Heat in Buildings: Multiple Ownership Mixed Use Buildings: Energy Retrofit Possibilities

November 2023

Scottish Government
Riaghaltas na h-Alba

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4. Introduction

The Scottish Government asked Energy Saving Trust (EST) to research properties of multiple ownership and mixed use (MOMU). This will help inform the Scottish Government's policy on reducing the environmental impact of these property types, through retrofit of energy efficiency and zero direct emissions heating in the line with the Heat in Buildings Strategy. Historically, decarbonising these buildings has proven problematic due to the requirement for cooperation between owners. This work was completed in two phases:

- Phase 1 – categorisation of the MOMU archetypes. In this phase, EST home analytics data was used to estimate the number of each property type and identify as much information on these properties as possible, affecting how they are treated. For example:
    - Ownership (rented/owner/social housing);
    - Conservation/listed status;
    - Current insulation levels, and
    - Current heating system.
- Phase 2 – detailed measure costing. In Phase 1 there was some initial exploration of the potential costs of retrofitting these properties. Phase 2 went beyond this to analyse which heating systems are more suitable for these types of properties and attempt to identify suitable measures within each group.

5. Phase 1 – Property identification

During Phase 1 of this project, properties which were classified with MOMU status were identified using Energy Saving Trust's Home Analytics data. This allowed the segregation of properties into various categories. Phase 1 also included some preliminary costings, however, since these have now been superseded by newer values in Phase 2 (see Section 6), only the property identification will be covered in this section.

5.1. Logic definition

The objective of Phase 1 of the project was to develop profiles of each MOMU archetype to inform research into retrofit and decarbonisation pathways. During the profiling, each property was classified into one of the five MOMU archetypes and their key characteristics were compared based on a number of different dwellings in the Home Analytics database.

5.1.1. Data sources

- Home Analytics Scotland v3.7.1 which holds known and modelled property data for all residential dwellings in Scotland.
- Ordnance Survey AddressBase & MasterMap, used to define relationships between Unique Property Reference Numbers (UPRN), Topographic Identifiers (TOIDs) and building blocks.

5.1.2. Defining MOMU archetypes

The physical structure of a building is shown in Figure 1. Each TOID is a building footprint with several individual flats, each with their own UPRN. A series of TOIDs in a row is called **block**.

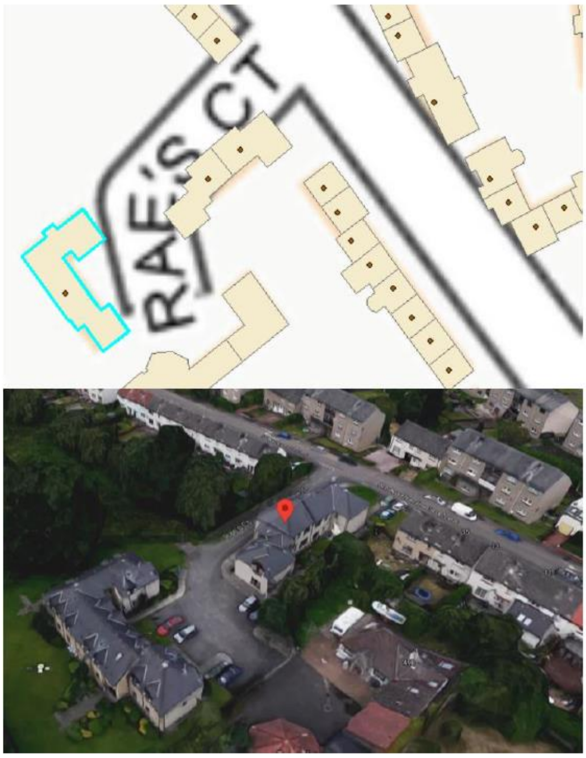
Figure 1: Illustration of how UPRNs, TOIDs and blocks interact in the home analytics database (left) and how they are defined on an actual building (right).

5.1.3. The MOMU archetypes

Four-in-a-block:

In this archetype there are 4 UPRNs in one building block and:

- 4 UPRNs per TOID and 1 TOID in block; or
- 2 UPRNs per TOID and 2 TOIDs in block



Low rise blocks

For these properties, the height should be <21 meters and:

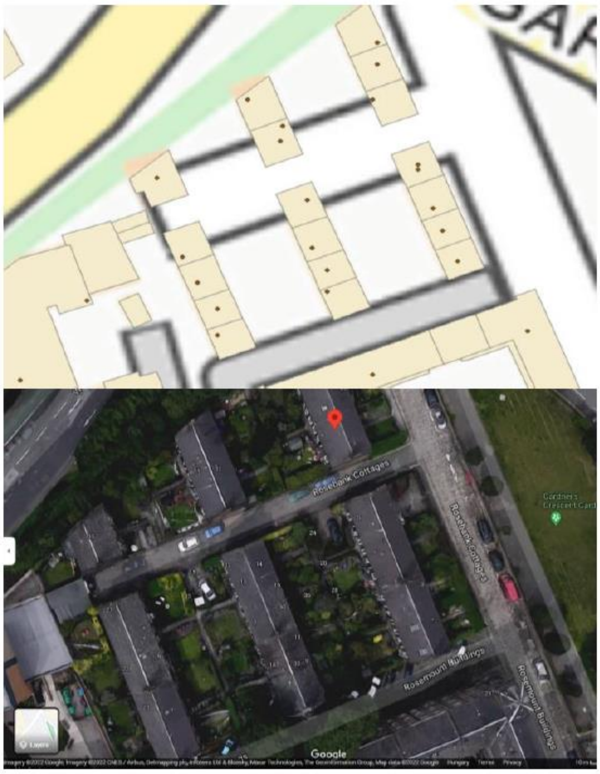
- >2 UPRNs per TOID and <3 TOIDs in block; or
- >19 UPRNs per TOID[1] and >2 TOIDs in block

[1] Excludes TOIDs with 4 UPRNs (overlap with four-in-a-blocks).

High rise blocks

For these properties, the height should be >=21 meters and:

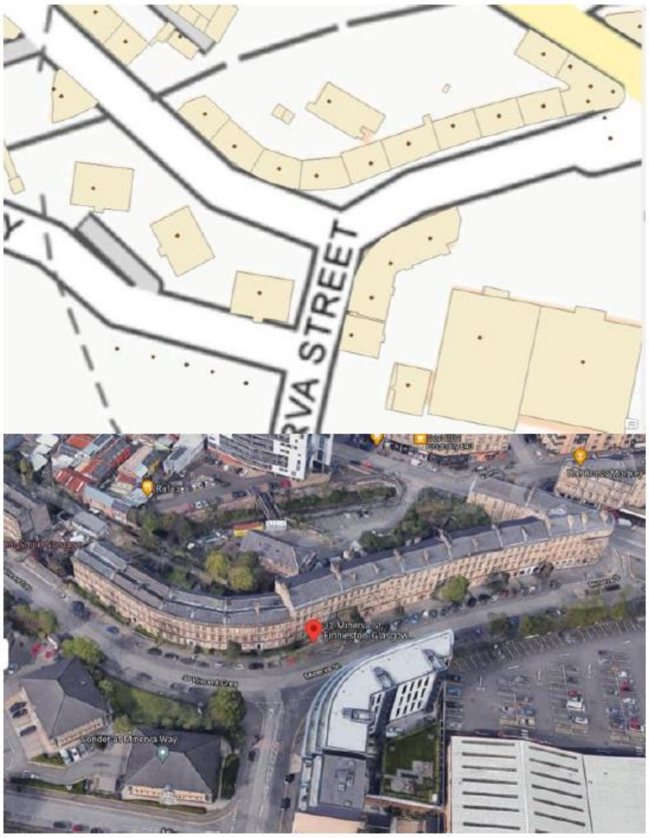
- >=21 UPRNs in TOID; or
- 1 TOID in block



Terraced flats

- There is always 2 UPRNs per TOID; and
- The number of UPRNs per block is two times the number of TOIDS in a block.[2] (for example if there are 3 TOIDs, we would have 6 UPRNs, if there are 4 TOIDs, we would have 8 UPRNs)

[2] There is an overlap with four-in-a-block flats that have 2 TOIDs, each with 2 UPRNs.



Tenements

In these properties there should be:

- >2 and <20 UPRNs[3] per TOID and >2 TOIDs in block; or
- 4 UPRNs per TOID and 2 TOIDs in block

[3] Avoids overlap with high rises. Tenements are not constrained by height but only a handful exceed 21m.

5.2. Property summary statistics

5.2.1. Total property numbers

As shown in Figure 2, tenements account for the largest share of MOMU dwellings (39%). Four-in-a-block flats account for the largest share of MOMU buildings (38%), and low/high rise blocks account for 35% of MOMU dwellings but only 15% of buildings.

