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Review of social housing archetypes to support EESSH2 review

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1 Executive summary

1.1 Aims

Social housing comprises almost a quarter of Scottish homes and the housing sector represents around 15% of Scotland's greenhouse gas emissions. While the sector has already made strong progress in reducing emissions, the entire housing stock will need to use zero direct emissions heating (ZDEH) systems to reach Scotland's net zero target by 2045.

This report defines archetypes for dwellings in the social housing sector enabling identification of suitable energy efficiency measures and an appropriate ZDEH system.

The archetypes represent a first step towards future development of a 'pattern book' or similar approach, which social landlords could use as a starting point for lowering emissions from their properties.

A degree of simplification was applied, which nevertheless allowed key differences to be addressed. More work that considers potentially important differences in some archetypes will, however, be necessary before full details of a pattern book can be developed.

The findings will support the review of the Energy Efficiency Standard for Social Housing 2 (EESSH2) and help ensure the new standard is based on the strongest available evidence.

1.2 Findings

We reviewed archetyping studies and used a dataset of all Scottish social housing from Home Analytics Scotland to define key physical archetype parameters such as property type, wall and floor construction (Table 1).

When applied to the whole stock, these parameters give a total of 24 archetypes, of which 12 represent over 90% of the total number of dwellings. For each archetype we provide a list of recommended energy efficiency measures appropriate to the building's physical characteristics.

Parameter	Possible values
Property type	Flat House
Wall construction	Cavity construction System Built Solid wall Timber frame
Floor construction	Solid Suspended Other dwelling/unheated space below

Table 1 Key physical archetype parameters

There are some constraints and variants on the main archetypes which may alter the suitability of one or more measures. In these cases, alternative suitable measures will be required.

The suite of ZDEH systems that can, in principle, apply across most or all archetypes are air and ground source heat pumps, district heat networks and direct electric heating. A limited potential role for biofuels and hybrid heat pumps is also discussed.

The resulting method, whereby social landlords can identify a route to ensuring properties are suitable for a net zero future, is summarised in Figure 1 as follows:

1. **Identify archetype** using property type, wall construction and floor construction in order to produce suite of suitable measures.
2. **Note constraints** such as room-in-roof, no wet heating system, mixed tenure property, conservation area or listed status, off gas grid to amend suite of measures.
3. **Select appropriate ZDEH system** such as air or ground source heat pump, heat network, direct electric heating or hybrid heat pump to ensure home is net zero ready.

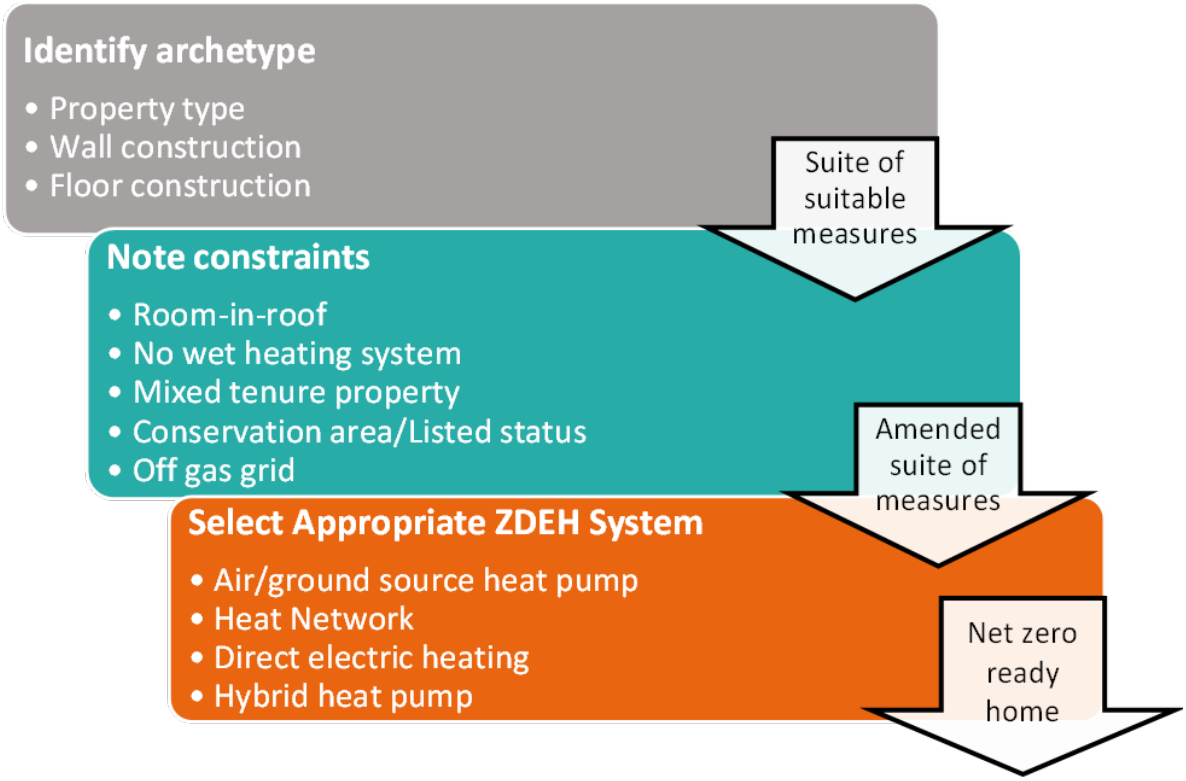

Figure 1 Summary of route to net zero for social housing properties

Contents

2 Glossary

ASHP	Air source heat pump
Capex	Capital expenditure
CWI	Cavity wall insulation
EE	Energy efficiency
EESSH	Energy Efficiency Standard for Social Housing
EPC	Energy Performance Certificate
EWI	External wall insulation
HAS	Home Analytics Scotland
IWI	Internal wall insulation
GSHP	Ground source heat pump
PV	Photovoltaics, more commonly known as solar panels
SAP	Standard Assessment Procedure
U-Value	A measure of thermal transmittance of building fabric elements such as the walls, roof, windows and doors – a lower value is shows that less heat is being lost from the building
ZDEH	Zero direct emissions heating
ZEST	Zero Emission Social Housing Taskforce

3 Introduction

3.1 Background

Social housing comprises almost a quarter of Scottish homes [1] and greenhouse gas emissions from the housing sector represent ~15% of total Scottish emissions [2][1]. The sector has already made strong progress in reducing emissions, but with a target of net zero by 2045 the use of Zero Direct Emissions Heating (ZDEH) systems across the entire housing stock will be required.

A useful way to determine the measures required to decarbonise and improve the energy efficiency of the housing stock is by grouping them into relevant archetypes with similar physical and other characteristics relevant to energy use. Using archetypes will be an effective way to assist social landlords to determine the available, most appropriate, and cost-effective energy efficiency measures and ZDEH system installation options to achieve decarbonisation goals across their housing stock.

Previous studies have proposed methods of archetyping Scottish properties. These include the Energy Efficiency Standard for Social Housing (EESSH) study [3] and the Zero Emission Social Housing Taskforce (ZEST) [4]. The latter, in particular, looked in more detail at wall construction types than this study. The details of which will ultimately be important in developing a full pattern book, and the research on this key topic is ongoing.

3.1.1 The EESSH milestones

EESSH aims to improve the energy efficiency of Scottish social housing. It will help to reduce energy consumption, fuel poverty and the emission of greenhouse gases [3]. The second milestone, EESSH2, was confirmed in June 2019 and stipulated that:

> "All social housing meets, or can be treated as meeting, EPC Band B (Energy Efficiency rating), or is as energy efficient as practically possible, by the end of December 2032 and within the limits of cost, technology, and necessary consent. In addition, no social housing below EPC Band D should be re-let from December 2025, subject to temporary specified exemptions." [5]

At the time of writing, the EESSH2 milestone was on hold, under review by the Scottish Government "to strengthen and realign the standard with the target for net zero heat in houses from 2040" [5]. For now, landlords are to revert to the first EESSH milestone which set targets for homes that varied depending on the dwelling type and fuel type used to heat it. Our study was instigated as a first step towards assisting landlords in deciding their next steps.

3.2 Goals of the study

This study defines archetypes that enable the specification of viable options for energy efficiency measures and ZDEH systems. The process of archetyping groups homes that share common physical and unchanging characteristics (e.g. those with cavity walls which could be insulated). This grouping process allows for the identification of potentially

[1] Based on emissions from the Residential sector in 2020, using a Climate Change Plan accounting basis.

appropriate measures available to improve their energy efficiency. The aim is to offer practical guidance to Local Authorities and Registered Social Landlords regarding the most suitable measures for their properties, which are required to reach net zero status (e.g. where insulation could best be added).

The archetypes represent a first step towards the future development of a 'pattern book' or similar approach that social landlords could use as a starting point for adapting their properties to meet net zero status. A degree of simplification was applied, which nevertheless allowed key differences to be addressed. Further effort is required to consider potentially important differences within certain archetypes before full details of a pattern book can be developed. This is particularly essential regarding the specific wall construction materials employed.

The goals of the archetyping are:

- To allow landlords to associate their properties with specific archetypes based on a small number of fixed, current, and well-understood building characteristics.
- To be a starting point for a pattern book of possible steps to achieve net zero status:
    - By detailing a list of suitable and necessary energy efficiency measures
    - By recommending appropriate and complementary ZDEH systems

The intention is to provide practical guidance to landlords on which broad categories of measures may be most suitable for their properties. The landlord should be able to describe their property in terms of simple well-known characteristics, or which could be determined from only a high-level house survey. This is illustrated in Figure 2.

