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ENERGY EFFICIENCY – TECHNOLOGY LANDSCAPING, SCOTLAND'S ENERGY EFFICIENCY PROGRAMME

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Summary

This report presents the findings from a ClimateXChange commissioned study into the landscaping of Energy Efficiency technologies that can support the delivery of Scotland's Energy Efficiency Programme (SEEP). The study compliments parallel studies into Heat and Smart technologies. This report covers NEF's; archetyping of the Scottish building stock, a summary of effective measures required to treat Scottish buildings, scored reviews of innovative new and emerging fabric energy efficiency technologies applicable to the Scottish building stock and market review through stakeholder workshop.

A focus on fabric energy efficiency technologies has been prioritised, due to these measures having the greatest potential to making our homes and places of work warmer. Further, applicability across the domestic and non-domestic building stock has been prioritised.

A total of 55 energy efficient technologies have been shortlisted and scored against a holistic scoring matrix. Their performance against the criteria has been documented and commentary on applicability offered. At a workshop with leading experts in the Scottish built environment, technologies and scoring were reviewed.

Of the total of 55 technologies, 44 (80%) are deemed suitable to domestic applications, 45 (82%) applicable to community buildings, 49 (89%) to public buildings, 46 (85%) applicable to commercial buildings and just 21 (38%) deemed applicable to industrial building types. This universal applicability of many of the identified energy efficiency technologies bodes well for Scotland and the opportunity for supply chain stimulation, job creation and economic impact potential.

Main findings and insights

- Draught proofing and insulation remain the most effective energy efficiency measures.
- Rather than any new game changing new energy efficiency technologies, we instead see a landscape where incremental enhancements are being made across the board. For example, innovation can be seen in:
    - Material enhancement – for example, in moisture management and resistance to fire and decay.

  - Novel systems – based upon off-site manufacturing, innovative system build-ups and taking a systems approach to improve airtightness and reduce thermal bridging.
  - Innovative surveying and installation - such as use of on-site laser scanning and site based robotics; allowing manufacturers, suppliers and contractors to work to high tolerances in the way they manufacture and install components.
  - Performance risk management – being largely addressed though the sheer range and diversity of products available to suit particular site requirements and building types.

- There is a strong applicability (greater than 80%) of technologies for all building types, with only industrial buildings less well suited to the types of fabric energy efficiency measures reviewed due to the nature and use of such buildings.
- Whilst this landscaping study identifies a wide range of technology options, we strongly recommend that the SEEP programme also focuses effort in ensuring that any energy efficiency retrofit technologies are properly specified, designed, implemented and then verified through testing and evaluation, regardless of scale of deployment.
- Based on the findings from the archetyping work, we also separately recommend the Scottish Government commissions a non-domestic building review and continues to commission strategic pilots to demonstrate the benefits of promising technologies when installed on applicable building types in a variety of different site contexts.

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Introduction

The brief

This is one of three technology landscaping studies commissioned by ClimateXChange, feeding in to the Research and Development (R&D) work stream of Scotland's Energy Efficiency Programme (SEEP). ClimateXChange is working closely with the Scottish Government policy team working on delivering SEEP.

The three landscaping studies are:

- Smart energy technologies – led by CAG Consultants in conjunction with Smarter Grid Solutions and Innovas.
- Energy efficiency technologies **(this report)** – by the National Energy Foundation
- Heat generation technologies – by BRE Scotland

Together the studies create a platform and common format for further developing and updating the understanding of technologies. The focus of this report is on technologies that are or will be 'ready' for commercial application under SEEP – the guideline for this being a Technology Readiness Level (TRL) of 8 or 9. Each shortlisted technology is assessed against an agreed set of criteria on technical, environmental, consumer, monetary, supply chain and policy grounds.

Scotland's Energy Efficiency Programme (SEEP)

SEEP is the "cornerstone" of Scottish Government's National Infrastructure Priority on buildings energy efficiency. It will combine existing energy efficiency and community energy programmes with new devolved powers over Supplier Obligations on energy efficiency and fuel poverty.

Alongside its draft energy strategy published in January 2017, Scottish Government is consulting on the SEEP framework[1.] A pilot phase is underway, with projects running to 2018/19. A development phase to 2022/23 will see implementation of advice and support services, an assessment and consumer protection framework. Thereafter will be a full-scale operation of SEEP, facilitated by new regulation as appropriate (e.g. of private sector rented sector).

The vision is a scheme which combines and consolidates interventions across all of Scotland's building stock – commercial, domestic and social – making use of delivery mechanisms shown to work and deliver value for money. The programme will pilot new and innovative approaches to energy efficiency for community groups and businesses alike.