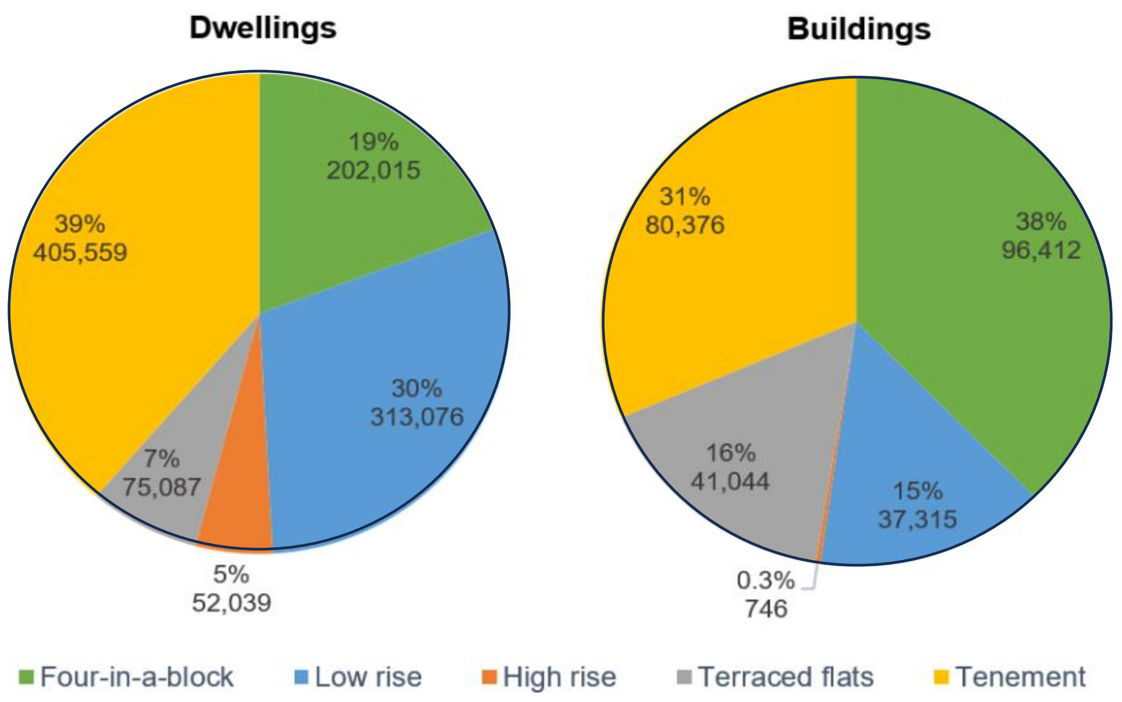


Figure 2: Total property numbers in MOMU archetypes. Shown here are dwellings (i.e., UPRNs) and buildings (i.e., TOIDs)

5.2.2. Urban / rural distribution

As shown in Figure 3, MOMU properties are predominantly located in urban areas.

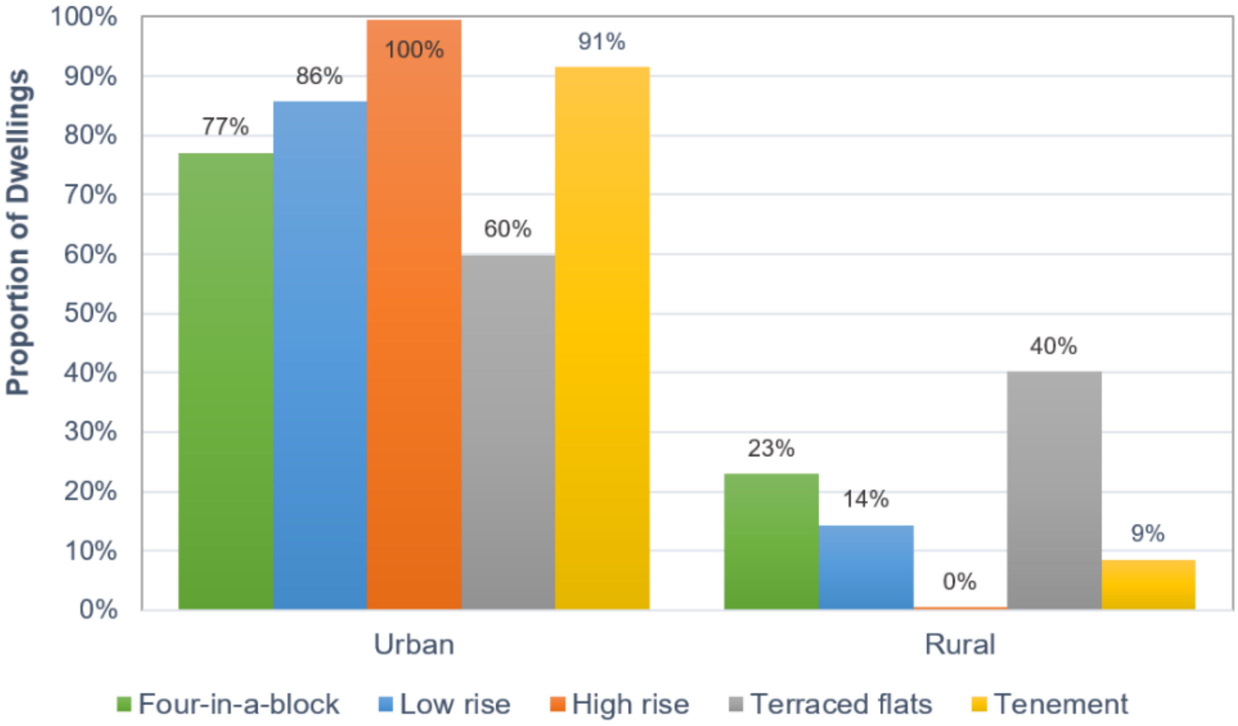


Figure 3: Distribution between urban and rural properties

40% of terraced flats are located in rural areas and nearly a quarter of four-in-a-block flats are located in rural areas. High rises are found solely in urban areas. This high density of urban properties does limit what is possible in many cases, with space at a premium in these environments. This may limit what measures are possible in such areas.

5.2.3. Property age

Figure 4 shows the distribution of the MOMU properties by property age. 48% of tenements were built before 1919 and 51% of four-in-a-blocks were built between 1919 and 1949. Three quarters of high rises were built between 1950 and 1983 and low-rise blocks have newer stock (43% built post-1984). Each age band presented with its own unique difficulties due to building regulations at the time. Where possible, measures were grouped across age bands for simplicity of presentation of these results.

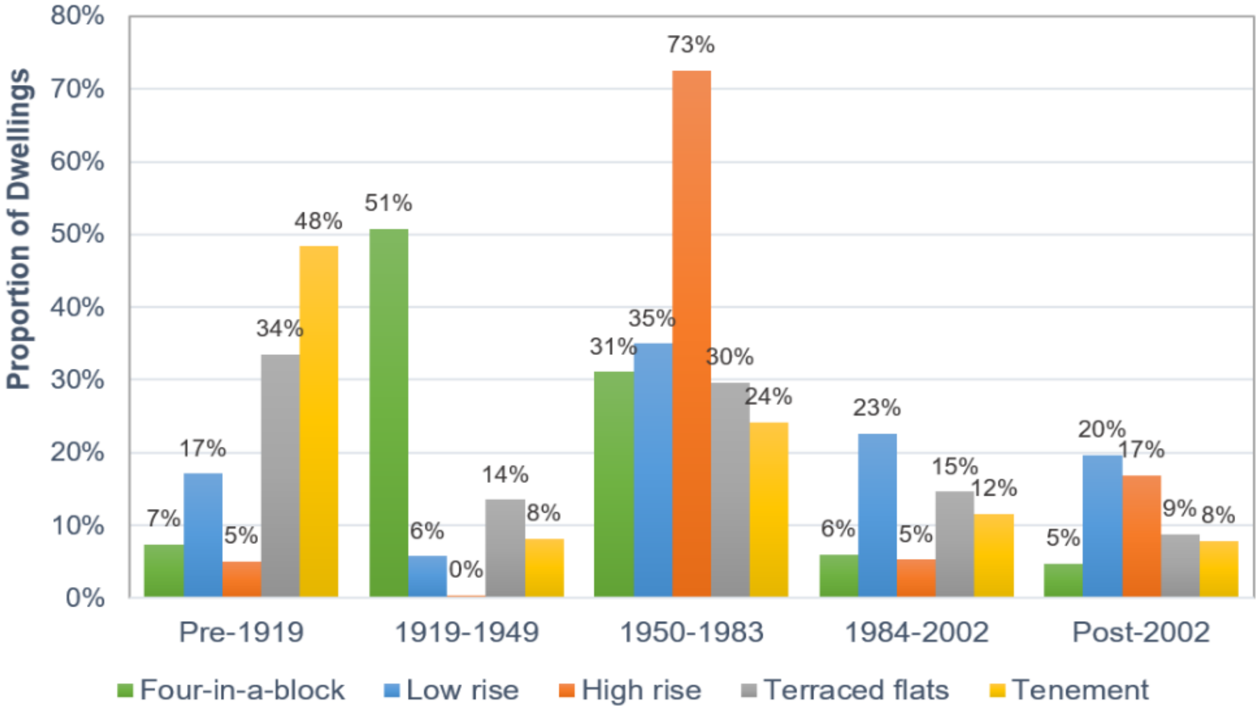


Figure 4: Distribution of MOMU properties by property age.

5.2.4. Wall construction type

Figure 5 shows the distribution of the wall types across the MOMU dataset. Four-in-a-block (71%) and low rise (50%) flats have the highest level of cavity walls. Tenements have the highest proportion of solid walls (56%). Terraced flats are split evenly between cavity / solid, and the majority of high rises are system built (72%).

