complexities and solutions of buildings that are listed, in conservation areas or simply have a historical context and affiliation.

The workshops aimed to discuss and debate the different challenges faced and how an archetype approach can be the vehicle for improving the conditions of buildings for sustained performance (energy & carbon) whilst providing comfort and well-being to its occupiers. Within the scope was to discuss the opportunities in the construction, conservation and retrofit skills and the need to train our current and future workforce. Lastly, there was the need to appropriately select the best possible heating technology that delivers demands in a low-carbon way and is feasible according to current infrastructure capacities but can adapt to changing and emerging energy delivery methods using renewables and the future decarbonised grid.

The debates focused on ways to characterise buildings and to find a common approach to retrofitting each typology resulting in building archetypes clustered by age, methods of construction and use. Within the conversations and round table discussions, were the challenges and opportunities for low-carbon heating that is suitable for each archetype considering the best technology and the required infrastructure to meet demand. Beyond identifying the technical challenges, the discussions acknowledged the need for workforce training in construction, conservation, and retrofitting skills. Additionally, choosing the right heating technology is crucial, balancing low-carbon performance with existing infrastructure limitations and adaptability to future renewable energy sources.

The culmination of these workshops will be to create a website and tool to access retrofit examples and case studies showcasing the before and after conditions of the buildings. This can be shown in a case study website available to all stakeholders and building owners/ occupiers to learn from exemplar projects that have applied retrofit interventions and there is evidence of its success and approaches. Data gathering of these case studies will help to show the impact of such work and also provide a series of best practice details suitable for different archetypes and technology solutions. A tool to select and suggest the best retrofit intervention with varying options for low-carbon heating can indicate energy and carbon reductions against the cost and other constraints such as required decanting and special planning/ building control restrictions.

The outcomes of these discussions hope to inform and agree on the best characterisation of domestic and non-domestic buildings with and without a significant historical location and classification. However, the approach and methods need to be available and easily interpreted by all levels of building users and stakeholders such as tenants, landlords, local authorities, conservation bodies, and government. Equally, the solutions and archetype measures need to be clear and concise for their application and procurement, material purchasing and technical viability.

6. List of participatory organisations

The workshops were attended by many organisations with excellent participation in the question and answer sessions after guest speakers, as well as during the round table debates on key questions. Attendance included a wide variety of participants such as representatives from homeowners/ building managers, contractors, local authorities, housing associations, construction and design professionals and the Scottish Government in all three events. Participants attended based on their area of interest relevant to each workshop.

The workshop organisers wish to thank all participants and attendees for their valuable input to the discussions.

The following is a list of some of the organisations that attended the three Edinburgh-based workshops:

BCA Group
Bennett Associates
Built Environment Smarter Transformation (BE-ST)
City of Edinburgh Council
City of Glasgow Council
Collective Architecture
Coltart-Earley Architecture
Community Energy Scotland
East Lothian Council
East Renfrewshire Council
Edinburgh Futures Institute
Edinburgh Leisure
Edinburgh Napier University
Edinburgh World Heritage Trust
Ener-Vate
Everwarm Group
Everwarm Group
Fife Council
Forth Valley Housing Association
Glasgow Life
Gray Marshall Contractors
Heriot Watt University
Highland Council
Historic Environment Scotland
Homes for Scotland
IES-VE
Jeffreys Interiors
John Gilbert Architects
Link Group
Loft Boarding Scotland
Matthew Clubb Architects
National Galleries of Scotland
National Libraries Scotland
National Trust for Scotland
Neoterra Energy
NHS Lothian
Renfrewshire Council
Royal Incorporation of Architects Scotland
Ryder Architecture/ BRS Scotland
Scottish & Southern Energy
Scottish Courts
Scottish Futures Trust
Scottish Government
Scottish Historic Buildings Trust
Scottish Power Energy Networks
Sustainable Estates Scotland
UK Green Building Council
Union Technical
University of Edinburgh
Vattenfall
Warm Works
Well House Housing Association
Wellhouse HA
Wheatley Group

7. Action plan – next steps:

To deliver mass retrofit interventions at the scale required that will also accelerate reducing future carbon emissions can be catalysed by using a consistent and clear methodology. Utilising building classification agreements and consensus for retrofitting technical aspects supports productivity, delivery, material supply chains and skills/workforce knowledge. Dwelling categories are often made based on the composition of the dwelling type, i.e. flatted, semi-detached, detached, or terraced; however, for mass retrofit approaches for existing buildings concerning the fabric and external envelope solutions knowledge is required that includes the original construction materials and/or any adjustments energy efficiency retrofits which have previously been undertaken.