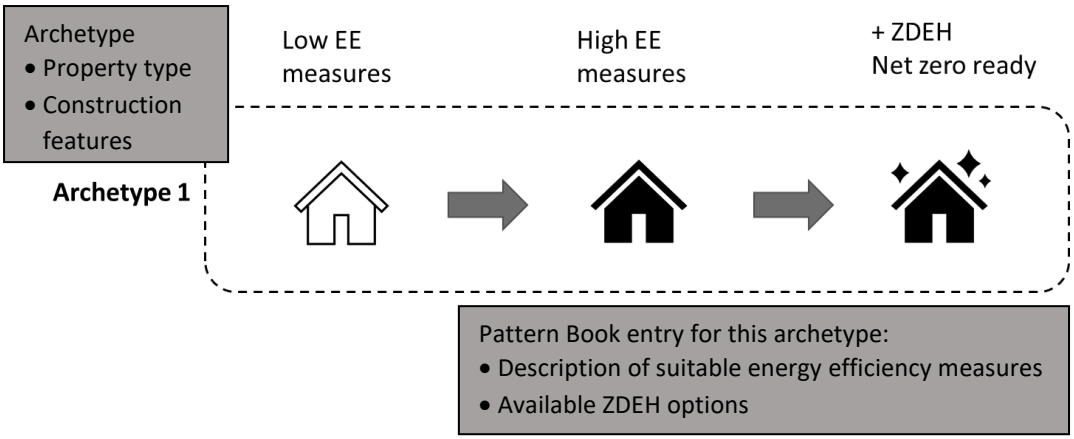

Figure 2 Schematic of derivation of archetypes and associated measures for net zero

4 Review of existing archetypes and current housing stock

4.1 Overview of current housing stock

Data on the Scottish housing stock was obtained from Home Analytics Scotland (HAS) dataset v3.8 via the Energy Saving Trust [6]. It was noted that approximately 50,000 dwellings in total have been built since 2020, of which over 36,000 are in the private sector [7]. A maximum of 14,000 new social housing sector dwellings have therefore been constructed, representing a little over 2% of the total. Findings from previous studies conducted prior to this remain relevant for the purpose of comparison.

From the data, 62.9% of the social housing stock are flats, and 66.3% of all social housing dwellings were built before 1950. There are a number of different wall and floor constructions all representing significant fractions of the stock, which will be of relevance to the archetyping. All of these are discussed in detail in section 5.1.

4.2 Stakeholder engagement

During the development of the archetypes we spoke to a number of stakeholders with whom we had informative discussions about the archetyping process. In particular, we discussed the decision to focus on physical characteristics. Details are in Appendix 8.2.

4.3 Case studies

We also identified three examples of retrofit projects which exemplify the principles under discussion. Currently, there are very few retrofit projects which explicitly deliver net zero capable homes. Nevertheless, these case studies demonstrate how relevant measures have been successfully implemented in the field. Details are in Appendix 8.2.

4.4 Previous archetyping studies

This work builds on a number of previous studies that defined archetypes for the housing stock in Scotland. Further details of those studies can be found in Appendix 8.1. We considered the approaches of and learnings from other archetyping studies conducted by other experts. The purpose of this work is not to duplicate or contradict other studies. Instead, our aim was to learn from past experience and identify any useful simplifications that could be applied. Additionally, we investigated the factors established as critical to the grouping of properties together or indeed maintain their clear separation in the interests of retrofit and pursuing net zero goals. Net zero is the end-state of a fully retrofitted dwelling, and we were interested in an archetyping methodology which differentiates between dwellings capable of utilising the application of a certain suite of measures to get to net zero. This means that we did not necessarily differentiate between similar dwellings which may be at different points on their journey to net zero in terms of measures implemented to date. A summary of key points from previous studies can be seen in Table 2.

Note that the HAS data only has 4 wall types, this limitation is discussed further in section 5.1.1. Four-in-a-blocks are also not a separate archetype.

Study	No of archetypes	Age	Dwelling type	Wall construction	Status of energy efficiency measures	Others	Key learnings for the current study
ZEST	6	✓(1)	✓ (2)	✓ (3)	Not included in archetypes	-	A small number of archetypes **can capture the key differences in building characteristics** which determine suitable measures for energy efficiency and net zero **Physical characteristics** are key descriptors Recognition of differences within archetypes today, but that **common end states** are achievable
Element Energy / East Dunbartonshire Council	12	✓(2)	✓ (4)	✓ (3)	Not included in archetypes	-	Viable to group by common characteristics with a range of energy efficiencies but with **common end states** in mind **Mixed tenure** buildings pose additional challenges
EESSH	350	✓(6)	✓ (8)	✓ (7)	Not included in archetypes	Fuel type and EPC rating Size Tenure Urban/ rural location	Wall construction is very important A relatively **small number of physical parameters** can be used but working groups may need to give more granularity Many suitable measures can apply **across archetypes**
Element Energy / Scottish Govt: Technical Feasibility of Low Carbon Heating in Domestic Buildings	54,000	✓(3)	✓ (5)	-	Roof insulation (5 levels) Wall insulation (5 types)	Fuel type Size Urban/rural/coastal District heating potential On/off gas grid	Full description of the stock requires multiple parameters This can nevertheless again be achieved with only a **few physical characteristics** A **small number of ZDEH strategies** can apply and many energy efficiency measures are suitable **across archetypes**

Table 2 Summary of factors considered in previous studies. Numbers in brackets refer to the categories within each heading, e.g., the EESSH study looked at eight separate dwelling types.

Key themes from previous studies suggest that a relatively small number of physical parameters can be used to adequately segregate the majority of the stock. This segregation allows for the description of suitable energy efficiency measures for a given dwelling type. However, more parameters are required in order to accurately describe the current status of the energy efficiency measures installed in dwellings. Furthermore, many measures are suitable for various archetypes. All the studies take the approach of finding a simplified way of describing the housing stock but there are differences in the level of detail they provide. Reasons for this stem from a different balance of accessibility and fine details, this is summarised in Figure 3.

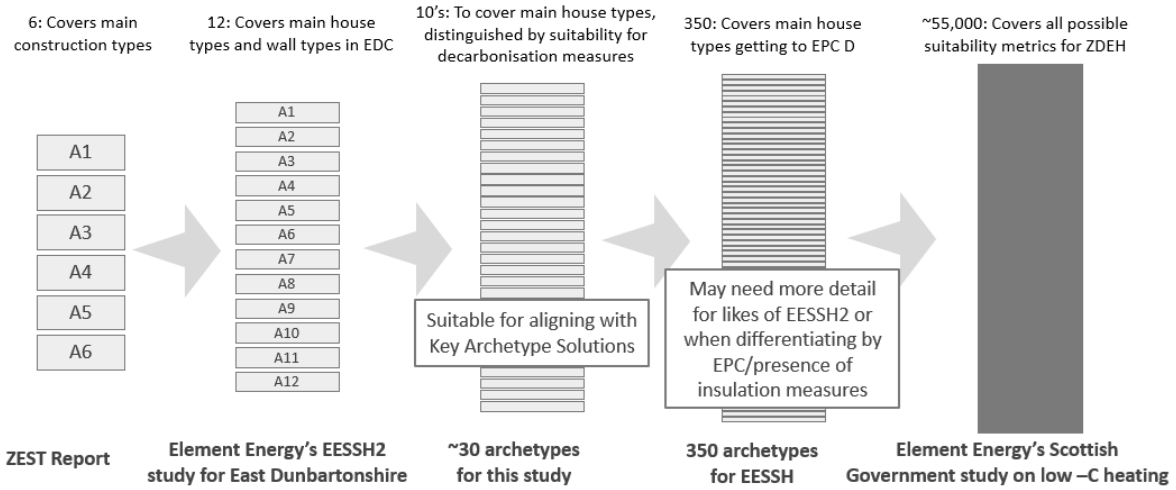

Figure 3 Schematic of archetype granularity

4.5 Archetyping approach – principles

The goal of this study is to define archetypes which allow identification of applicable energy efficiency and ZDEH measures capable of enabling net zero emissions in dwellings in the future. It is therefore less important to discriminate between different levels of energy efficiency currently in place, and more important to distinguish differences in the potential energy efficiency measures that could be applied. Parameters within the HAS dataset which refer to current insulation state can therefore be removed. Properties within a single archetype may already have one or more of the recommended measures in place or not. It is the achievable end state of the property which defines the archetype.

The archetypes are defined by the physical parameters which determine suitable energy efficiency and ZDEH measures. Potential differences in suitable measures for properties within an archetype, such as those in a conservation area or featuring a room-in-the-roof, are considered as variant or constraint parameters. These will be discussed separately from the main archetype definitions. The implications of these variations will have a similar impact across most or all archetypes – for example, restrictions on listed properties will be the same independent of their wall or floor construction. In many cases, these variants or constraints only apply to a small percentage of the stock. This approach is illustrated in Figure 4.

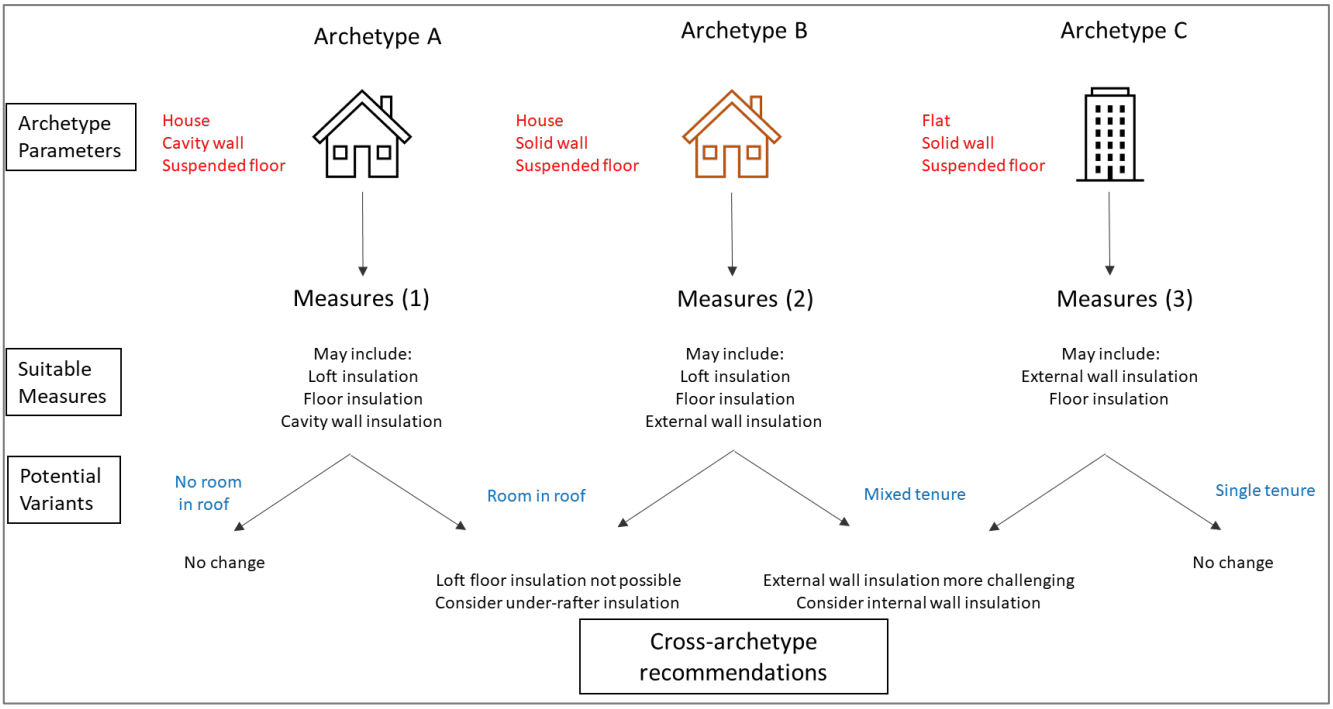

Figure 4 Cross-archetype treatment of anticipated variants (illustrative)

In conclusion:

- Critical physical parameters need to remain in the archetype descriptions.
- The focus should be on the achievable end-state.
- Parameters which do not realistically affect suitable measures are unnecessary.
- Certain parameters affecting details of suitable measures can be captured outside of the main archetyping process, e.g. limitations of being in a conservation area.