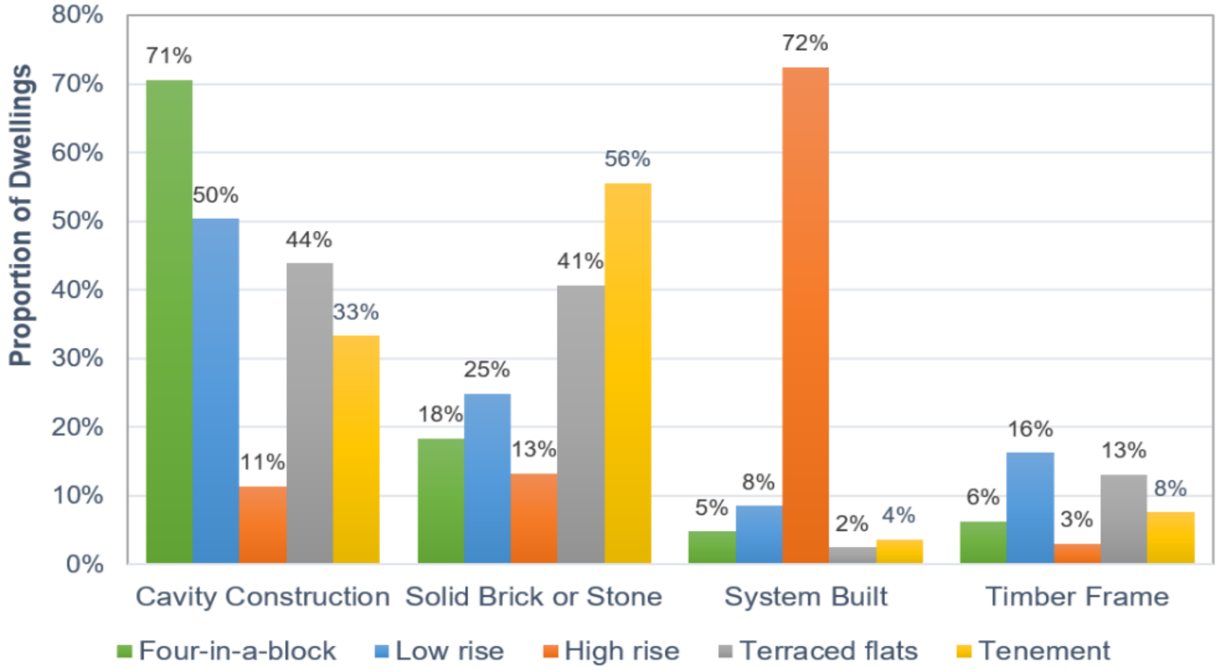


Figure 5: Distribution of wall types for the MOMU dataset

5.2.5. Wall insulation

Figure 6 shows the levels of wall insulation in the MOMU properties. MOMU wall insulation levels follow wall type distributions: terraced flats / tenements have the highest rate of solid walls and lowest insulation level (<43%), high rises are newer, with system-built walls and the highest insulation rate (75%).

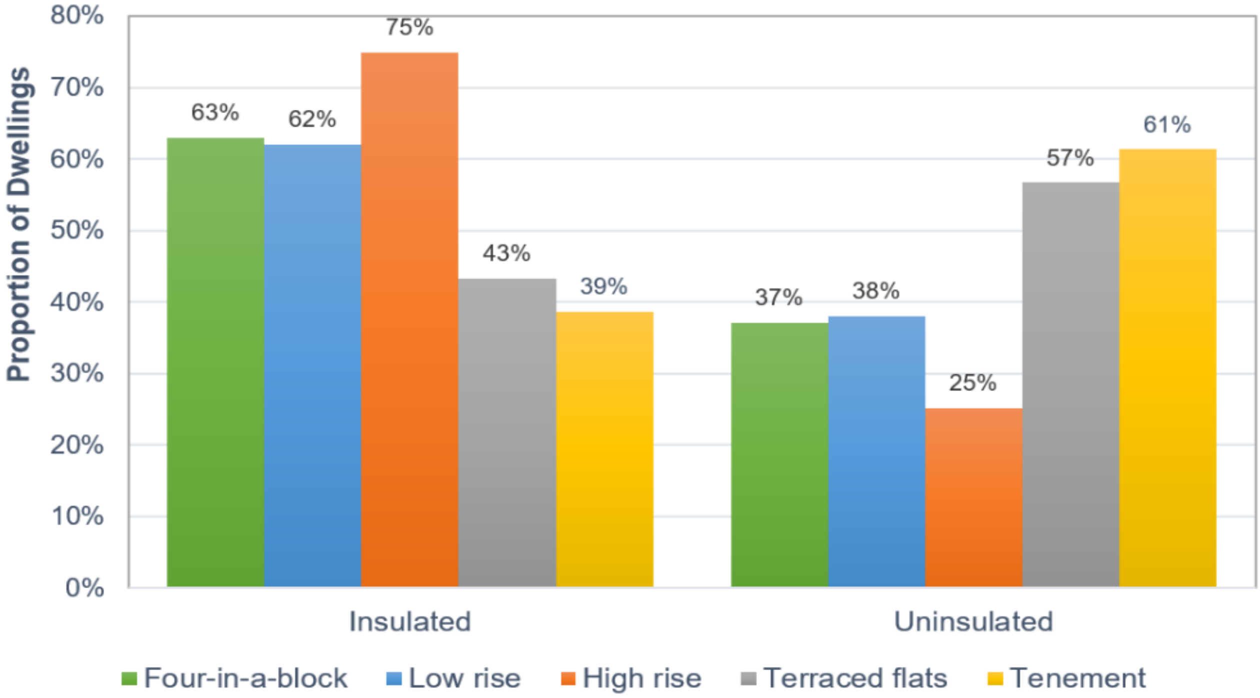


Figure 6: Distribution of whether a MOMU property has insulated walls or not.

5.2.6. Glazing type

Figure 7 shows the glazing levels for the MOMU dataset which shows a high rate of double/triple glazing across MOMU archetypes. Tenements and terraced flats have the lowest relative glazing levels, due in part to older buildings. It should be noted that the EPC data does not indicate the quality of the double glazing and in many cases, it is likely it would be beneficial to replace it.

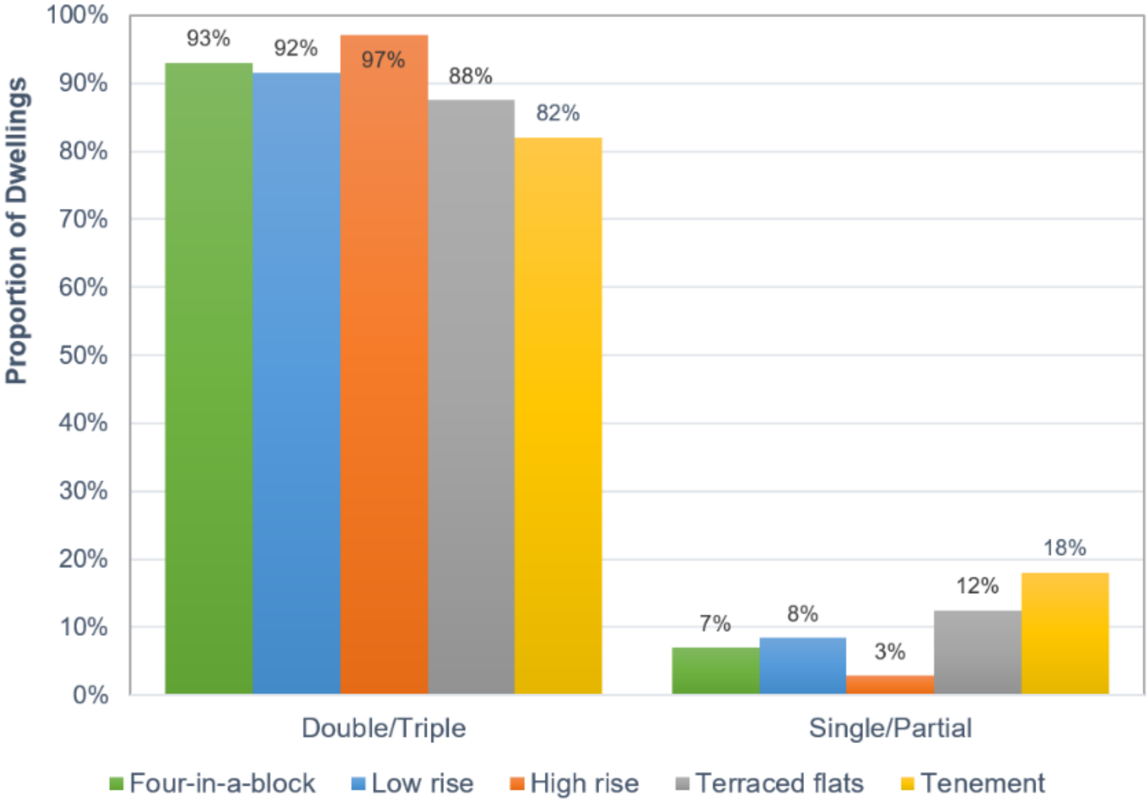


Figure 7: Glazing levels for the MOMU dataset.

5.2.7. Main fuel type

Figure 8 shows the main heating fuel type in the MOMU properties. Four-in-a-blocks (90%) and tenements (82%) are mainly on gas. Electric heating accounts for nearly three quarters of high-rise dwellings. Oil is a relatively significant heating fuel for rural terraced flats.