These distinctions have a direct effect on the retrofit approach itself, as it often relates to the existing original conditions and materials used. For this reason, a simple dwelling composition may not be enough, particularly as over the decades there have been evolutions in materials and methods of construction.

7.1. Archetype definition

The archetype classification of Scottish homes and buildings is principally defined by the different existing wall-type materials of the original method of construction (MOC) under the following categories, see Appendix A1 and A2 for examples:

- Solid wall – stone or brick
- Cavity - Traditional brick-cavity-block (insulated and non-insulated)
- Timber - Traditional timber frame (insulated and non-insulated)
- Non-traditional methods – Steel, aluminium, concrete, no-fines, timber[7]

Within the above categories, variations will emerge, however, these will be particular to the analysed housing stock. Solutions to these variations will be explored in detail based on the principal archetype and considering suitable materials, a technique of application and past test data of the archetype intervention.

Other components will be analysed but will not form part of the principal archetype classification. For example, solutions to roofs and floors will emerge in each principal archetype and have some variations but are likely in many cases to be applicable across a range of different archetypes (e.g. insulated cold roof designs, room-in-roof, suspended ground floors or raft floor construction. Sub-sets will emerge with different configurations as to the type of insulation used (rigid, batte, roll, polymer-based or mineral wool).

7.2. Requirements to assess stock

Building stock requires an assessment of its energy demand and carbon intensity by comparing it against existing data sets, i.e. similar archetype dwellings based on CIBSE TM46. A Scottish building benchmark by Zero Waste Scotland and the Scottish Energy Officers Network (SEON) developed the Scottish Public Sector Energy Benchmarking Tool (SPSEBT), useful for comparing archetypes.

A defined archetype of building stock requires an evaluation of its net zero carbon potential (NZP). Using an evaluation and score of 0-100% where a closer score to 0% requires the

[7] Also known and considers under the System Built homes in the Home Analytics datasets.

least effort to reach net-zero performance, considers operational, embodied, renewables and sequestered carbon.

A condition assessment of the stock is required, selecting the following:

- **Original condition** (no past retrofit, which provides knowledge of the baseline original construction performance),
- **Standard replacements and maintenance** improvements i.e. windows, doors, boilers, occupant energy frugality,
- **Light retrofit** i.e. roof insulation top-up, cavity wall insulation, stone/ brick repairs, draftproofing, external wall insulation,
- **Deep retrofit** i.e. complete heating system change, detailed insulation in walls, roof and floors, airtightness seals across the building envelope & detailed thermal bridging reduction.

It is recommended as part of the retrofit archetype approach, to support consistency of data, performance tracking and data analysis, the following tests and data need to be obtained before and after applying retrofit interventions, where possible:

Existing Documentation	Documentation that confirms its condition, i.e. original, standard, light or deep retrofit,
Data documentation (past)	Pre-Works - 12 months total heat and electricity energy demand in kWh/year
Testing (1)	72hr in-situ wall U-value measurement (principal wall in the dwelling)[1]
Testing (2)	72hr indoor temperature (˚C) and humidity (RH%) assessment (occupied dwelling),
Testing (3)	Airtightness test @50 Pa using the Low-pressure pulse (LPP)[2] or fan pressurisation methods[3],
Testing (4)	Internal wall, roof and floor infra-red thermography survey[4]
Data analysis (future)	Post Works - 12 months total heat and electricity energy demand in kWh/year

7.3. Codification of archetypes and assessment of stock

The dwelling type will be defined by using a code that states its principal archetype and condition. These can be defined by: Wall type/ Build type (e.g. Timber frame; Stone Tenement); Variation(s) and Condition

A code will be issued that identifies:

A) its baseline original construction condition,

B) followed by suitable retrofit interventions for fabric,

Or

C) Where complete system data is known, following previous major retrofit works [original build type + fabric retrofit + low or zero emission carbon technology heating system]

This provides three useful factors:

A) Baseline U-values for original external walls for that specific archetype (not yet retrofited construction) which will help future EPC categories and worst case starting point.