5 New archetype definition

5.1 Methodology

5.1.1 Initial analysis

The starting point for this work was a dataset obtained from the Energy Saving Trust containing data held by Home Analytics Scotland on the social housing stock in Scotland (including both local authority and housing association stock). From the data, 85 separate parameters were included, falling broadly into the following categories:

- Geographical location identifiers
- Whole building characteristics e.g. property type, size, age, loft or room-in-roof presence, floor area, wall construction and roof orientation
- Energy efficiency and heat demand e.g. loft/hot water cylinder insulation, estimated wall insulation status, fuel and meter type, glazing, boiler efficiency, SAP rating and heat demand estimates
- Estimated suitability for various technologies
- Estimated status on fuel poverty, extreme cold, exposure and related metrics

The dataset is detailed but not exhaustive, with no data recorded on property condition and some simplifications, especially in terms of the important parameter of wall construction. The “System Build” category is a single broad heading which in practice includes 4 categories and over 650 types and would need further work on specific details of a retrofit strategy for these dwellings. Geographical location was not included as a factor for archetyping since this should not affect the measures which are broadly suitable. Suitability is instead determined based on physical construction. However, geographical factors may influence the appropriateness of some measures. Variants such as cavity-wall considerations in areas of severe exposure are dealt with in section 5.6.10, and there may be other locally specific issues which are beyond the scope of this report.

The data from Home Analytics was grouped to analyse properties with similar characteristics. First, we removed the categories deemed irrelevant to this study. Those referring to geographical location, and continuous variables such as heat demand and estimated probabilities for some parameters were removed. In line with the focus on end states, we also eliminated those related to current energy efficiency including loft and cylinder insulation, SAP & environmental impact ratings, heat demand, fuel bill, and CO_2 estimates, all of which refer to the status quo. Removing these categories still left a large number of property groupings, in the tens of thousands, and further simplification was needed.

5.1.2 Archetype simplification strategy

Two key steps were taken to simplify the data. The property type was simplified to either “house” or “flat”, and property age was removed as a separate archetyping parameter.

The decision to simplify the dwelling description to only house or flat was based on the premise that the key distinction is likely to be loft or floor insulation suitability. A block of flats could contain many dwellings where neither loft or floor insulation was feasible or where options were restricted, whereas typical houses retain this option in most cases.

Separating terraced or semi-detached house when both are suitable for loft, wall or floor insulation and the same ZDEH system is not worthwhile, generating near-duplicate archetypes with identical suitable measures.

Given the focus on achievable end states and suitable measures, the year of a property's construction was also not deemed critical. This decision had a significant effect on the number of archetypes, and further justification is discussed alongside Figure 5 considering the final archetype definitions.

The next step was to consider parameters from the HAS data that could be relevant but would leave a large number of archetypes if used. These were considered for use as variant or constraint parameters that could be added to the final archetypes if relevant. The modifications as a result of this approach are detailed in Table 3.

Parameter	Simplification	Justification
Property Tenure	Considered as a variant/constraint	General principles for the effect on measure suitability are discussed in section 5.6
Listed/conservation status	Considered as a variant/constraint	This represents a small fraction of the stock and is discussed in section 5.6.3
Solar panel suitability	Considered as a variant/constraint	General principles for the effect on measure suitability is discussed in section 5.3.10
Urban/Rural location type	Not used	Not thought likely to affect suitable measures
Fuel type	Not used	A net zero fuel will need to be specified, so today's fuel system is less important
Room-in-roof presence	Considered as a variant/constraint	This represents a small fraction of the stock and is discussed in section 5.6.2
On/off gas grid	Considered as a variant/constraint	Potentially only affecting hydrogen or biogas as ZDEH options, neither of which is thought likely to play a major role in providing ZDEH
Size constraint	Considered as a variant/constraint	General principles for the effect on measure suitability is discussed in section 5.6
Narrow cavity risk (<50mm)	Considered as a variant/constraint	This represents a small fraction of the stock and is discussed in section 5.6.5
Presence of wet heating system	Considered as a variant/constraint	General principles for the effect on measure suitability is discussed in section 5.6

Table 3 Assumptions and simplifications to reduce the number of archetypes

5.1.3 Final archetype parameters

The final list of parameters used to determine the archetypes is given in Table 4.

Parameter	Possible values
Property type	Flat House
Wall construction	Cavity construction System-built Solid wall Timber frame
Floor construction	Solid Suspended Other dwelling/unheated space below

Table 4 Final list of parameters for archetyping

Net-zero retrofit energy assessments may lead to a recommendation for a particular amount or type of wall insulation material as a next step, but that level of detail is beyond the scope of this report. It is recognised that by including only "solid walls" there are potential differences depending on material used and interactions with e.g. floor construction.

Grouping the stock using the parameters in Table 4 led to a total of **24** archetypes to cover the entire stock. With 90% of the stock being covered by only 12 archetypes. The details of the final set of archetypes are shown in Table 5.

Archetype number	Property type	Wall Construction	Floor Construction	Stock
1	Flat	Cavity Construction	Unheated space/Other premise below	131734
2	House	Cavity Construction	Suspended	126025
3	Flat	Cavity Construction	Suspended	74770
4	Flat	Solid Brick or Stone	Unheated space/Other premise below	53470
5	Flat	System Built	Unheated space/Other premise below	45951
6	Flat	Timber Frame	Unheated space/Other premise below	31505
7	House	Timber Frame	Suspended	28548
8	Flat	Timber Frame	Solid	27227
9	House	Cavity Construction	Solid	26196
10	Flat	Solid Brick or Stone	Suspended	20105
11	House	Timber Frame	Solid	17520
12	House	Solid Brick or Stone	Suspended	16682
13	House	System Built	Suspended	14254
14	Flat	Cavity Construction	Solid	11572
15	House	System Built	Solid	8468
16	Flat	Timber Frame	Suspended	6443
17	Flat	System Built	Suspended	4666
18	House	Solid Brick or Stone	Solid	4257
19	Flat	System Built	Solid	3393
20	Flat	Solid Brick or Stone	Solid	2878
21	House	Cavity Construction	Unheated space/Other premise below	1077
22	House	Timber Frame	Unheated space/Other premise below	577
23	House	Solid Brick or Stone	Unheated space/Other premise below	292
24	House	System Built	Unheated space/Other premise below	142

Table 5 Details of the final 24 archetypes

5.1.4 Note on property age

The Home Analytics Scotland data has six bands for the date of construction of a property. Properties of all age bands are present in each of the final 24 archetypes, and properties of a given age band appear in nearly all archetypes. However, there are some notable correlations between archetype attributes and age band, as shown in Figure 5. For example, pre-1919 homes are most prevalent in archetypes 4, 10 and 20, all representing solid wall properties, and post-2002 homes make up a large share of archetypes 6, 7, 8, 11 and 22, which represent timber frame properties. By defining archetypes based on key physical attributes which correlate with age, including the wall and floor construction, we are able to capture the factors impacting the suitability of measures without the need to explicitly distinguish property age in the archetype definition. This allows us to define a manageable

number of archetypes which represent a large portion of the social housing stock sufficiently well to provide meaningful guidance to landlords.

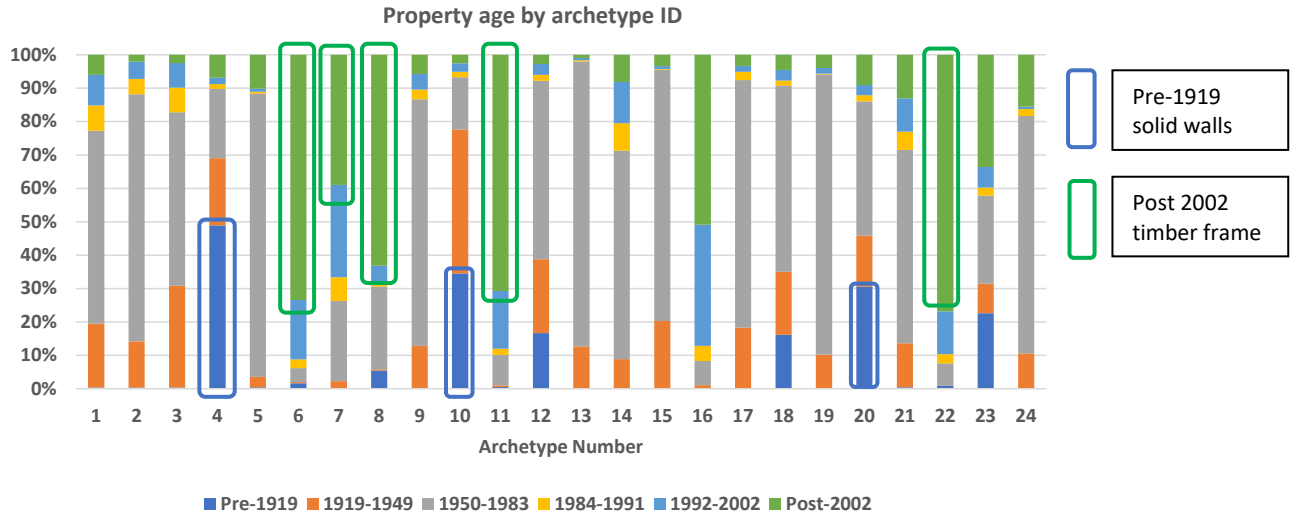

Figure 5 Distribution of age within each archetype, highlighting pre-1919 tenements and modern timber-frame buildings as commonly represented building types

5.2 Energy efficiency & ZDEH systems

5.2.1 Energy efficiency – benefits of improvements

If energy used to heat a dwelling is itself from a zero direct emissions source, then no emissions are produced on a Climate Change Plan accounting basis. However, in a dwelling with low energy efficiency this would be expensive as more would be required to maintain a given temperature as more energy escapes through the fabric of the dwelling compared with an energy-efficient one. The EESSH2 standards originally imposed energy efficiency targets for 2025 and 2032, where (with limited exceptions) all properties should be let only if they meet EPC band D and B respectively. The enforcement of these targets, which would necessitate significant energy efficiency improvement, are now on hold (with the outcome of the review expected in 2023), although landlords are still required to meet the EESSH1 standards of EPC band E for an oil-heated house and C for a gas-heated one. Improving energy efficiency represents an important method of making immediate progress towards net zero.