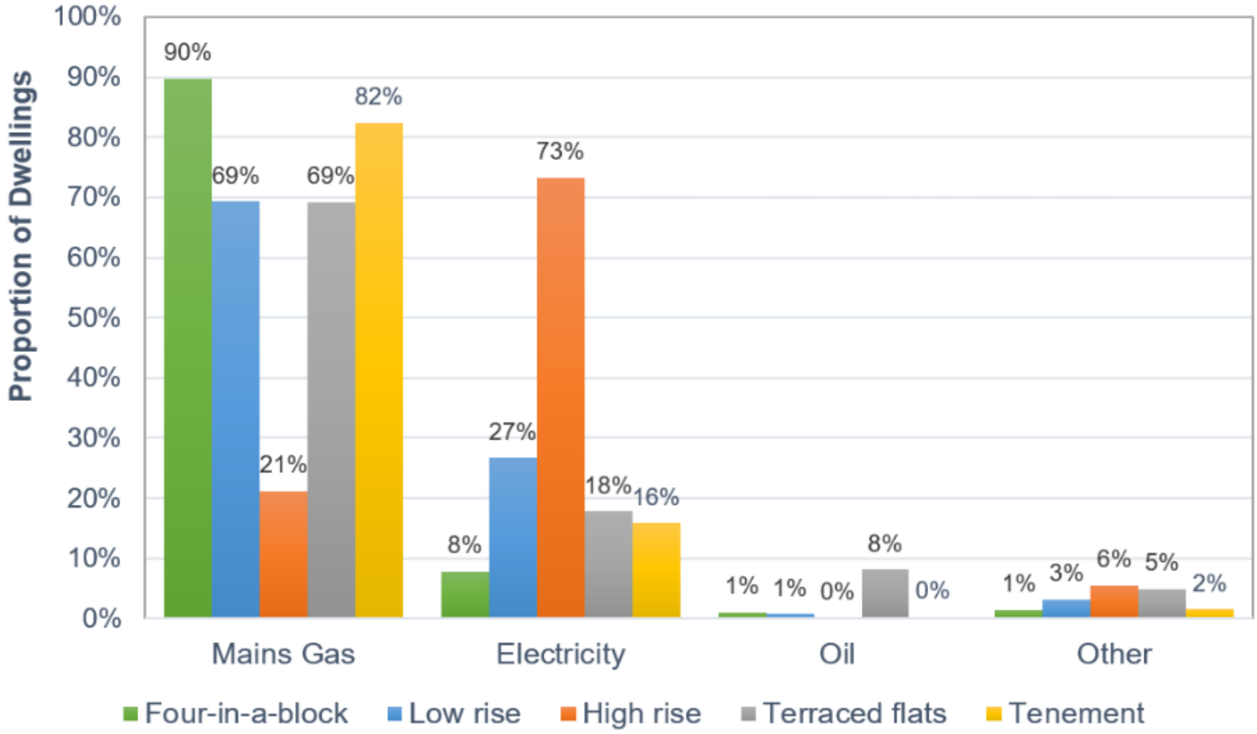


Figure 8: Distribution of main heating fuel types in MOMU properties.

5.2.8. SAP band

Figure 9 shows the SAP bands[4] for the MOMU dataset. Low-rise and high-rise blocks have the highest energy efficiency (two thirds above SAP C). Tenements and four-in-a-blocks have medium efficiency whereas terraced flats have the lowest efficiency level (only 42% above SAP C).

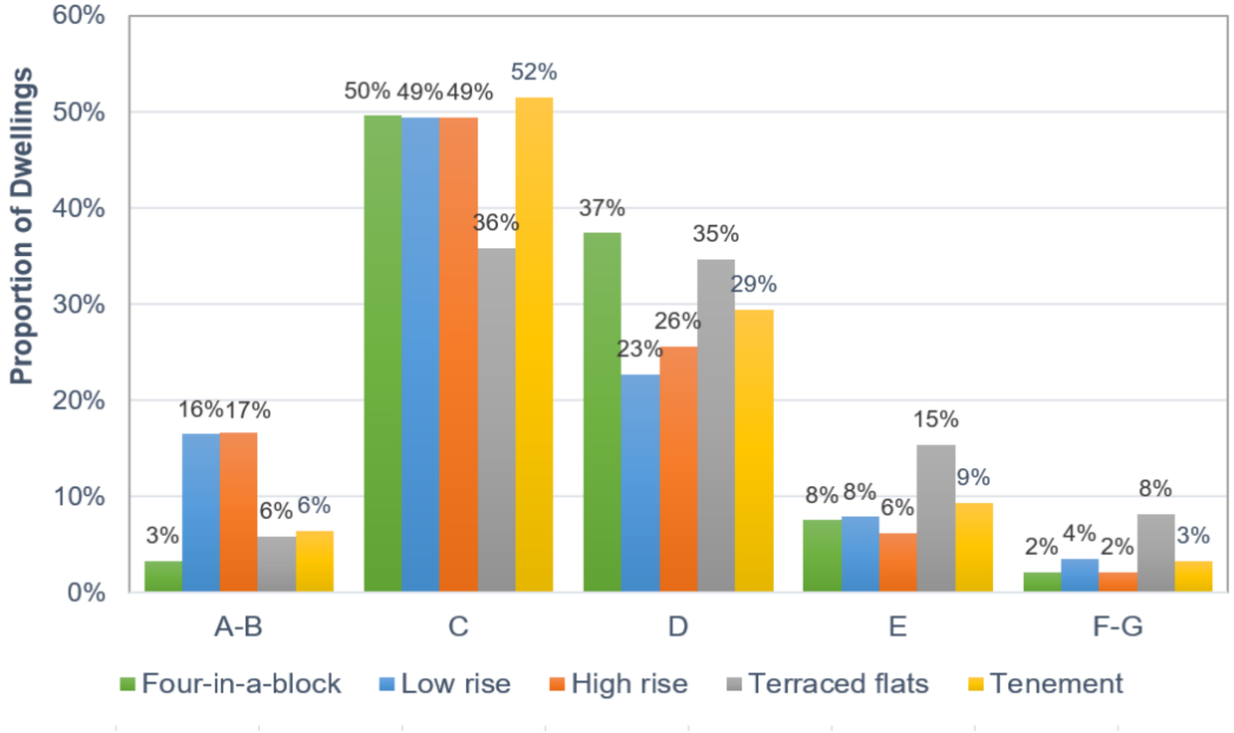


Figure 9: SAP bands for the MOMU dataset.

[4] A Standard Assessment Procedure (SAP) is the system used to produce a home energy rating on an EPC

5.2.9. Conservation areas

Figure 10 shows the percentage of MOMU properties that lie within a conservation area. The properties within a conservation area may have to be treated differently to keep the look of the properties consistent with their cultural significance. For example, some properties in a conservation area may have to retain the same external appearance meaning that external wall insulation may not be suitable. Most MOMU properties are located outside conservation areas. Tenements (25%) have the highest concentration and nearly all four-in-a-block flats are located outside conservation areas (96%).

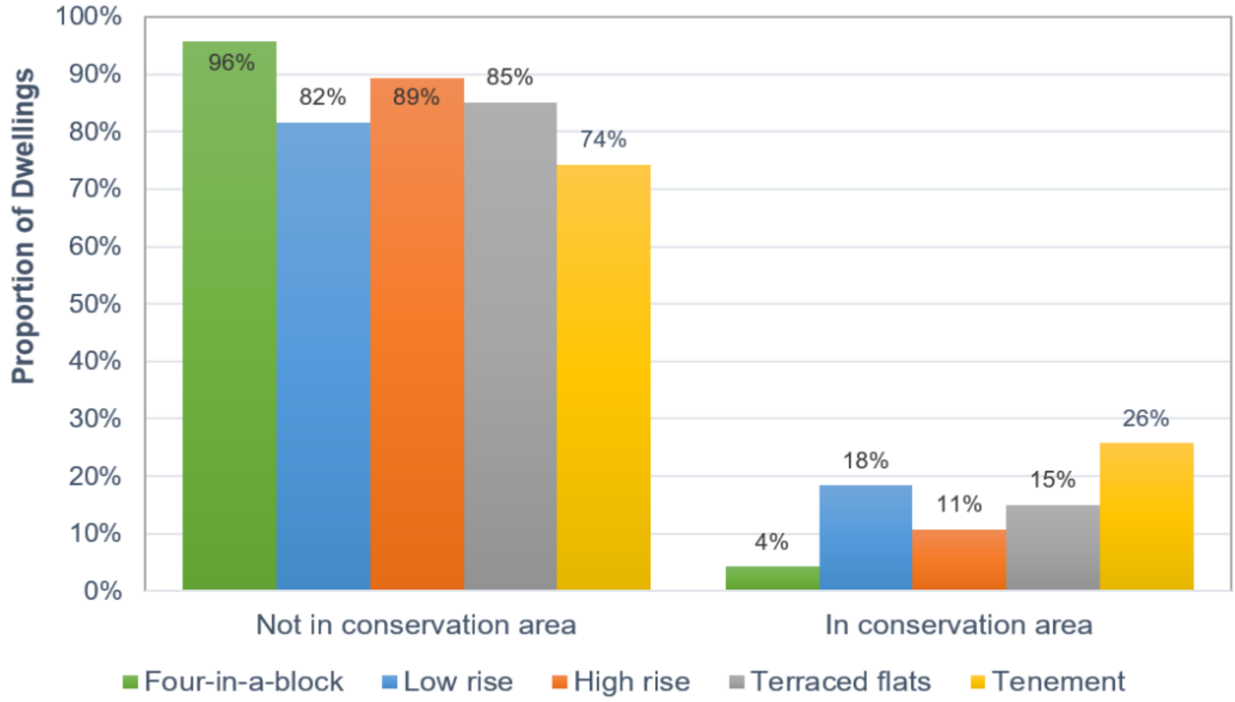


Figure 10: Percentage of MOMU properties within a conservation area

5.2.10. Listed building status

Figure 11 shows the percentage of properties that have listed status. As with properties in conservation areas, these properties will have specific requirements on how they can be treated. This would likely increase the cost of retrofitting these properties as specific techniques may need to be used to ensure it is completed sensitively to their history. All MOMU archetypes have at least 90% of their dwellings in unlisted buildings - tenements (9%) and low-rise blocks (7%) have the most listed buildings.