Report structure

All three studies use a similar reporting structure, as follows:

- Scottish building context – identifying the application context (both domestic and non-domestic) for innovative technologies
- Technology area – introduction to the groups of energy efficiency technologies reviewed
- Methodology – overview of the consultant's methodology
- The technologies – a narrative on shortlisted technologies, trends emerging from the assessment, contextual observations and identification of key data gaps. Databases of technologies and assessment scores accompany the three reports.
- Closing remarks and future work

[1] National Infrastructure Priority for Energy Efficiency – Scotland's Energy Efficiency Programme. January 2017. http://www.gov.scot/Publications/2017/01/2195/downloads#res-1

Scottish Building Context: Domestic Stock Analysis

Purpose

To initiate our study we conducted a thorough Scottish building stock analysis, both for domestic and non-domestic buildings. The purpose of which was twofold. Firstly, without context, the scoring of the technologies could arrive at technically innovative, but lacking widespread application in the Scottish building context. Secondly, the analysis has led to the identification of suitable domestic and non-domestic archetypes. This identification has opened up the opportunity to consider the applicability leading energy efficiency technologies, as scored via the matrix, against the Scottish building archetypes.

Introduction

This analysis was developed primarily based upon the public report, *Scottish House Condition Survey: 2015; Key Findings*, published by the Scottish Government. Additional research and references are noted in the appendix. The objective of the analysis was with a view to developing standardised house types which could be used as a basis for considering the applicability of particular energy efficiency technology innovations and to appreciate the specific challenges presented by the Scottish building stock and its context. In Scotland, it is standard that each flat in a block or tenement is a freehold; so multi-tenant buildings may require joint permission from multiple owners in order to make certain improvements, for example. Similarly, the Scottish building stock presents unique challenges in relation to conservation of historical features and facades in the main cities such as Glasgow and Edinburgh; challenges in relation to high wind and rain exposure across the highlands and coastal areas; a variety of trends in the use of novel non-traditional construction methods and also; a diverse spread of properties off the gas grid, dependant on electricity, solid fuels and renewables for heating and hot water. As can be seen from the archetypes identified, this context presents a wide range of innovation challenges for the Scottish supply chain to respond to.

In headline terms, there are approximately 2.5 million households in Scotland.

- 76% of Scotland's domestic stock comprises of buildings built pre-1982 i.e. before standards for minimum levels of energy efficiency and airtightness were introduced.
- 91% of Local Authorities' and about half (49%) of the Housing Association's stock were built between 1919 and 1982; private rented sector dwellings accounted for 36%.
- In 2015, 37% of Scottish homes were in EPC band C or better and about a fifth (20%) were in bands E, F or G.
- 34% of social housing dwellings have uninsulated walls, 48% in private sector dwellings.
- Overall, 89% of solid wall dwellings and 29% of cavity wall dwellings are uninsulated.
- The share of dwellings in the lowest energy efficiency bands (F and G) is particularly high for pre-1919 dwellings (14%), non-gas heated properties (between 17% and 20%), detached properties (11%), and in the private rented stock (9%).

From an energy efficiency perspective, what is particularly notable is the general trend of improvement. Over the period 2010-2015, the proportion of properties in the lowest EPC bands, E, F and G, nearly halved; down from 27% in 2010 compared with 15% in 2015. The biggest gains have been seen in the social housing sector, where 10% are in the E, F and G bands compared to 22% in the owner occupied and 38% in the private rented sector. This is again important when it comes to considering the type and nature of innovation that may be required to be driven under the new SEEP programme. Anecdotally we know that challenges for the private housing sectors include awareness, upfront costs, technical complexity and installation disruption, especially when it comes to harder to treat buildings such as those with solid walls and in off-gas areas.

Fuel Poverty Vulnerability

Built property characteristics aside, another priority under the SEEP programme is to deliver economic benefits not just through an improved buildings energy efficiency supply chain, but also to ensure that homes and businesses are affordable to heat and use.

Insights arising from the 2015 Scottish House Condition Survey in relation to fuel poverty among households include:

- Approximately two thirds (67%) of fuel poor households live in houses. The remaining third (33%) in flats.
- 25% of the dwellings of fuel poor households were built pre-1919 and 59% with homes built 1919-1982.
- 31% of Scottish households were under the fuel poverty line in 2015. The majority of fuel poor households are owner occupiers (59%), 46% of whom own their property outright and only 13% with a mortgage.
- 13% of fuel poor households are families with children, 43% older one or two-person households and the remaining 43% all other types of households with adult residents.
- Rural fuel poverty is now almost equal to the level of fuel poverty in urban areas (30% in 2015)

From an innovation standpoint, these statistics highlight the need to consider not only the applicability of technologies to certain building types but also that household composition, occupancy patterns and the financial position (inc. age and ability to invest or borrow) also all stand to influence the likely take-up and the potential impact of certain interventions.

Housing Quality

In 2015, 73% of all dwellings had some degree of disrepair, however minor. Disrepair to critical elements stood at 52%, 33% of dwellings had some instances of urgent disrepair, and in 8% of the housing stock some extensive disrepair was present. Around 9 out of 10 properties were free from any damp or condensation, an improvement of around 3 percentage points since 2013.

In Scotland around three quarters of dwellings have external cavity walls and the remaining one quarter have solid or other construction types of external wall. These "other" types include steel or timber-frame dwellings and dwellings made from pre-fabricated concrete. As of 2015, 89% of these "other" wall types were not insulated, and 29% of cavity walls were uninsulated, 10% of which were hard-to-treat-cavities.