5.2.2 Cost of energy

The cost of energy is naturally important to tenants. Energy efficiency measures directly reduce the energy a tenant uses to heat their home and hence the cost of doing so.

5.2.3 Suitability and effectiveness of heat pump installation

Heat pumps are considered as ZDEH solutions by Scottish government accounting practices and will be a key solution. They are most efficient when operating at low flow temperatures, and their ability to do so is strongly linked to the energy efficiency of the dwelling [8]. If energy demand is high then heat pump installation may need to be accompanied by significant upgrading of the radiators in terms of size or pipe bore, the flow temperature

may need to be higher, or in some cases a heat pump may not be able to adequately heat the home during periods of highest heat demand. Energy efficiency measures which lower the home's heat demand therefore can enable the adoption of this key ZDEH solution. Which energy efficiency measures are suitable and necessary will vary between homes, even for those within the same archetype, and should be assessed by a professional heat pump installer on a case-to-case basis.

5.3 Energy efficiency – potential measures

Property features such as a cavity wall, and energy efficiency measures such as floor insulation, are relevant to multiple archetypes. A summary of the available suite of energy efficiency measures, their benefits and potential limitations, which are thus relevant to all archetypes is given in Table 6. This provides a qualitative indication of the typical effect of a given measure in an individual dwelling.

Insulation measure	Applicability	Emission reduction potential	Indicative cost
Loft	Houses without a room in the roof, some top floor flats	L/M	L
Cavity Wall	Non-timber frame dwellings with a cavity wall ~50-150mm cavity size only	L/M	L/M
External wall	Any dwelling with sufficient outside area	L	M/H
Internal wall	Some loss of space	L/M	M
Floor (solid)	Ground floor only	L/M	H
Floor (suspended)	Not necessary with heated room or other dwelling below	L/M	M
Improved glazing	Listed buildings or those in a conservation area may be restricted	M	H

Table 6 Potential energy efficiency/insulation measures [2]

Note that several other measures widely applicable to any dwelling are often highly recommended. These measures include insulation for pipework and hot water cylinders, draughtproofing measures, among others. However, these are not discussed in detail here as we are focusing on potential differences between archetypes.

5.3.1 Loft insulation

This is a relatively low-cost measure with minimal disruption which should be fitted in all properties with a loft. A depth of 250-280mm is recommended, but if a property already has

2 Adapted from [29] and Element Energy experience

>150mm of insulation the extra benefit of topping up may not be worthwhile [9]. Some flats will have a loft, a common example in Scotland would be the top floor of a four-in-a-block property, although this is not separately identified in the HAS data. Most properties with a loft will be straightforward to treat but some, for example with access issues, may present additional challenges.

5.3.2 Cavity wall insulation

Cavity wall insulation (CWI) can typically reduce energy demand by more than loft insulation but is more expensive, and with a wider range of cost depending on specific property features. It is also a whole-building measure which may be more challenging with mixed tenure dwellings. The cavity should ideally be ~50-150mm wide. Narrower cavities pose particular problems for insulation and are likely to require specialist advice [10].

5.3.3 External wall insulation

External wall insulation (EWI) can be applied to solid wall properties without a cavity. It is typically more expensive than CWI but highly effective at reducing heat demand. It is another whole-building measure.

5.3.4 Internal wall insulation

Internal wall insulation (IWI) is typically slightly less effective in reducing heat demand but less costly in absolute terms than EWI and is again suitable for non-cavity wall dwellings. It can be applied to individual dwellings, but internal space is reduced slightly, typically by 80-100mm per wall.

5.3.5 Wall insulation – general

It is not usually necessary or cost effective to install both EWI and IWI although the combined effect will be greater than either alone, and for maximum efficiency this is an option. It is possible to have both EWI and CWI and this may be appropriate for a deep retrofit. Both CWI and IWI is however not advisable due to the risk of damp accumulation in the cavity wall which will be insulated from warmth from the dwelling by the IWI itself [11].

5.3.6 Suspended floor insulation

This is an effective measure typically lower in cost than IWI but with lower associated heat demand reduction. Care is needed to ensure that moisture does not build up, but this does not preclude this measure in any archetype and professional advice should be sought. Applicable on the ground floor or where the floor is above e.g. a garage or other unheated space. Insulating between occupied flats e.g. in a tower block is unnecessary.

5.3.7 Solid floor insulation

This is more expensive and disruptive than suspended floor insulation but can achieve similar levels of efficiency improvement. The floor level may need to be raised sufficiently to require rewiring of sockets etc. This measure is likely to be less of a priority than wall insulation. This is a ground floor only measure.

5.3.8 Insulation – general

It may be the case that upgrading existing old or inadequate insulation makes sense depending on the type, quantity and state of repair of the existing insulation material.

5.3.9 Improved glazing

Upgrading single glazing to double glazing is worthwhile from an energy efficiency viewpoint but is relatively expensive compared to other measures discussed. Currently, less than 7% of stock is only single glazed. Secondary glazing is a viable option for these properties (in all archetypes), offering less energy efficiency benefit than double glazing, but at lower cost. Upgrading from double to triple glazing is unlikely to be necessary [12].

5.3.10 Solar panels

Whilst not strictly an energy efficiency measure in that they do not reduce demand, solar panels do provide energy free at the point of use, reduce demand on the electricity grid and have relatively short payback periods at current energy prices. Maintenance costs are also low. Maximum generation times will typically not coincide with peak demand however, so supplying all a building's heating needs directly would be highly unlikely; this would preferentially require the addition of e.g. battery storage at relatively high cost. Using solar energy to heat water for later use is an alternative form of energy storage and may be appropriate for some properties. This would significantly increase the cost, which has been found to be recoverable only in very specific circumstance where Smart time-of-use tariffs are employed in conjunction with specific demand patterns [13], and as such this is not recommended generally here. Therefore, solar panels do not represent a ZDEH solution by themselves. As a general cross-archetype principle, however, solar panels are a good fit for any property with available roof space facing anywhere between South-west and South-east. This can in principle include the roof space of flats if space is available, which may face whole-building consent issues (see section 5.6.1).

5.3.11 Other measures

There are a range of other measures which are in principle applicable across all archetypes, including draught proofing of windows and doors, and insulation for pipework and hot water tanks. While these straightforward measures are likely to be cost effective across all archetypes, they will not be discussed in detail here. Further measures such as insulated doors may or may be worthwhile but should also be considered.

5.3.12 Energy efficiency measures - general

For all of the above measures it is important to consider the cumulative effect on the ventilation of the property, which must remain adequate to minimise the risk of damp and condensation. The interaction between the various measures and numerous subtle differences between construction types and materials, plus out-of-scope considerations including damp courses, ventilation bricks, and the state of a property's repair mean that this issue cannot be discussed in detail here. The topic of ventilation should be an area of focus on the ongoing work which will feed into pattern book development in future. Construction materials and wall design have an impact on this critical consideration, some noteworthy examples being the necessity for traditional buildings to "breathe" and allow water vapour to be moved to the outside, for timber-frame buildings to be designed in such

a way that moisture build-up which risks rot build-up are avoided and for cavity-wall buildings to be constructed such that interstitial condensation is not permitted to build up in cavities and potentially affect wall ties. None of the measures proposed in this report are ruled out in principle as a result of these considerations, but professional advice is recommended, and specific cases will need to be considered in future pattern book development.

Typically the first step in a retrofit project will be to assess the current state of repair of a property and to make good any defects, including to current measures applied. At this stage an assessment of the type of insulation measures in place will take place and it may be that e.g. improved materials are available which would be a worthwhile upgrade.

5.4 Mapping archetypes to suitable measures

The 24 archetypes can now each be assigned measures suitable for the enablement of achieving net zero. There is a good deal of commonality between certain archetypes in terms of recommended measures, but each one has its own combination of measures and associated commentary in terms of priority and archetype-specific considerations. Where possible we have aimed to ensure that sufficient measures are in place so that at a minimum the option of installing a heat pump is viable, given that this is expected to be the largest single ZDEH solution in future years.

5.4.1 Archetype 1

Property Type Flat
Wall Construction Cavity Construction
Floor Construction Unheated space/Other premise below

Property feature	Recommended measures
Walls	Cavity wall insulation External wall insulation
Floor	Underfloor insulation in the case of an unheated space below
Loft	Minimum 250mm insulation where a loft is present

Comments: Doing both CWI and EWI will not be necessary if the effect of one measure (and underfloor insulation if fitted) is sufficient to enable the successful installation of a heat pump. The choice of CWI or EWI will be dependent on the individual property taking into account cost, internal space, and heat demand.

5.4.2 Archetype 2

Property Type House
Wall Construction Cavity Construction
Floor Construction Suspended

Property feature	Recommended measures
Walls	Cavity wall insulation External wall insulation
Floor	Underfloor insulation
Loft	Minimum 250mm insulation

Comments: Doing both CWI and EWI will not be necessary if the effect of one measure and underfloor insulation is sufficient to enable the successful installation of a heat pump. The choice of CWI or EWI will be dependent on the individual property taking into account cost, internal space and heat demand.