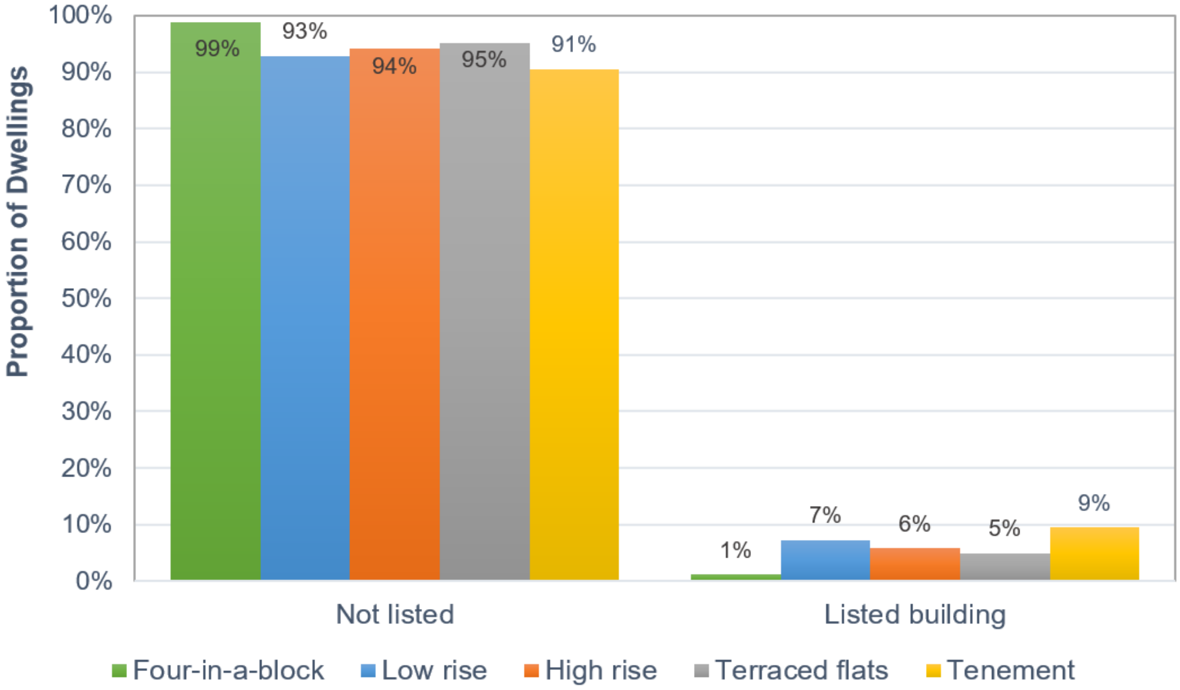


Figure 11: Percentage of MOMU properties that have listed status.

6. Phase 2 – Detailed costing

Some preliminary costings were provided alongside the property numbers and statistics. In Phase 2, the costings were extended to provide more accurate values for the different archetypes derived in Phase 1.

6.1. Approach

A similar approach was followed for Phase 2 as in Phase 1 costings where averaged data was used for each of the individual archetypes. The work that was done in Phase 1 was extended by the following:

- Analysis/extension of current archetypes – We re-analysed the archetypes to increase the number we could analyse, while also grouping them together where possible as to not over complicate with a huge volume of numbers;
- Assess differences across archetype’s age bands. Age bands which would likely have similar treatment options are grouped together;
- Assess fabric and heating measures that are suitable for each archetype/age band combination, and
- Produce costs for each combination of archetype/age band.

6.2. Revision of archetypes

To understand the difference between properties within and between archetypes, we conducted some random spot checks of properties in the MOMU dataset. The procedure followed was thus:

- Select UPRN at random from archetype (e.g., terraced flat) and age band (e.g., pre-1919);
- Identify all properties within the same TOID and block and check that Phase 1 logic holds. Note any discrepancies (e.g., properties with different age bands within the same TOID/block, very different addresses within TOID/block);
- Find property on google maps and street view. Note any issues with property (e.g. is actually a different property type such as semi-detached, archetype similar to another), and;
- Look on property websites for floorplans of this property or any other nearby that appears to be similar. Compare dimensions to assumed floor area to external wall ratios.

For each property type and age band a minimum of two properties were examined in this way resulting in the analysis of a minimum of 60 properties (two properties from each of the five archetypes, each with six age bands). The key findings are summarised below:

- Tenements and low-rise flats can be considered the same in terms of the logic developed in phase 1. Pre-1919 (and some 1919-1949) properties in both these categories give the classic tenements (e.g. Marchmont/Newington areas in Edinburgh) that you expect from this type in Scotland. Post-1919 flats within these two categories were also very similar with the only difference being the length/number of blocks.
- High-rise flats which are not the typical ‘tower block’ can also be categorised the same as tenements and low rises, with the only difference being the height. While for the purposes of this report these higher tenements are considered the same as low rise flats and tenements to give the reader an initial idea of costs. different external insulation materials may be required due to due changes in legislation from June 2022. This is subject to further change in light of developments in relation to the Scottish Government’s Cladding Remediation programme and the Grenfell inquiry outputs.
- The terraced flat category is subject to a high number of errors in the properties that we see. We generally expect two flats, one above the other, with a shared roof. This can include the typical ‘colony’ property (where the front door to the top and bottom flats are on opposite sides of the property to allow both flats to have a front garden) as well as a classic maisonette flat. However, we see a large number of semi-detached properties in this category due to the way the TOIDs are defined. We therefore caution that the number of properties in the terraced flat category may be highly over-estimated. Example errors are:
    - One TOID covers two semi-detached properties. Usually, we would expect each home to have its own TOID.

    - Grid coordinates for individual UPRNs are in the wrong TOID. For example, numbers 74 and 82 in a row of terraced houses were located in the same TOID.
- The four-in-a-block and terraced flats are generally similar in terms of construction and general style. This allows the same fabric and heating measures to be applied to them. However, they are costed separately due to the significant difference in external wall areas.
- There is no clear trend for variation in relative property dimensions with property age (e.g., % external wall area compared to floor area) in the selection of properties we examined. It was concluded that the same assumptions for external wall area to floor area and other property parameters would be used for every property age.

The following archetypes were therefore considered when assessing measures:

- Flats - tenements, low rise and high-rise (not tower blocks) flats (Box 3);
- Tower blocks – just classic high-rise tower types (Box 3);
- Terraced flats; and
- Four-in-a-block.

Box 3: Archetypes explained.

The new 'flat' definition covers all flats which do not fit into the other categories: terraced flats, four-in-a-block flats, or tower blocks. This predominantly covers traditional tenement buildings as well as apartment blocks. These will have more than 2 flats per building (UPRNs per TOID), can have any number of TOIDs in a block and typically are below 21 m. However, there are some buildings within this category which are above 21 m which are typically tall tenements or apartment buildings with multiple buildings together in a block.

The 'tower block' definition includes only buildings which are above 21 m in height. These can be differentiated from the high-rise tenement or apartment buildings as they only have one building (or TOID) per block, although there is likely to be some overlap within these definitions. It is expected that this overlap will result in no significant difference to the measures required in these types of property.

6.3. Effect of property age on measures

The MOMU dataset was analysed based on the property age to ascertain any variation in measures that can be applied to the different age bandings. The following upgrades are considered for each property:

- Fabric
    - Loft insulation
    - Cavity wall insulation (CWI)
    - External wall insulation (EWI)
    - Internal wall insulation (IWI)
    - Floor insulation
    - Replacement windows
    - Replacement external doors
    - General draught proofing
- Heating systems
    - Air source heat pumps (ASHP) (air to water)
        - Standard system
        - Small flat ducted system
        - Communal system
    - Air-to-air heat pumps
    - Direct electric heating
    - Storage heaters
    - Biomass
    - Communal ground source heat pump (GSHP)

6.3.1. Fabric measures

- Cavity walls are unlikely (<2%) to be found in properties in the pre-1919 age bracket and were therefore excluded as a possible measure for that age band.
- After 1991, all properties have been assumed to have the walls fully insulated as building regulations suggested this should have been done. Therefore, we have excluded all wall and loft/roof fabric upgrades for these properties. We will keep general draughtproofing for doors and windows as we expect in some cases these may still be necessary. This will give a conservatively high estimate for total fabric upgrade costs for post 1991 properties.