B) Retrofit U-value data for different retrofit fabric approaches, where fabric retrofit is required to be applied on properties supporting the social housing knowledge and archetype delivery journey [but yet undecided on low or zero carbon heating systems to be specified]

C) Full system approaches – showing complete fabric retrofit and heating system solutions which can then be utilised by social housing providers for that specific archetype.

The following steps would produce the given archetype and its retrofit intervention solutions:

1. Determination of the wall method of construction allowing for archetypes 1, 2 3…
2. Identify variations and sub-set types – room-in-roof, dormers, basement, floor type,
3. Benchmark the chosen archetype against other archetypes and regional or UK data,
4. Assess the level of net-zero potential – considerations used,
5. Retrofit interventions with codes linked to materials, applications, skills/QA and CO_2 calculations,
6. Low-carbon heating solutions with codes
7. Re-evaluation of net-zero potential – how close to 0% net-zero carbon per building & benchmarks,
8. Whole life carbon and costing, links to funding and contractors

This summary and proposal have been developed by the University of Edinburgh and the School of Engineering and Centre for Future Infrastructure authored by Dr Julio Bros-Williamson (j.broswilliamson@ed.ac.uk) and Prof Sean Smith (sean.smith@ed.ac.uk)

APPENDIX - A1

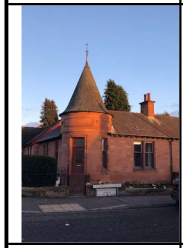
Example of Common Archetypes in Scotland

Archetype	Most Common External Wall KEY Archetypes	Coding	Sub-Categorisation Guidance within KEY Archetypes
1	Pre1919 sandstone house (solid)	SW - SS - 1	Variation of finishes room side
2	Pre1919 sandstone tenement flat (solid)	SW - SS - 2	Variation of finishes room side and overall wall depth
3	Pre1919 granite stone (solid)	SW - GS - 1	Variation of finishes room side
4A to 4E	Timber frame based (block or brick outer leaf)	CW - TF - A	90mm mineral wool insulation (inner leaf)
	Timber frame based (block or brick outer leaf)	CW - TF - B	rigid foam insulation (inner leaf)
	Timber frame based (block or brick outer leaf)	CW - TF - C	expanding foam (inner leaf) - note different types
	Timber frame based (block or brick outer leaf)	CW - TF - D	140mm mineral wool insulation (inner leaf)
	Timber frame based (block or brick outer leaf)	CW - TF - E	Other - e.g. SIPS inner leaf
5	Brick full depth (solid)	SW - B - 1	Variation of finishes room side and outer leaf
6A to 6D	Masonry & block cavity wall	CW - MB - A	Brick outer skin - dense block inner skin
	Masonry & block cavity wall	CW - MB - B	Block & render outer skin - dense block inner skin
	Masonry & block cavity wall	CW - MB - C	Block & render outer skin - LWA block inner skin
	Masonry & block cavity wall	CW - MB - D	Block & render outer skin - Aircrete block inner skin
7	Steel frame (block or brick outer leaf)	CW - SF - 1	Mineral wool insulation (inner leaf)

Example of Specific Non Tradional Archetypes in Scotland

Non-Traditional Archetypes		
NT Atholl Steel		NT Lawrence MK1 / MK2
NT Bellstone		NT Myton
NT BISF		NT Orlit
NT Brydon		NT Orlit Bungalow
NT Carmyle		NT No Fines
NT Corolite		NT Scotcon
NT Cowieson		NT Solid Cedar
NT Craig-Atholl		NT SSHA Canadian Timber
NT Crosswall		NT SSHA Commissioners Resumption
NT Cruden Rural		NT SSHA Wartime Cellular Concrete
NT Dorran		NT Swedish Timber (timber cladding)
NT Duo-Slab		NT Tarron-Clyde
NT Glasgow Foamed Slag		NT Tee Beam
NT Hall-Cottage		NT Weir Steel
NT Hilcon		NT Weir Timber (timber cladding)
NT Keyhouse Unibuilt		NT Wilson Block