5.4.3 Archetype 3

Property Type Flat
Wall Construction Cavity Construction
Floor Construction Suspended

Property feature	Recommended measures
Walls	Cavity wall insulation External wall insulation
Floor	Underfloor insulation
Loft	Minimum 250mm insulation where a loft is present

Comments: Doing both CWI and EWI will not be necessary if the effect of one measure and underfloor insulation is sufficient to enable the successful installation of a heat pump. The choice of CWI or EWI will be dependent on the individual property taking into account cost, internal space and heat demand.

5.4.4 Archetype 4

Property Type Flat
Wall Construction Solid brick or stone
Floor Construction Unheated space/Other premise below

Property feature	Recommended measures
Walls	External wall insulation or Internal wall insulation
Floor	Underfloor insulation in the case of an unheated space below
Loft	Minimum 250mm insulation where a loft is present

Comments: Either IWI or EWI will be necessary. Solid floor insulation will only be necessary if the effect of the wall insulation is insufficient to enable the successful installation of a heat pump. The choice of IWI or EWI will be dependent on the individual property taking into account cost, internal space and heat demand as well as the potential effects of mixed tenure.

5.4.5 Archetype 5

Property Type Flat
Wall Construction System Built
Floor Construction Unheated space/Other premise below

Property feature	Recommended measures
Walls	External wall insulation or internal wall insulation
Floor	Underfloor insulation in the case of an unheated space below
Loft	Minimum 250mm insulation where a loft is present

Comments: System built homes are either not built with a cavity, or there are reports of significant issues with suitability of cavity wall insulation if one exists [14]. EWI or IWI is therefore recommended, however if cavity wall insulation has been installed then IWI should not be considered.

5.4.6 Archetype 6

Property Type Flat
Wall Construction Timber Frame
Floor Construction Unheated space/Other premise below

Property feature	Recommended measures
Walls	External wall insulation or Internal wall insulation
Floor	Underfloor insulation in the case of an unheated space below
Loft	Minimum 250mm insulation where a loft is present

Comments: Either IWI or EWI will be necessary. The choice of IWI or EWI will be dependent on the individual property taking into account cost, internal space and heat demand as well as the potential effects of mixed tenure.

5.4.7 Archetype 7

Property Type House
Wall Construction Timber Frame
Floor Construction Suspended

Property feature	Recommended measures
Walls	External wall insulation or internal wall insulation
Floor	Underfloor insulation
Loft	Minimum 250mm insulation

Comments: Either IWI or EWI will be necessary. The choice of IWI or EWI will be dependent on the individual property taking into account cost, internal space and heat demand.

5.4.8 Archetype 8

Property Type Flat
Wall Construction Timber Frame
Floor Construction Solid

Property feature	Recommended measures
Walls	External wall insulation or internal wall insulation
Floor	Solid floor insulation
Loft	Minimum 250mm insulation where a loft is present

Comments: Either IWI or EWI will be necessary. Solid floor insulation will only be necessary if the effect of the wall insulation is insufficient to enable the successful installation of a heat pump. The choice of IWI or EWI will be dependent on the individual property taking into account cost, internal space and heat demand as well as the potential effects of mixed tenure.

5.4.9 Archetype 9

Property Type House
Wall Construction Cavity Construction
Floor Construction Solid

Property feature	Recommended measures
Walls	Cavity wall insulation External wall insulation
Floor	Underfloor insulation
Loft	Minimum 250mm insulation

Comments: Cavity wall insulation is likely to be preferred unless there are specific reasons which make this a hard-to-treat property which can raise costs significantly. Solid floor insulation will only be necessary if the effect of the wall insulation is insufficient to enable the successful installation of a heat pump.

5.4.10 Archetype 10

Property Type Flat
Wall Construction Solid brick or Stone
Floor Construction Suspended

Property feature	Recommended measures
Walls	External wall insulation or internal wall insulation
Floor	Underfloor insulation
Loft	Minimum 250mm insulation where a loft is present

Comments: Either IWI or EWI will be necessary. The choice of IWI or EWI will be dependent on the individual property taking into account cost, internal space and heat demand as well as the potential effects of mixed tenure.

5.4.11 Archetype 11

Property Type House
Wall Construction Timber Frame
Floor Construction Solid

Property feature	Recommended measures
Walls	External wall insulation or internal wall insulation
Floor	Underfloor insulation
Loft	Minimum 250mm insulation

Comments: Either IWI or EWI will be necessary. Solid floor insulation will only be necessary if the effect of the wall insulation is insufficient to enable the successful installation of a heat pump. The choice of IWI or EWI will be dependent on the individual property taking into account cost, internal space and heat demand.

5.4.12 Archetype 12

Property Type House
Wall Construction Solid brick or Stone
Floor Construction Suspended

Property feature	Recommended measures
Walls	External wall insulation or internal wall insulation
Floor	Underfloor insulation
Loft	Minimum 250mm insulation

Comments: Either IWI or EWI will be necessary. Solid floor insulation will only be necessary if the effect of the wall insulation is insufficient to enable the successful installation of a heat pump. The choice of IWI or EWI will be dependent on the individual property taking into account cost and heat demand.

5.4.13 Archetype 13

Property Type House
Wall Construction System Built
Floor Construction Suspended

Property feature	Recommended measures
Walls	External wall insulation or internal wall insulation
Floor	Underfloor insulation
Loft	Minimum 250mm insulation

Comments: System built homes are either not built with a cavity, or there are reports of significant issues with suitability of cavity wall insulation if one exists. EWI or IWI is therefore recommended, however if cavity wall insulation has been installed then IWI should not be considered.

5.4.14 Archetype 14

Property Type Flat
Wall Construction Cavity Construction
Floor Construction Solid

Property feature	Recommended measures
Walls	Cavity wall insulation or External wall insulation or Internal wall insulation
Floor	Underfloor insulation
Loft	N/a – presence of a solid floor implies a ground floor flat, so no loft is likely to be present

Comments: Cavity wall insulation is likely to be preferred unless there are specific reasons which make this a hard-to-treat property which can raise costs significantly. The choice of IWI or EWI will be dependent on the individual property taking into account cost, internal space and heat demand or the potential effects of mixed tenure.

5.4.15 Archetype 15

Property Type House
Wall Construction System Built
Floor Construction Solid

Property feature	Recommended measures
Walls	External wall insulation or internal wall insulation
Floor	Underfloor insulation
Loft	Minimum 250mm insulation

Comments: System built homes are either not built with a cavity, or there are reports of significant issues with suitability of cavity wall insulation if one exists. EWI or IWI is therefore recommended, however if cavity wall insulation has been installed then IWI should not be considered. Solid floor insulation will only be necessary if the effect of the wall insulation is insufficient to enable the successful installation of a heat pump.

5.4.16 Archetype 16

Property Type Flat
Wall Construction Timber Frame
Floor Construction Suspended

Property feature	Recommended measures
Walls	External wall insulation or internal wall insulation
Floor	Underfloor insulation
Loft	Minimum 250mm insulation where a loft is present

Comments: Either IWI or EWI will be necessary. The choice of IWI or EWI will be dependent on the individual property taking into account cost, internal space and heat demand or the potential effects of mixed tenure.

5.4.17 Archetype 17

Property Type Flat
Wall Construction System Built
Floor Construction Suspended

Property feature	Recommended measures
Walls	External wall insulation or internal wall insulation
Floor	Underfloor insulation
Loft	Minimum 250mm insulation where a loft is present

Comments: System built homes are either not built with a cavity, or there are reports of significant issues with suitability of cavity wall insulation if one exists. EWI or IWI is therefore recommended, however if cavity wall insulation has been installed then IWI should not be considered.

5.4.18 Archetype 18

Property Type House
Wall Construction Solid brick or Stone
Floor Construction Solid

Property feature	Recommended measure
Walls	External wall insulation or internal wall insulation
Floor	Underfloor insulation
Loft	Minimum 250mm insulation

Comments: Either IWI or EWI will be necessary. Solid floor insulation will only be necessary if the effect of the wall insulation is insufficient to enable the successful installation of a heat pump. The choice of IWI or EWI will be dependent on the individual property taking into account cost, internal space and heat demand.

5.4.19 Archetype 19

Property Type Flat
Wall Construction System Built
Floor Construction Solid

Property feature	Recommended measures
Walls	External wall insulation or internal wall insulation
Floor	Underfloor insulation
Loft	N/a – presence of a solid floor implies a ground floor flat, so no loft is likely to be present

Comments: System built homes are either not built with a cavity, or there are reports of significant issues with suitability of cavity wall insulation if one exists. EWI or IWI is therefore recommended, however if cavity wall insulation has been installed then IWI should not be considered. Solid floor insulation will only be necessary if the effect of the wall insulation is insufficient to enable the successful installation of a heat pump.

5.4.20 Archetype 20

Property Type Flat
Wall Construction Solid brick or Stone
Floor Construction Solid

Property feature	Recommended measures
Walls	Internal wall insulation or External wall insulation
Floor	Underfloor insulation
Loft	N/a – presence of a solid floor implies a ground floor flat, so no loft is likely to be present

Comments: Either IWI or EWI will be necessary. Solid floor insulation will only be necessary if the effect of the wall insulation is insufficient to enable the successful installation of a heat pump. The choice of IWI or EWI will be dependent on the individual property taking into account cost, internal space and heat demand as well as the potential effects of mixed tenure.

5.4.21 Archetype 21

Property Type House
Wall Construction Cavity Construction
Floor Construction Unheated space/Other premise below

Property feature	Recommended measures
Walls	Cavity wall insulation or External wall insulation
Floor	Underfloor insulation in the case of an unheated space below
Loft	Minimum 250mm insulation

Comments: Cavity wall insulation is likely to be preferred unless there are specific reasons which make this a hard-to-treat property which can raise costs significantly.

5.4.22 Archetype 22

Property Type House
Wall Construction Timber Frame
Floor Construction Unheated space/Other premise below

Property feature	Recommended measures
Walls	External wall insulation or internal wall insulation
Floor	Underfloor insulation in the case of an unheated space below
Loft	Minimum 250mm insulation

Comments: Either IWI or EWI will be necessary. The choice of IWI or EWI will be dependent on the individual property taking into account cost, internal space and heat demand.