6.3.2. Heating system

It was concluded that the property age band will have no fundamental effect on which heating system can be fitted to improve energy efficiency. There will be certain cases where it will be more suitable for one technology or another, but this does not exclude another technology being installed. For example, where a property had storage heaters installed previously, it could make sense to be replaced by new storage heaters, however it is also possible to install a hydronic heating system (to be paired with a boiler or heat pump) for a higher upfront cost but which over time may be cheaper.

6.4. Summary of interventions

6.4.1. Fabric measures

Table 1: Fabric measures per archetype

Archetype	Loft (Not post-1992)	Walls (not post 1992)			Floor (not post 1992)	Windows	Doors	Draught-proofing
		CWI (not pre-1919)	EWI	IWI				
Terraced flats	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Four-in-a-block	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Flats	Yes	Yes	Yes	Yes	Yes	Yes		Yes
Tower blocks	Yes	Yes	Yes	Yes	Yes	Yes		Yes

Table 1 shows the possible measures for each archetype and age band, with the exclusions detailed in Section 6.3.1. We should note that due to the large range of various construction types out there (particularly for traditional builds), not all insulation measures will be suitable for each type of property. For example, those with ventilated air spaces (e.g. space behind lathe and plaster) may not be suitable for external wall insulation as the airspace is treated as being the temperature of the external air according to BRE.[5] Care should be taken in the design of each insulation solution considering the building physics of each to ensure targets are met and thermal and moisture issues are controlled for.

6.4.2. Heating measures

6.4.2.1. Exclusions

We have excluded communal biomass and ground source heat pumps from our analysis. We expect that communal biomass systems would likely have to be on a heat network in order to be feasible in terms of numbers and therefore beyond the scope of this report. Ground source heat pumps are also excluded as they would require a large area to lay the pipes or dig a borehole – typically a 100 m deep borehole produces 6 kW of heat and requires 5-6 m between each borehole. Therefore eight flats which each require 4 kW might require 300-400 m^2 of outdoor space to dig boreholes. In most of the MOMU dataset, these are in high density urban environments and are therefore less likely to be feasible.

Larger air-to-air systems using warm air heating systems are unlikely to be appropriate as retrofitting air ducts in properties is not possible in many cases. Single room air-to-air systems with outdoor fan units (similar to traditional single room AC systems seen in other countries) might be applicable in a small number of cases where you have open plan properties but is thought to be unlikely to be used extensively. “Multi-head” air-to-air systems could be feasible but are similar in most characteristics to air-to-water heat pumps

[5] Conventions for U-value calculations, BRE, section 4.7.3 BR 443, 2019 Edition, https://www.bregroup.com/wp-content/uploads/2019/10/BR443-October-2019_consult.pdf

(with respect to the requirement for a suitable location for the outside evaporator unit), and so have not been considered separately.

Newer small capacity air-to-air systems can provide up to around 3 kW of heating (or cooling) and just require two ducts drilled through the wall to absorb and release heat from the outside air[6]. These systems are mounted on the inside of an external wall and blow heated air into the room. This has advantages over the traditional air-to-air systems in that all the equipment is inside and there is no requirement for an outside evaporator unit, which is particularly important buildings where there may be planning issues or physical constraints.

These small capacity air-to-air units require an external wall for mounting. However, depending on the heat demand of the property, it is possible that not all rooms would require a separate unit. The largest units at 3 kW will be oversized for most properties (although it should be noted that this output is at an air temperature of around 7°C so would not be able to produce as much at lower temperature) – the average system size for the flats in this project is between 2 and 4 kW. Any 'internal' rooms without an external wall could be heated by heat transfer from other rooms with small direct electric booster heaters to provide any additional heat demand. As with all heating systems, a detailed design should be carried out prior to any installation.

Due to their larger capacity, these would be best suited for flats with a more open-plan design, possibly catering for the larger capacity requirements of the more inefficient flats. These systems were only identified for the final draft and have therefore not been investigated and costed fully and are not included in the subsequent tables. However, installation labour costs are likely to be relatively low (1-2 days' work for a whole flat), with small capacity air-to-air units costing approximately £1,000-£2,000 each.

These can be combined with dedicated ducted hot water (HW) heat pumps (which must be located with access to an external wall) to provide a whole flat heating solution using heat pumps with the proviso that the HW heat pump needs to be located next to an external wall. For properties without this option, they could simply retain an existing immersion heated cylinder.

The exclusion of a technology from our analysis does not mean it should never be considered or would never be installed. It is solely considered unlikely to be a commonly feasible option, and so not worth including in analysis at this level.

[6] Powrmatic website with an example of an air-to-air heat pump system
Electriq website with an example of an air-to-air heat pump system

6.4.2.2. Measures by archetype

Table 2: Heating measures possible per archetype

Archetype	ASHP			Direct electric	Storage heaters
	Standard	Internal ducted	Communal		
Terraced flat	Yes	Yes		Yes	Yes
Four-in-a-block	Yes	Yes		Yes	Yes
Flats		Yes	Yes	Yes	Yes
Tower blocks		Yes	Yes	Yes	Yes

Table 2 shows the possible heating systems for the various archetypes. Standard individual heat pumps are only possible on terraced flats and four-in-a-block properties where they can be mounted on the ground or relatively low. They have been excluded from flats and tower blocks as the external units would not be easily accessible for servicing when higher on the side of a property. There are also questions around the aesthetic appeal of such systems.

If possible, communal air source heat pumps would be mounted on flat roofs of flats and tower blocks. Depending on access requirements and number of flats serviced, there may be limits to how many can be mounted on the roof.

The other three heating systems (internal ducted ASHPs, direct electric and storage heaters) have no restrictions and can be fitted in any property type (assuming a large enough cupboard next to an external wall for the internal ducted ASHP).

6.5. Estimating savings and system sizes

We have estimated potential energy savings based on the measures installed. We have used EST's SAP-based energy model 'Dynamic Engine' to determine this. We have modelled the percentage energy savings from installing the various measures based on the typical dimension of a flat used in our models. Each of the fabric measures has been modelled and the percentage saving determined as shown in Table 3. It is unlikely that more than one measure of either internal wall insulation, cavity wall insulation or external wall insulation would be carried out. While it is possible to insulate the cavity and add external wall insulation, we have assumed only one measure is likely to be carried out at one time. Loft insulation can only be done on the top floor, and floor insulation on the ground floor. There is an acoustic benefit from insulating floors between flats which could also provide a thermal benefit if the floor space is somehow ventilated (e.g. the area behind the lathe and plaster in stone-built properties is often ventilated to the outside and this may be connected to the underfloor space). However, we have assumed that only the ground floor would receive insulation.

Table 3: Summary of fabric measure savings as a percentage of heat demand.

Measure	Percentage Saving
Single dwelling measures	
Loft insulation (just top floor)	24%
Floor insulation (just ground floor)	15%
Internal wall insulation	36%
Replacement windows (single to double A+)	19%
Replacement external doors	Included in draught-proofing
General draught-proofing / air tightness	6%
Communal measures	
Cavity wall insulation	27%
External wall insulation	36%

Savings can be combined to show the maximum for each of the combinations of fabric measures. Results are shown in Table 4. The range given accounts for the fact that some properties cannot receive certain types of insulation and that only top and bottom floor flats would benefit from loft and floor insulation, respectively. The figure in brackets gives the individual dwelling savings without any wall insulation for the case where communal wall insulation measures must be carried out. Note: solid wall savings (36%) were assumed for all properties where the external walls were insulated.

Table 4: Possible percentage energy savings for individual dwellings for the different archetypes and age bands. (Figures without wall insulation)

Archetype	Pre-1919	1919-1991	Post-1992
Terraced flats	55% - 57% (29% - 33%)	48% - 57% (29% - 33%)	23% (23%)
Four-in-a-block	55% - 57% (29% - 33%)	48% - 57% (29% - 33%)	23% (23%)
Flats	51% - 57% (29% - 33%)	44% - 57% (29% - 33%)	23% (23%)
Tower blocks	NA	51% - 57% (29% - 33%)	23% (23%)

6.6. Cost results

6.6.1. Cost data

Cost data from EST's latest cost database was used to determine overall costs for each archetype. This covered all the fabric measures as well as smart storage heaters. While we have a cost for standard ASHPs, this becomes less accurate for smaller systems. Therefore, bespoke costs were obtained for all ASHP systems.

There are a limited number of internal ASHPs on the market. These are systems which have two ducts drilled into the external wall rather than having an external unit. Two systems were considered for this project:

- GroundSun small home and apartment heat pump which is rated for around 2.5 kW.[7] This unit costs around £5k and combined with installation, the cost is estimated to be around £6-8k, depending on whether any radiators need to be replaced.
- The Sime Revolution 30 is a hybrid heat pump, combining a 4 kW heat pump and a 30 kW combi boiler in a single unit.[8] We have used this to illustrate the fact that 4 kW systems are possible when ducted, and it is likely in the future that this might be improved. In the MOMU dataset, 4 kW is the highest average of the archetype's estimated system sizes (seen in pre-1919 terraced flats and four-in-a-blocks). This particular system would have to be combined with a thermal store/hot water cylinder as in the GroundSun system but that is not likely to be a huge technical leap to do so. The Sime Revolution costs around £6k for the unit and combined with installation we estimate it to be around £7-10k.
- We have therefore estimated internal ASHPs to all be within the range of £6-10k.