Appendix A2: Examples of archetype database for a stock assessment

Common image	Archetype No.	MoC Archetype	External Wall Code	Other components	Wall Finish		U-Value		Case Study codes	Variations
					Internal	External	Calculated	Measured		
	1	Pre 1919 Sandstone **house** - Solid blond or red stone Victorian or Edwardian - 1850's to 1920's	SW - SS -1	Slate covered timber roof truss and joists with original ash deafening and limited insulation and lath/ plaster finish. Floors suspended joists with softwood boards or stone flagstones and early use of concrete (kitchens)	1. Lath/ plaster 2. Plaster on the stone 3. Retrofited plasterboard	1. Ashlar stone 2. Rubble stone 3. Rough stone finish	1.21 W/m^{2}K	0.96 W/m^{2}K	1. xxxx 2. xxxx	* Back walls may have brick patches. * Flat or pitched dormer windows * High quality stone at the front with rubble and High mortar ratio.
	2	Pre 1919 Sandstone **flat** - Solid blond or red stone Victorian or Edwardian - 1850's to 1920's	SW - SS -2	Slate covered timber roof truss and joists with original ash deafening and limited insulation and lath/ plaster finish. Floors suspended joists with softwood boards or stone flagstones and early use of concrete (kitchens)	1. Lath/ plaster 2. Plaster on the stone 3. Retrofited plasterboard 4. Common areas brick & painted/ tiles	1. Ashlar stone 2. Rubble stone 3. Rough stone finish	1.40 W/m^{2}K	1.39 W/m^{2}K	1. xxxx 2. xxxx	* Back walls may have brick patches. * Flat or pitched dormer windows * High quality stone at the front with rubble and High mortar ratio. * Bay windows
	3	Pre 1919 Sandstone **flat & house** - Solid granite stone Victorian or Edwardian - 1850's to 1920's	SW - GS - 1	Slate covered timber roof truss and joists with original ash deafening and limited insulation and lath/ plaster finish. Floors suspended joists with softwood boards or stone flagstones and early use of concrete (kitchens)	1. Lath/ plaster 2. Plaster on the stone 3. Retrofited plasterboard	1. Granite stone 2. Rubble granite stone 3. Rough granite stone finish	xx W/m^{2}K	xx W/m^{2}K	1. xxxx 2. xxxx	* Back walls may have brick patches. * Cantered dormer windows * High quality stone at the front with rubble and High mortar ratio. * Bay windows
	4a	Timber open panel frame (based), flats and houses - brick or block outer leaf	CW - TF - A	Pitched Slate or cement tile with timber roof truss and joists ceiling level (cold roof) insulation and plasterboard finish. Floors suspended timber joists with softwood boards or concrete floor	1. Plasterboard & plaster finish/ paint	1.Bare brick 2. Brick and render 3. Block and render 4. Timber or composite cladding	xx W/m^{2}K	xx W/m^{2}K	1. xxxx 2. xxxx	A - 90mm mineral wool (inner leaf)
	4b		CW - TF - B							B - Rigid foam insulation (inner leaf)
	4c		CW - TF - C							C - Expanding foam (inner leaf)
	4d		CW - TF - D							D - 140mm mineral wool (inner leaf)
	4e		CW - TF - E							E - Other - e.g. SIPS
	5	Pre 1919 Solid brick flat or **house** (Flemish or Dutch Bond) * 1 brick (215 mm), 1 1/2 brick (330mm) 2 brick (445 mm), 2 1/2 brick (555 mm) 3 brick (665 mm)	SW - B - 1	Slate covered timber roof truss and joists with original ash deafening and limited insulation and lath/ plaster finish. Floors suspended joists with softwood boards or stone flagstones and early use of concrete (kitchens)	1. Lath/ plaster 2. Plaster on the brick 3. Retrofited plasterboard	1. Flemish brick bond 2. Dutch (English) brick bond 3. Rough cast (wet dash) on brick	xx W/m^{2}K	xx W/m^{2}K	1. xxxx 2. xxxx	* High ceilings * Converted industrial buildings * Large windows
	6a	Blockwork cavity wall with render finish or brick outer leaf	CW - BL -A		1. Plasterboard on dab or timber strap	See variations (A to D)	xx W/m^{2}K	xx W/m^{2}K	1. xxxx 2. xxxx	A - Cavity fill and insulated render finish
	6b		CW - BL - B							B - Cavity fill - render or brick finish
	6c		CW - BL - C		2. Plaster finish					C - No fill - insulated render finish
	6d		CW - BL - D							D - No fill - brick or render finish