5.4.23 Archetype 23

Property Type House
Wall Construction Solid brick or Stone
Floor Construction Unheated space/Other premise below

Property feature	Recommended measures
Walls	External wall insulation or internal wall insulation
Floor	Underfloor insulation in the case of an unheated space below
Loft	Minimum 250mm insulation

Comments: Either IWI or EWI will be necessary. The choice of IWI or EWI will be dependent on the individual property taking into account cost, internal space and heat demand.

5.4.24 Archetype 24

Property Type House
Wall Construction System Built
Floor Construction Unheated space/Other premise below

Property feature	Recommended measures
Walls	Cavity wall insulation External wall insulation
Floor	Underfloor insulation in the case of an unheated space below
Loft	Minimum 250mm insulation

Comments: System built homes are either not built with a cavity, or there are reports of significant issues with suitability of cavity wall insulation if one exists. EWI or IWI is therefore recommended, however if cavity wall insulation has been installed then IWI should not be considered.

5.5 ZDEH systems

The archetypes all require use of ZDEH systems if net zero emissions across the social housing stock is to be achieved. The following sections provide descriptions of net zero compatible systems which are suitable in certain circumstances across many of the archetypes discussed. They each have their limitations and specific suitability and cross-archetype variations that alter the suitability are discussed in section 5.6.

It is important to note that net zero compliance is not an immediate requirement in social housing, and the availability (and likely also the cost) of ZDEH systems will improve over time. For example, as heat pumps become more prevalent they will be subject to economies of scale, more engineers will become trained in their installation and the supply chain in general will be more streamlined and mature.

5.5.1 Air source heat pumps (ASHPs)

Space and potential cost constraints around shared-loop ground source heat pumps mean that individual dwelling air source heat pumps are likely to be the most numerous ZDEH system in future. Assessment of heat demand and loss is required in all cases before a final decision can be made on suitability. Potential factors which could affect a decision on their suitability are as follows:

- Heat demand and loss is too high for the HP to adequately heat the property. Energy efficiency measures can in most cases be put in place to avoid this and in principle, all archetypes can be suitable for ASHPs [15].
- There may not be enough outdoor space for the heat pump unit (1x3m is recommended) or internal hot water cylinder to be situated, although slimmer cylinders are now on the market. Planning regulations and noise constraints may also be factors.
- There is no existing wet heating system in the property and the costs of installing and maintaining one are deemed prohibitive (see section 5.6.4).
- An installed heating system may require upgrades in terms of radiator or pipework dimensions to optimise performance.

A range of heat pumps are available with different outputs, including high-temperature heat pumps which may be more appropriate in high heat demand dwellings. It is possible, depending on total heat demand, for multiple properties to be connected to a single heat pump but the decision to do this will depend on local factors.

5.5.2 Ground source heat pumps (GSHPs)

GSHPs are typically more efficient than ASHPs but may also be more expensive to install [16]. This market is evolving, and as for ASHPs government grants are available and innovative funding mechanisms are emerging. Space constraints for the groundworks can restrict their use significantly. GSHPs are capable of serving multiple properties such as a row of terraced houses or a moderately sized block of flats, as well as individual properties. As with all multiple connection solutions this relies on agreement between the occupants of all the homes concerned.

5.5.3 District heat networks

It is anticipated that heat networks will grow significantly in Scotland in the next few years, with a government target of increasing heat supplied to 2.6 TWh by 2027 and 6 TWh by 2030 [17]. A potential domestic connection to a heat network would offer a ZDEH solution. This will typically be in urban areas, where a sufficient local heat density (heat demand per m^2) is more likely due to a higher density of dwellings.

Smaller scale communal heat networks, analogous to district heating but where a single energy centre supplies heat to multiple dwelling in one building are also viable options, potentially solving some space issues discussed above which may be encountered with individual heat pumps.

5.5.4 Direct electric heating

An alternative electric solution can also be net zero compatible. It will use significantly more electricity than a heat pump but may be appropriate if the cost and disruption of installing upgrades necessary to enable heat pump fitment, including potentially a new wet heating system, are deemed too high. Supplying a given heat demand with direct electric heating is more expensive than doing so with gas heating, so a given energy efficiency measure is more likely to be cost-effective. A retrofit where all possible measures are installed, including e.g. potentially disruptive solid floor insulation, is more likely to be worthwhile.

5.5.5 Biofuel solutions

Zero carbon biofuels such as bio-LPG or biomethane, whilst theoretically an option, are limited by availability and are likely to be relatively high cost. The Scottish Government strategy sees only a very limited role for biofuels [18]. They may in a small number of cases be an alternative of last resort to direct electric heating, however, if replacing a conventional gas boiler in a house which is ultimately deemed unsuitable for a heat pump.

5.5.6 Hybrid heat pumps

Hybrid heat pumps use a combination of electricity and a zero emissions fuel for periods of peak demand. A ZDEH compatible fuel would have to be a biofuel as per section 5.5.5 or low carbon hydrogen. Hydrogen has been excluded from this report due to its current unavailability and significant uncertainty as to its future availability or cost, including the Scottish Government's view about its lack of a central role in domestic heat [19]. The role of hybrid heat pumps in general is also under review and not being prioritised at this time [18].

5.6 Cross-archetype variants

The measures outlined above will apply to the majority of dwellings within each archetype. However, there are exceptions where an alternative may be required for one or more measure. These will apply across archetypes and are presented here separately.

5.6.1 Mixed tenure properties

Gaining the agreement of all affected occupants of a mixed tenure building to implement a measure which impacts the whole building is more challenging than when they share the same social landlord. If this agreement is not reached then alternative measures, targeting individual homes, may need to be considered. These are outlined in Table 7.

Measure or ZDEH system	Reason for potential restriction	Alternative
External wall insulation	Impractical other than as a whole-building measure	Internal wall insulation
Communal air source or shared loop ground source heat pump	Insufficient connected users may make them inefficient and/or costly	Individual heat pumps
Cavity wall insulation	Impractical other than as a whole-building measure	Internal wall insulation
Air source heat pump	Individual ASHPs may require siting in communal areas	Direct electric heating with all suitable energy efficiency measures

Table 7 Potentially restricted measures in mixed tenure properties and alternatives

5.6.2 Dwellings with a room in the roof

The presence of a room in the roof will rule out traditional loft insulation which is sited on the floor of the loft. Insulation in such a dwelling can be placed between the rafters or on floor or walls as discussed elsewhere. If a minimum level of insulation sufficient to enable successful heat pump fitment is desired, then the former is likely to be lower cost.

5.6.3 Dwellings in a conservation area or listed with Historic Environment Scotland

Retrofitting a listed building is possible but it is beyond the scope of this report to provide definitive guidance. Measures which preserve the character of the building or which are "like-for-like" should be permissible [20]. All measures will require written consent, and those which are least likely to receive permission are external and internal wall insulation as well as the installation of most standard double glazing, although some designs are permitted. Loft insulation is highly likely to be acceptable. Permission will be required for the installation of a heat pump although this is not objected to in principle. In the event this is not granted, use of direct electric heating may be the only alternative to achieve net zero direct emissions.

5.6.4 Dwellings with no wet heating system

Wet heating systems are pre-requisites for air-to-water heat pumps. Installing a new wet system is relatively expensive and disruptive and landlords may not choose to take this route. Maintenance costs can also be higher compared to direct electric heaters[3]. In this case direct electric heating is the most likely net zero compatible alternative. However, it is then highly advisable to maximise the installation of suitable energy efficiency measures in order to reduce the building heat demand as far as possible, since the efficiency of direct electric heating is much lower than an electric heat pump, leading to much higher costs to satisfy the same heat demand. All suitable measures for energy efficiency should ideally be enacted.

If a wet heating system is newly installed, then it can be designed such that heat pumps are immediately compatible and performance optimised. Heat pumps may therefore be a viable option for these dwellings, but the cost-benefit analysis will be different for these cases.

Air-to-air heat pumps may be an option for smaller homes but water heating would need to be considered separately to space heating. Usually this would be by an electric immersion

[3] Feedback from Paul Leask of Hjaltland Construction

heater, meaning that water would be heated with direct electric heating with its associated lower efficiency [21].

5.6.5 Narrow cavity walls

Cavity walls need to be at least 50mm wide to be effectively filled and deliver optimum insulation. Approximately 2.5% of the stock are believed to have a narrow cavity according to the HAS dataset used. For these cases cavity wall insulation should generally be avoided, and other wall insulation measures should be prioritised.

5.6.6 Off gas grid dwellings

Properties not currently connected to the gas grid are likely to either have direct electric heating and no wet heating system or may use oil/LPG. In the former case these properties are subject to the same considerations as those with no wet heating system; the latter may find it relatively straightforward to transition to biofuels or would in principle be suitable for a heat pump in the same way those on the gas grid would.

5.6.7 Heat demand density

In the event of potential connection to a heat network the heat demand density must be sufficient – see section 5.5.3.

5.6.8 Size of property

This can affect the suitability of both internal wall insulation, where individual rooms may be small enough for the typical 80-100mm loss of internal dimensions to be prohibitive, and heat pump use, where a sufficient footprint for the unit (typically up to 1x3m) and for a hot water cylinder if one was not previously present are required.

5.6.9 Connection to the electricity network

An individual dwelling may encounter difficulties connecting to the electricity network if the local capacity is tight. Collectively, a large shift from fossil fuels to electrification implies a significant upgrade in output and connection capacity is required. Both of these constraints are being addressed in the long term with national plans for DNOs and government to facilitate major upgrades to enable net zero and the associated extra demand. Therefore, there may be constraints on electrification in the short term, however this is a question of timing and not one of inherent suitability for the measures proposed.

5.6.10 Exposure to wind and rain

Some dwellings have higher heat loss due to geographical factors such as wind and rain exposure. This is a cross-archetype effect and there will be a general requirement for extra energy efficiency to achieve a given heat loss. Extra care should be taken with cavity wall insulation, with some specific restrictions applying in severe or very severe exposure areas [22]. In these cases, a focus on alternative measures may be necessary but professional advice should be sought.