It is worth noting that many heating systems have under-sized radiators, which could usefully be upgraded whether paired with a boiler or a heat pump. Under-sized radiators cause both heating system types to run less efficiently.

Communal ASHPs have single or multiple larger outdoor units, either on the roof or on the ground. These supply hot water to properties, which each has a unit to transfer heat to their own heating system. The costs depend on how many properties can be supplied by a single unit and therefore we have given an indicative cost per property. Due to terraced

[7] At the time of the analysis this was an option but not at the time of publishing.
[8] Sime website with an example of a hybrid heat pump

flats and four in a block having fewer individual flats (two and four, respectively), we have excluded communal heat pumps from these properties.

It was not possible to obtain installation cost data for communal systems, so this was estimated using a bottom-up approach for a block of 8 flats, accounting for the material (heat pump unit, individual heat interface units, valves, pumps, piping, controls, electric work) and labour costs for individual components of the system. It was assumed that the heat pump is located on a flat portion of the roof (although it could potentially be ground mounted if space allowed and it complied with noise restrictions), with a heat interface unit in each flat replacing an existing combi or system boiler. The cost accounts for replacement radiators and hot water cylinder. This gave a typical cost of £8-10k.

Direct electric boilers are a possible direct replacement for gas boilers. The costs are similar, with gas units slightly cheaper. However, installation of an electric boiler is in some ways simpler with no condensate or flue pipe required. We have therefore assumed the same replacement cost for all boilers.

6.6.2. Results

Summary costs for the measures for each of the archetypes are shown below, with more detailed tables with individual measures presented in Section 7. Measures that can be applied to individual properties and to groups of properties have been presented separately to show the range of possible costs with different approaches. Please note that costs are based on each age group's average dimensions and heating loads, and we have assumed that only one of the three wall insulation options (EWI, IWI or cavity) will be carried out.

6.6.2.1. Terraced flats

Table 5: Upgrade costs for terraced flats

Upgrade	Criteria and constraints	Cost (£) Pre-1919	1919-1991	Post-1992
Fabric upgrades				
Individual dwelling measures				
Fabric measures subtotal (with individual dwelling wall insulation)	Without wall insulation	5,226 - 8,732	4,546 - 6,898	4,071 - 4,071
	With wall insulation	11,650 - 15,157	8,988 - 11,340	4,071 - 4,071
Communal measures				
Fabric measures subtotal (with communal wall insulation)	With wall insulation	15,471 - 18,977	4,973 - 15,123	4,071
Heating system upgrades				
Heating system size (kW)		3.9	2.4	3.2
Individual dwelling measures				
Heating system costs		4,000 - 10,000	4,000 - 10,000	4,000 - 10,000
Fabric and heating measure subtotal (with individual dwelling wall insulation)	Without wall insulation	9,226 - 18,732	8,546 - 16,898	8,071 - 14,071
	With wall insulation	15,650 - 25,157	12,988 - 21,340	8,071 - 14,071
Overall range (individual or communal measures)	All measures	15,650 - 28,977	12,973 - 25,123	8,071 - 14,071

6.6.2.2. Four-in-a-block

Table 6: Upgrade costs for four-in-a-block flats

Upgrade	Criteria and constraints	Cost (£) Pre-1919	1919-1991	Post-1992
Fabric upgrades				
Individual dwelling measures				
Fabric measures subtotal (with individual dwelling wall insulation)	Without wall insulation	7,013 – 10,092	6,088 – 8,284	5,507
	With wall insulation	18,298 – 21,377	14,279 – 16,475	5,507
Communal measures				
Fabric measures subtotal (with communal wall insulation)	With wall insulation	22,213 – 25,292	6,901 – 20,330	5,507
Heating system upgrades				
Heating system size (kW)		3.5	2.2	2.8
Individual dwelling measures				
Heating system costs		4,000 - 10,000	4,000 - 10,000	4,000 - 10,000
Fabric and heating measure subtotal (with individual dwelling wall insulation)	Without wall insulation	11,013 – 20,092	10,088 – 18,284	9,507 – 15,507
	With wall insulation	22,298 – 31,377	18,279 – 26,475	9,507 – 15,507
Overall range (individual or communal measures)	With wall insulation	22,298 – 35,292	14,901 – 30,330	9,507 – 15,507

6.6.2.3. Low/high-rise flats (no tower blocks)

Table 7: Upgrade costs for non-tower block low/high-rise 'flats'. Note: Pre-1919 properties of this type are generally the typical tenements

Upgrade	Criteria and constraints	Cost (£) Pre-1919	1919-1991	Post-1992
Fabric upgrades				
Individual dwelling measures				
Fabric measures subtotal (with individual dwelling wall insulation)	Without wall insulation	4,158 – 6,512	4,339 – 6,393	4,183
	With wall insulation	9,420 – 11,775	10,478 – 12,532	4,183
Communal measures				
Fabric measures subtotal (with communal wall insulation)	With wall insulation	13,219 – 15,573	4,941 – 16,348	4,183
Heating system upgrades				
Heating system size (kW)		2.5	2.1	2.6
Individual dwelling measures				
Heating system costs		4,000 - 10,000	4,000 - 10,000	4,000 - 10,000
Fabric and heating measure subtotal (with individual dwelling wall insulation)	Without wall insulation	8,158 – 16,512	8,339 – 16,393	8,183 – 14,183
	With wall insulation	13,420 – 21,775	14,478 – 22,532	8,183 – 14,183
Communal measures				
Communal heating system costs		8,000 – 10,000	8,000 – 10,000	8,000 – 10,000
Fabric and heating measure subtotal (with communal wall insulation)	With wall insulation	21,219 – 25,573	12,941 – 26,348	12,183 – 14,183
Overall costs				
Overall range (individual or communal measures)	With wall insulation	13,420 – 25,573	12,941 – 26,348	8,183 – 14,183

6.6.2.4. Tower blocks

Table 8: Upgrade costs for tower blocks. It should be noted that there are no 'tower blocks' before 1919

Upgrade	Criteria and constraints	Cost (£) Pre-1919	1919-1991	Post-1992
Fabric upgrades				
Individual dwelling measures				
Fabric measures subtotal (with individual dwelling wall insulation)	Without wall insulation		4,206 – 6,419	4,100
	With wall insulation		9,738 – 11,951	4,100
Communal measures				
Fabric measures subtotal (with communal wall insulation)	With wall insulation		13,542 – 15,755	4,100 – 4,100
Heating system upgrades				
Heating system size (kW)			1.9	2.6
Individual dwelling measures				
Heating system costs			4,000 - 10,000	4,000 - 10,000
Fabric and heating measure subtotal (with individual dwelling wall insulation)	Without wall insulation		8,206 – 16,419	8,100 – 14,100
	With wall insulation		13,738 – 21,951	8,100 – 14,100
Communal measures				
Communal heating system costs			8,000 – 10,000	8,000 – 10,000
Fabric and heating measure subtotal (with communal wall insulation)	With wall insulation		21,542 – 25,755	12,100 – 14,100
Overall costs				
Overall range	With wall insulation		13,738 – 25,755	8,100 – 14,100

6.6.3. Summary costs

Table 9: Summary of cost ranges for all measures by archetype

Property Type	Pre-1919	1919-1991	Post-1992
Terraced flats	£15,650 - £28,977	£12,973 - £25,123	£8,071 - £14,071
Four-in-a-block	£22,298 - £35,292	£14,901 - £30,330	£9,507 - £15,507
Tower block		£13,738 - £25,755	£8,100 - £14,100
Flats	£13,420 - £25,573	£12,941 - £26,348	£8,183 - £14,183

6.7. Summary

The main outputs from this report are the cost tables found in Section 6.6.2. Detailed tables of the properties within each archetype and associated information on them has been provided separately. This section will provide a brief commentary on the outcomes of this work and highlight some potential limitations.

- Costs are based on the retrofit of an individual property (e.g., one flat). Should retrofit be conducted more methodically (e.g., doing an entire street at once), the costs are likely to change. There would be some benefit from economies of scale, however there may be additional costs if the work is carried out to a certain specification (e.g., PAS2035, Enerphit Retrofit standard, or the AECB Retrofit standard).
- The analysis was carried out on averaged data across the archetypes grouped by age band. Individual property data is available and could be used for a more detailed costing on an individual property/block level. However, we are not sure this would add much useful information at this stage. This approach would likely give more accurate costs overall, although questions would still remain around the whole building/block approaches required. It would potentially provide more accurate information on the suitability for small home and apartment heat pumps which at the moment have a capacity limit. This will likely rise in the years to come and can be temporarily overcome using a ducted/hybrid solution.
- Due to the high urban concentration of properties, district heating systems could potentially benefit many of these systems although the cost of these is beyond the scope of this report.
- The use of individual ASHPs (both air-to-air or air-to-water) with external units on tower blocks and low/high rise flats has been excluded as the units would be mounted on the wall at elevated levels. This would lead to issues in the services, maintenance and noise problems as well as being aesthetically displeasing. The ducted heat pumps appear to be a promising solution for these situations but have limited deployment at present. It is unknown how this type of heat pump will develop over the years, and more research on this would be beneficial.
- Other technologies (e.g., individual air-to-air ducted heat pumps) could provide a solution to low carbon heating systems for properties which are difficult to fit with a wet heat pump system or require a higher capacity of system (e.g. low energy efficiency flats).

7. Detailed Cost Tables - Appendix

7.1. Terraced flats

Table 10: Upgrade costs for terraced flats

Upgrade	Criteria and constraints	Cost (£) Pre-1919	1919-1991	Post-1992
Fabric upgrades				
Individual dwelling measures				
Loft insulation	For top floor only Usually top up Much more expensive if room-in-roof or flat roof	775	604	
Internal wall insulation	Typically for pre-1919 Could be added to CWI Could be instead of CWI	6,424	4,442	
Floor insulation	Ground floor only Suspended floor to 1983 More expensive for solid floor	4,281	2,956	
Replacement windows	More expensive in conservation areas Secondary glazing may be cheaper in conservation areas Single glazing more common in older buildings Replacement of poor DG possible at any age	3,740	3,267	3,386
Replacement external doors	More expensive in conservation areas	600	600	600
General draught-proofing / air tightness		112	75	84
Individual dwellings subtotal	Without wall insulation	5,226 - 8,732	4,546 - 6,898	4,071 - 4,071
	With wall insulation	11,650 - 15,157	8,988 - 11,340	4,071 - 4,071

Upgrade	Criteria and constraints	Cost (£) Pre-1919	1919-1991	Post-1992
Communal measures				
Cavity wall insulation	Jointly with other floors Typically for 1919 to 1983		426	
External wall insulation	Jointly with other floor Typically for pre-1919 Could be added to CWI Not for conservation areas	10245	8224	
Communal fabric subtotal	With wall insulation	15,471 - 18,977	4,973 - 15,123	4,071
Heating system upgrades				
Heating system size (kW)		3.9	2.4	3.2
Individual dwelling measures				
Standard ASHP	Property 2 floors max Consent for external units	6,000 - 10,000	6,000 - 10,000	6,000 - 10,000
Internal ASHP/Hybrid	Airing cupboard by external wall	6,000 - 10,000	6,000 - 10,000	6,000 - 10,000
Direct electric heating	External space	4,000	4,000	4,000
Smart storage heaters		7,028	4,749	5,324
Individual dwelling measures only totals	Without wall insulation	9,226 - 18,732	8,546 - 16,898	8,071 - 14,071
	With wall insulation	15,650 - 25,157	12,988 - 21,340	8,071 - 14,071
Overall range	All measures	15,650 - 28,977	12,973 - 25,123	8,071 - 14,071

7.2. Four-in-a-block

Table 11: Upgrade costs for four-in-a-block flats

Upgrade	Criteria and constraints	Cost (£) Pre-1919	1919-1991	Post-1992
Fabric upgrades				
Individual dwelling measures				
Loft insulation	For top floor only Usually top up Much more expensive if room-in-roof or flat roof	712	581	
Internal wall insulation	Typically for pre-1919 Could be added to CWI Could be instead of CWI	11,285	8,192	
Floor insulation	Ground floor only Suspended floor to 1983 More expensive for solid floor	3,790	2,777	
Replacement windows	More expensive in conservation areas Secondary glazing may be cheaper in conservation areas Single glazing more common in older buildings Replacement of poor DG possible at any age	4,902	4,163	4,164
Replacement external doors	More expensive in conservation areas	1,200	1,200	1,200
General draught-proofing / air tightness		200	144	144
Individual dwellings subtotal	Without wall insulation	7,013 – 10,092	6,088 – 8,284	5,507
	With wall insulation	18,298 – 21,377	14,279 – 16,475	5,507

Upgrade	Criteria and constraints	Cost (£) Pre-1919	1919-1991	Post-1992
Communal measures				
Cavity wall insulation	Jointly with other floors Typically for 1919 to 1983		813	
External wall insulation	Jointly with other floor Typically for pre-1919 Could be added to CWI Not for conservation areas	15,200	12,046	
Communal fabric subtotal	With wall insulation	22,213 – 25,292	6,901 – 20,330	5,507
Heating system upgrades				
Heating system size (kW)		3.5	2.2	2.8
Individual dwelling measures				
Standard ASHP	Property 2 floors max Consent for external units	6,000 – 10,000	6,000 – 10,000	6,000 – 10,000
Internal ASHP/Hybrid	Airing cupboard by external wall	6,000 – 10,000	6,000 – 10,000	6,000 – 10,000
Direct electric heating	External space	4,000	4,000	4,000
Smart storage heaters		6,185	4,441	4,444
Individual dwelling measures only totals	Without wall insulation	11,013 – 20,092	10,088 – 18,284	9,507 – 15,507
	With wall insulation	22,298 – 31,377	18,279 – 26,475	9,507 – 15,507
Overall range	With wall insulation	22,298 – 35,292	14,901 – 30,330	9,507 – 15,507

7.3. Low/high-rise flats (no tower blocks)

Table 12: Upgrade costs for non-tower block low/high-rise 'flats.' Note: Pre-1919 properties of this type are generally the typical tenements

Upgrade	Criteria and constraints	Cost (£) Pre-1919	1919-1991	Post-1992
Fabric upgrades				
Individual dwelling measures				
Loft insulation	For top floor only Usually top up Much more expensive if room-in-roof or flat roof	605	561	
Internal wall insulation	Typically for pre-1919 Could be added to CWI Could be instead of CWI	5,262	6,139	
Floor insulation	Ground floor only Suspended floor to 1983 More expensive for solid floor	2,959	2,615	
Replacement windows	More expensive in conservation areas Secondary glazing may be cheaper in conservation areas Single glazing more common in older buildings Replacement of poor DG possible at any age	3,463	3,672	4,048
General draught-proofing / air tightness		90	106	135
Individual dwellings subtotal	Without wall insulation	4,158 – 6,512	4,339 – 6,393	4,183
	With wall insulation	9,420 – 11,775	10,478 – 12,532	4,183

Upgrade	Criteria and constraints	Cost (£) Pre-1919	1919-1991	Post-1992
Communal measures				
Cavity wall insulation	Jointly with other floors Typically for 1919 to 1983		602	
External wall insulation	Jointly with other floor Typically for pre-1919 Could be added to CWI Not for conservation areas	9,061	9,955	
Communal fabric subtotal	With wall insulation	13,219 – 15,573	4,941 – 16,348	4,183
Heating system upgrades				
Heating system size (kW)		2.5	2.1	2.6
Individual dwelling measures				
Internal ASHP/Hybrid	Airing cupboard by external wall	6,000 – 10,000	6,000 – 10,000	6,000 – 10,000
Direct electric heating	External space	4,000	4,000	4,000
Smart storage heaters		4,755	4,161	4,648
Individual dwelling measures only totals	Without wall insulation	8,158 – 16,512	8,339 – 16,393	8,183 – 14,183
	With wall insulation	13,420 – 21,775	14,478 – 22,532	8,183 – 14,183
Communal heating system				
Communal ASHP		8,000 – 10,000	8,000 – 10,000	8,000 – 10,000
Communal total	With wall insulation	21,219 – 25,573	12,941 – 26,348	12,183 – 14,183
Overall range	With wall insulation	13,420 – 25,573	12,941 – 26,348	8,183 – 14,183

7.4. Tower blocks

Table 13: Upgrade costs for tower blocks. It should be noted that there are no 'tower blocks' before 1919

Upgrade	Criteria and constraints	Cost (£) Pre-1919	1919-1991	Post-1992
Fabric upgrades				
Individual dwelling measures				
Loft insulation	For top floor only Usually top up Much more expensive if room-in-roof or flat roof		584	
Internal wall insulation	Typically for pre-1919 Could be added to CWI Could be instead of CWI		5,532	
Floor insulation	Ground floor only Suspended floor to 1983 More expensive for solid floor		2,797	
Replacement windows	More expensive in conservation areas Secondary glazing may be cheaper in conservation areas Single glazing more common in older buildings Replacement of poor DG possible at any age		3,527	3,971
General draught-proofing / air tightness			95	129
Individual dwellings subtotal	Without wall insulation		4,206 – 6,419	4,100
	With wall insulation		9,738 – 11,951	4,100
Communal measures				
External wall insulation	Jointly with other floor (at least) Typically for pre-1919 Could be added to CWI Not for conservation areas			9,335

Upgrade	Criteria and constraints	Cost (£) Pre-1919	1919-1991	Post-1992
Communal fabric subtotal	With wall insulation		13,542 – 15,755	4,100 – 4,100
Heating system upgrades				
Heating system size (kW)			1.9	2.6
Individual dwelling measures				
Internal ASHP/Hybrid	Airing cupboard by external wall		6,000 – 10,000	6,000 – 10,000
Direct electric heating	External space		4,000	4,000
Smart storage heaters			4,475	6,067
Individual dwelling measures only totals	Without wall insulation		8,206 – 16,419	8,100 – 14,100
	With wall insulation		13,738 – 21,951	8,100 – 14,100
Communal measures				
Communal ASHP			8,000 – 10,000	8,000 – 10,000
Communal total	With wall insulation		21,542 – 25,755	12,100 – 14,100
Overall range	With wall insulation		13,738 – 25,755	8,100 – 14,100

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