6 Conclusions and recommendations

6.1 Conclusions

Around 600,000 dwellings in the Scottish social housing sector have been divided into 24 archetypes based on their physical construction. The parameters identified are property type, wall construction and floor construction. The 24 unique combinations of these parameters form the 24 archetypes that fully describe the Scottish social housing stock.

These archetypes have each been associated with a suite of suitable measures to improve energy efficiency and reduce heat demand, which will have immediate impact on fuel bills and carbon emissions. In some cases, measures may already be present, but the suite of measures represent a suitable end state for the stock within each archetype that is compatible with net zero. The installation of these measures will enable future fitment of a Zero direct emissions heating system.

Relevant variants, constraints and exceptions may apply to all archetypes and alternatives are described where these impact on the suitable measures.

The archetyping strategy proposed results in a useful starting point for determining measures, but as with other studies some simplifications and assumptions have been made. Care is required with system-built homes in particular, where the specific details of the build type, especially wall construction, will need to be identified to be certain of appropriate measures.

We have identified ZDEH system options compatible with the final suite of proposed measures. The preferred ZDEH system is a heat pump, most commonly an individual air source heat pump, but there are a number of alternative solutions.

6.2 Recommendations

The measures described in this report should be seen as a stepping-off point for social landlords, describing potential and suitable measures that can be applied to fit properties for net zero.

Further work to explore archetypes in more detail will be necessary to complete a pattern book. Other projects, which are still ongoing, will also have useful contributions to this aim. Additionally, there will always be work necessary to determine dwelling-specific measures for each retrofit project.

The necessary simplifications made here in terms of wall and floor type, and in the generic descriptions of internal and external wall insulation mean that expert advice will always be required. The specific type and quantity of appropriate insulation material will vary from dwelling to dwelling.

Feedback and further experience from retrofit projects may lead to the archetypes being refined and the outcome of ongoing activities recommended as part of other studies is expected to further inform necessary guidance for social landlords. This includes the proposed Housing Net Zero Technical Steering group discussed in the ZEST report [23] (see Appendix D) which will bring further insights to the issue of wall construction in particular.

Achieving net zero by 2045 requires concerted action for more than 20 years. The Scottish Government's Heat in Buildings Strategy underlines that this is a realistic goal but recognises that improving energy efficiency in the short to medium term is key to achieving net zero.

It is not currently possible to install ZDEH systems in all dwellings. Many require their heat demand to be lowered as a first step, and improved energy efficiency is a desirable and achievable goal for essentially all dwellings. The scale of the challenge is large and will require an ongoing programme of action. This report, taken with the learnings from a range of other focused studies mentioned, offers a vision of how the goal can be achieved.

The archetyping approach we have described can aid the prioritisation of properties for energy efficiency retrofit and ZDEH system installation and gives a focus on the appropriate types of measures that can enable this critical target to be hit.

7 References

[1] Scottish Government, “Scottish household survey 2019: key findings,” 2020. [Online]. Available: https://www.gov.scot/publications/scottish-household-survey-2019-key-findings/.

[2] Scottish Government, “Scottish Greenhouse Gas Statistics 2020,” 2022. [Online]. Available: https://www.gov.scot/publications/scottish-greenhouse-gas-statistics-2020/.

[3] Scottish Government, “The Energy Efficiency Standard for Social Housing (EESSH): Scottish Government Guidance for Social Landlords,” 2020. [Online]. Available: https://www.gov.scot/publications/energy-efficiency-standard-social-housing-eessh-scottish-government-guidance-social-landlords-revised-2020/documents/.

[4] S. Smith, “Developing Net Zero Technical Solutions for Scotland’s Future Mass Retrofit Housing Programme,” 2021. [Online]. Available: https://www.gov.scot/binaries/content/documents/govscot/publications/strategy-plan/2021/07/developing-net-zero-technical-solutions-for-scotlands-future-mass-retrofit-housing-programme/documents/zest-proposal-paper/zest-proposal-paper/govscot%3Adocument/St.

[5] Scottish Government, “Policies: Home energy and fuel poverty - Energy efficiency in social housing,” [Online]. Available: https://www.gov.scot/policies/home-energy-and-fuel-poverty/.

[6] Energy Saving Trust, “Home Analytics,” [Online]. Available: https://energysavingtrust.org.uk/service/home-analytics/.

[7] Scottish Government, “Housing statistics quarterly update: new housebuilding and affordable housing supply,” 2022. [Online]. Available: https://www.gov.scot/publications/housing-statistics-for-scotland-new-house-building/.

[8] Energy Saving Trust, “In-depth guide to heat pumps,” [Online]. Available: https://energysavingtrust.org.uk/advice/in-depth-guide-to-heat-pumps/.

[9] TheGreenAge, “How much loft insulation do you need,” 2014. [Online]. Available: https://www.thegreenage.co.uk/how-much-loft-insulation-should-you-install/#:~:text=With%20loft%20insulation%2C%20there%20is,worthwhile%20to%20add%20any%20more..

[10] Changeworks, “Guide to insulating Hard-to-Treat Cavities,” Changeworks, Edinburgh, 2014.

[11] Back To Earth, “A Guide to Internal Wall Insulation,” [Online]. Available: https://www.backtoearth.co.uk/a-guide-to-internal-wall-insulation/.

[12] Energy Saving Trust, “Reducin home heat loss: Windows and doors,” [Online]. Available: https://energysavingtrust.org.uk/advice/windows-and-doors/.

[13] Element Energy, “Home Response: Domestic Demand Side Response Insights Report,” Greater London Authority, London, 2022.

[14] First Choice Energy Ltd, “Cavity Wall Insulation Removal,” [Online]. Available: https://firstchoiceenergy.co.uk/cavity-wall-insulation-removal/.

[15] Energy Saving Trust, “From flats to terraced houses: heat pumps are suitable for all property types,” 2022. [Online]. Available: https://energysavingtrust.org.uk/from-flats-to-terraced-houses-heat-pumps-are-suitable-for-all-property-types/#:~:text=Could%20you%20install%20a%20heat%20pump%20in%20your%20home%3F&text=Many%20people%20think%20that%20you,fact%20suitable%20for%20heat%20pum.

[16] Green Match, “Total Cost of Heat Pumps in the UK,” 2023. [Online]. Available: https://www.greenmatch.co.uk/blog/2014/08/the-running-costs-of-heat-pumps.

[17] Scottish Government, “Heat networks delivery plan,” 31 March 2022. [Online]. Available: https://www.gov.scot/publications/heat-networks-delivery-plan/documents/.

[18] Scottish Government, “Heat in Buildings Strategy - achieving net zero emissions in Scotland's buildings. Chaper 2 A 2045 Pathway for Scotland's Homes and Buildings,” 7 October 2021. [Online]. Available: https://www.gov.scot/publications/heat-buildings-strategy-achieving-net-zero-emissions-scotlands-buildings/pages/3/.

[19] Scottish Government, “Draft Energy Strategy and Just Transition Plan. Chaper 4: Energy demand,” 10 January 2023. [Online]. Available: https://www.gov.scot/publications/draft-energy-strategy-transition-plan/pages/6/.

[20] Historic Environment Scotland, “Advisory standards of conservation and repair for the historic building environment in Scotland,” [Online]. Available: https://www.historicenvironment.scot/media/5283/advisory-standards-conservation-repair.pdf.

[21] Energy Saving Trust, “Air-to-air heat pumps,” [Online]. Available: https://energysavingtrust.org.uk/advice/air-to-air-heat-pumps/.

[22] NHBC, “NHBC Standards 2023: External masonry walls: Exposure,” [Online]. Available: https://nhbc-standards.co.uk/6-superstructure-excluding-roofs/6-1-external-masonry-walls/6-1-6-exposure/.

[23] Zero Emissions Social Housing Taskforce (ZEST), “Achieving net zero in social housing: The Zero Emissions Social Housing Taskforce Report,” Scottish Government, Edinburgh, 2021.

[24] Scottish Government, “Low carbon heating in domestic buildings - technical feasibility: report,” 2020. [Online]. Available: https://www.gov.scot/publications/technical-feasibility-low-carbon-heating-

domestic-buildings-report-scottish-governments-directorate-energy-climate-change/.

[25] D. J. P. a. N. Terry, “Faster Deploymen tof Heat Pumps in Scotland: Settling the figures,” 2023. [Online]. Available: https://www.wwf.org.uk/sites/default/files/2023-02/CAR-Report-Faster-deployment-of-heat-pumps.pdf.

[26] Passivhaus Trust, “A retrofit template for hard-to-treat tenement homes,” 10 October 2021. [Online]. Available: https://passivhaustrust.org.uk/news/detail/?nId=1020.

[27] Passipedia: The Passive House Resource, “EnerPHit - the Passive House Certificate for retrofits,” 2022. [Online]. Available: https://passipedia.org/certification/enerphit.

[28] Historic Environment Scotland, “Refurbishment Case Study 11,” 1 April 2013. [Online]. Available: https://www.historicenvironment.scot/archives-and-research/publications/publication/?publicationId=db047b98-e3b3-4af2-96f1-a59300f48ac8.

[29] Element Energy, “Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget,” Climate Change Committee, 2021.

8 Appendices

8.1 Previous archetyping studies

Several studies have looked at Scottish housing using their own archetyping methodologies. A common theme across all studies has been to further the aims of decarbonisation of Scottish homes, but each study had slightly different remits. An overview of these studies is discussed below:

8.1.1 Zero Emissions Social Housing Taskforce (ZEST, 2021) [23]

A proposal paper published as part of the work of the ZEST group aimed to prepare Scottish social housing for zero emissions by taking a fabric-first approach and also identified areas for immediate action to reduce energy use. Its premise was that the stock comprises a limited number of building types, allowing a small number of archetypes based on physical construction to be defined. Six portfolio archetypes were defined, and are listed below:

- Pre-1919 and Georgian tenements
- High-rise
- No fines construction (with concrete shell)
- 4-in-a-block
- Masonry Cavity Wall
- Timber frame

Working groups for each portfolio archetype were proposed, recognising that full solutions within each portfolio will vary slightly. A fabric-first approach to reduce heat demand was advocated, using data on U-values, workmanship and materials. Being based on physical construction, current energy efficiency was not a differentiating factor in the archetyping. Rather the goal was to enable definition of common end states for each archetype.

The 6 archetypes cover ~80% of the stock and the study aims at rapid action in response to the Scottish Government 2045 net zero target by defining a low number of different pathways to decarbonisation. Six is too few for there to only be six different paths to net zero however, so this approach needs to be expanded in the current work. How to handle the 20% “tail” of the stock is not discussed in detail, forming part of the remit of the working groups. The working groups are a recognition that the details of suitable measures cannot be fully captured by a small number of archetypes and that measures may differ slightly within archetypes.

8.1.2 Element Energy Social Housing study for East Dunbartonshire Council (2021)[4]

Again, this study identified a small number of archetypes to cover the majority of stock, aiming to identify decarbonisation measures to raise the EPC rating by 1 or 2 bands. The focus was not chiefly on fitness for net zero, but on improving energy efficiency. The factors used are shown in Table 8.

[4] Confidential report, unpublished (2021)

Age	Property type	Wall Construction	Other
Pre-1991 Post 1991	Semi-detached Terrace Flat 4-in-a-block	Cavity Solid wall Timber	Electrically heated

Table 8 East Dunbartonshire Council archetyping – factors considered

The report quantified the effect of specific measures e.g., wall insulation or solar panel fitment across archetypes. The deployment of a measure in a given archetype then represents a common end state irrespective of whether it had already been adopted. An advantage of this approach was that a low number of archetypes was achieved by grouping dwellings of varying current energy efficiency, e.g., grouping all post-1991 terraced houses irrespective of levels of installed insulation. Dwellings within each archetype may all have a certain measure recommended even if it were already present.

A key observation was that a mixture of social and private housing tenure within a larger building can lead to reduced options for communal measures such as heat pumps serving more than one dwelling, since agreement of all affected private landlords or owner-occupiers would be required. This may also affect whole-building measures e.g., cavity wall insulation.

8.1.3 Energy Efficiency in Social Housing (EESSH) [5]

The EESSH study focused on assessing energy efficiency (as defined by EPC rating) and measures to improve these to at least Band D by 2025 and Band B by 2032 with only limited exceptions. As such the archetyping approach was more granular, but still based on a property's physical characteristics. Property type, age, and construction were broken down into more categories, and the EPC rating was included as well, leading to ~350 archetypes. The criteria used are outlined in Table 9.

Age	Property type	Wall Construction	Others
Pre-1919 1919-64 1964-75 1976-83 1983-91 Post 1991	Semi-detached/end terrace Mid terrace Detached house Flat derived from a house Tenement 4-in-a-block Tower/slab	Cavity (Brick) Cavity (other) Sandstone Granite Solid brick Timber System built	EPC rating Fuel type Urban/rural location

Table 9 Factors considered for EESSH archetypes

This methodology led to the separation of physically similar dwellings with different energy efficiency and EPC ratings, unlike the studies above which did not include current insulation levels within archetype definitions. It was found that the age of the property was a useful proxy for energy efficiency as a result of new building regulations applicable to stock built after certain dates. The current state of the properties' energy efficiency and heat demand, and measures to improve EPC ratings, were of more importance than the potential end states of a net-zero compatible home. This is a key difference to the current study, but identifying property type and construction as key parameters for suitable energy efficiency

measures is valuable. Wall construction was identified as particularly important in determining suitable measures.

The report and associated guidance [3] produced by the Scottish Government lists reasonable measures not associated with any particular archetype. The starting point for the guidance is not an individual archetype, but the physical construction of the building. It follows that an approach of discussing potentially suitable measures for all dwellings with, e.g. solid walls, makes sense.

8.1.4 Low-carbon Heating Technical Feasibility Study – Element Energy (2020) [24]

This report for the Scottish Government compiled by Element Energy was aimed at fully describing the housing stock to define appropriate measures to enable low carbon heating technologies. The archetyping produced a highly granular description by including a wide range of factors including the degree of insulation present and the presence or absence of measures such as wall insulation rather than an assessment of if the property is capable of having these installed. Location-related factors which affected suitability for e.g., solar panels or district heating were also included, and ~55,000 archetypes were identified. A full list of the factors considered in presented in Table 10.

Age	Property type	Wall construction	Others
Pre-1919 1919-91 Post-1991	Detached Semi-detached Terrace Flat (block) Flat (other)	Solid (insulated) Solid (uninsulated) Cavity (insulated) Cavity (uninsulated, low exposure) Cavity (uninsulated, high exposure)	Degree of loft insulation Fuel type Urban/Rural location Coastal location (y/n) SW/S/SE roof for solar (y/n) Gas grid (y/n) District Heating potential (y/n)

Table 10 Factors considered for the 2020 Scottish low-carbon heating feasibility study

As can be seen from Table 10 some simplifying assumptions were made about property type and age. A large number of archetypes nevertheless arose from the high granularity in the definition of *existing* energy efficiency measures in order to define the current status as fully as possible. This study went on to consider 26 possible low-carbon heating packages and which of them could be suitable for each of the archetypes. The full information within each archetype was intended to enable accurate specification of required measures for all the archetypes, distinguishing for example between insulated and uninsulated lofts.

The conclusion that suitable measures and ZDEH systems will apply to multiple archetypes emerges again in this study. A dwelling is defined first by its physical characteristics and these determine the suitability of measures. Many different combinations of characteristics can lead to the same suite of measures and an individual measure will typically be associated with one physical characteristic e.g. solid walls and external insulation.

8.1.5 WWF – Faster Deployment of Heat Pumps in Scotland [25]

This report is another example of one which seeks to describe the housing stock with a small number of archetypes focused on physical parameters, deriving 12 in all which cover ~93% of all stock (including non-social housing). This study had slightly different aims but is useful for this work in its conclusion that heat pumps, the key ZDEH system referred to in this

report, are viable solutions across all archetypes. A further conclusion was that the same energy efficiency measures, including cavity wall or solid wall insulation, loft insulation and draught proofing, are both energy and cost-effective across archetypes.

In common with this work, some cross-archetype restrictions were noted which required alternatives to be considered such as the dwelling being in a conservation area, or space being restricted for an air to water heat pump, in which case an air-to-air version may be a viable alternative option.

8.2 Stakeholder engagement and case studies

Stakeholders were chosen for their experience of efforts to lower both the energy consumption of housing stock and the emissions associated with heating, as well as for their experience working in the social housing sector in Scotland. We spoke with representatives of the following bodies:

- East Dunbartonshire District Council (Derek Lyon, Programme Manager)
- Hjaltland Housing Association, Shetland (Paul Leask, Head of Asset Management)
- River Clyde Homes, Glasgow (Duncan Smith, Sustainability Manager)
- (Via email) Ken Gibb, Professor in Housing Economics, Glasgow University

The engagement the first three cases consisted of a 1-1.5 hour conversation on the topic of social housing retrofit experience with a focus on notable successes and commonly encountered barriers or issues. The topic of archetyping was also discussed in the context of how the stakeholders themselves decided on which dwelling or dwelling type to prioritise and how they were grouped together for that purpose. Current experience in all cases was chiefly on energy efficiency rather than achieving net zero as such, given the timeframes involved. We also found three examples of retrofit projects which exemplify the principles under discussion, one of which was the subject of the email discussions with Professor Gibb. The number of retrofit projects which currently explicitly deliver net zero capable homes is very few however, but these case studies do show how relevant measures have been successfully implemented in the field.

The intention of the case studies was to illustrate how the archetyping work described aligns with real world examples, showing that the relevant measures identified can be carried out, and to illustrate how the approach of considering variants to the main measures applies.

8.2.1 Hjaltland Housing Association, Virkie, Shetland Isles

This case study is of a property which has the variation of not having a wet heating system. A heat pump was decided against since the cost of installation and maintenance was deemed too high, and the existing direct electric heating system was retained. The retrofit of this property delivered over 30% heat demand reduction compared with the starting point where full loft insulation and some, albeit low, levels of other insulation were present. This suggests that savings compared with a worst-case scenario property with no measures in place would be higher still. The details of the case study are summarised in Table 11.

Archetype	Existing measures	Retrofit measures	ZDEH system
House Timber Frame Suspended Floor **(Archetype #7)**	300mm Loft insulation Low level of IWI Low level of floor insulation	Improved IWI Improved Floor insulation Solar PV	Direct electric

Table 11 Hjaltland Housing Association retrofit example

8.2.2 Southside Housing Association, Niddrie Road, Glasgow [26]

The Southside Housing Association project is a flagship example of retrofitting to a higher standard than is currently required, aiming in this case at the EnerPHit [27] standards. As a result of this the retrofit included the addition of triple glazing and the use of both EWI and IWI, and the total cost was high, certainly higher than necessary to enable net zero compatibility. 8 flats were renovated, and additional measures included Mechanical Ventilation and Heat Recovery (MVHR). The project is ongoing and the ZDEH system was installed in only 4 flats to allow a comparison with state-of-the-art gas boilers which were newly installed in the other 4, data for which is still being collected. The details of this project are summarised in Table 12.

Archetype	Existing measures	Retrofit measures	ZDEH system
Flat Solid Walls Suspended floor and Solid floor (ground floor flat) **(Archetypes #10 and #20)**	Believed to be none	Loft insulation IWI EWI (rear and gable end) Triple glazing Suspended floor insulation (upper flats - Archetype #10 Solid floor insulation - ground floor flats - Archetype #20	ASHP

Table 12 Details of the Southside Housing Association retrofit

8.2.3 Castle Rock Edinvar Housing Association, Newtongrange [28]

This project is a retrofit example which was aimed at reducing the energy consumption of the property but as yet has not resulted in a full transition to including a ZDEH system. Naturally given this is not yet a requirement, the majority of dwellings in Scotland are at this stage. Nevertheless, this exemplifies the energy efficiency measures necessary for ZDEH fitment, and a >70% reduction in U-value achieved in this retrofit almost certainly means that this property is ready for this in future. This is also an example of where solid floor insulation was not deemed worthwhile and the other measures were sufficient, as discussed for archetype 18 in Section 5.4.18. The details of this project are given in Table 13.

Archetype	Existing measures	Retrofit measures	ZDEH system
House Solid walls Solid floor **(Archetype #18)**	Loft insulation	Enhanced loft insulation IWI Double glazing	n/a

Table 13 Castle Rock Housing Association retrofit project details

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