The next section of this report considers the above insights, in addition to wider research and also experience in developing retrofit programmes with social housing providers and private stock holders within Scotland; concluding with a small set of archetypes that each present unique challenges and opportunities in relation to retrofit of energy efficiency measures.

Selection of Representative Dwellings

Four representative dwellings have been identified, based on both the SHCS:2015 data as well as the Spéird Project, which looked specifically at clarifying the delineation of fuel poverty in the Scottish housing stock. These have been chosen based their proportional volume of stock as well as general vulnerability to poor performance and fuel poverty. The four main clusters of interest are outlined below.

Table 1. Number of Occupied Dwellings by Age Band and Type, 2015 (Thousands)

Age of dwelling	Detached	Semi-detached	Terraced	Tenement	Other flats	Total
pre-1919	103	46	62	218	59	**488**
1919-1944	33	76	27	36	103	**274**
1945-1964	40	139	162	108	76	**524**
1965-1982	127	118	178	79	52	**554**
post-1982	228	101	94	138	33	**594**
Total	**531**	**480**	**522**	**579**	**322**	**2,434**
Sample size						*2,754*

Pre-1919 tenement flats

These are predominantly located in more urban areas. They make up approximately 9% of the housing stock, and can be some of the more difficult to treat, due to; the adjacency issues with other units, traditional construction techniques, and sometimes complicated geometry. Pre-1919 Tenements have an average floor area of 70m^2.[2] 73% of pre-1919 properties have uninsulated walls.

"4-in-a-block" flats

These were commonly built as social housing between 1919 and 1965 (72% of all flats of this type fall in that age category, and are categorised as "Other Flats" in Table 1). In total, there are 223,000 flats of this type in Scotland, which represents nearly 10% of the Scottish housing stock. Of the data available, mid-century flats (of all types i.e. slab blocks, house conversions, as well as 4-ina-a-block) have an average floor area of 70m^2.

Post-war terraced houses

Terraces built between 1945 and 1982 represent approximately 14% of the housing stock and have an average floor area of 85m^2.

Post-war, Timber-Framed Detached

These are a highly common house-type in Scotland, especially in rural areas, and notoriously problematic when it comes to energy efficiency. This construction typology has been specifically chosen due to being singled out by the Spéird Project as both common and vulnerable to fuel poverty, due to the larger size and exposure, and potentially larger family size. The 1945-1982 detached houses represent approximately 7% of the total stock, which includes some system-built and non-standard construction types, so the exact proportion of timber-framed homes cannot be easily determined. Just over half (213,000) of all rural dwellings are detached. When the post-1982 homes are included, the detached typology represents ~16% of total housing stock. Detached homes built 1945-1982 have an average floor area of 125m^2.

A fifth potential house type is a post-war semi-detached house, though the challenges to address these are similar to their detached counterparts.

[2] From Figure 2: Average Floor Area by Dwelling Type and Age; Scottish House Condition Survey: 2015

Tenements

Tenements are mostly found in urban areas and are predominantly pre-1919 solid-stone wall construction dwellings, typically constructed in rows or full streets of terraces.

General Construction

Tenements have a common stairwell, or "close", which uses a single external entrance for all flats with internal doors to each unit. This means all flats have a wall adjacent to the internal close space (often unheated), as well as a party-wall on the opposite side and one or two or three aspects with external walls, depending if it's at the end of a terrace. They typically have tall windows (~2 metres), and ceilings (~3 metres), which is common to Victorian, Georgian, and Edwardian buildings. The lack of external surfaces in tenements is partly why the Energy Efficiency Rating of tenements and the banding from the EPCs are generally better than other dwelling types in Scotland[3] (see Table 1).

	EE Rating		Band		
	Mean	Differences from 2014	BC	DE	FG
Dwelling Type					
Detached	58.2		26%	63%	11%
Semi	61.1		26%	69%	4%
Terraced	63.3		35%	62%	3%
Tenement	66.4		51%	47%	3%
Other flats	66.0		46%	52%	1%

Table 2. SAP 2012: Mean EER, Differences from 2014 and Broad EPC Band, by Dwelling Characteristics, 2015

The "close" is typically uninsulated, and often has single-glazed windows on each landing. These are often in a poor state of repair in older properties, causing draughts and heat loss in the common close, due to the delay and complication in carrying out maintenance and upgrades to common parts of the building, as it requires all freeholders agree, and contribute to the cost of maintenance, repair and upgrades. The front doors of closes are often also in a poor state of repair, poorly fitted, and uninsulated. This means the close is a sheltered, but not fully "indoor" space, which can often have significant draughts and heat loss.[4]

Both original and replacement windows can be very draughty, often due to poor fit around the perimeter. Due to the size of the windows, this can cause significant cold draughts and heat loss. Tenements typically have chimneys in each major room. Many have been sealed off over the years.

Tenements are typically made of stone (Ashlar, squared or random Rubble), ~600-800mm thick, with lathe and plaster or dry-lined internal finish. According to in-situ U-value tests carried out by Historic Environment Scotland, the typical tenement U-value of an uninsulated 600mm solid stone wall with lathe and plaster internal finish is ~1.1 (+/-0.2)

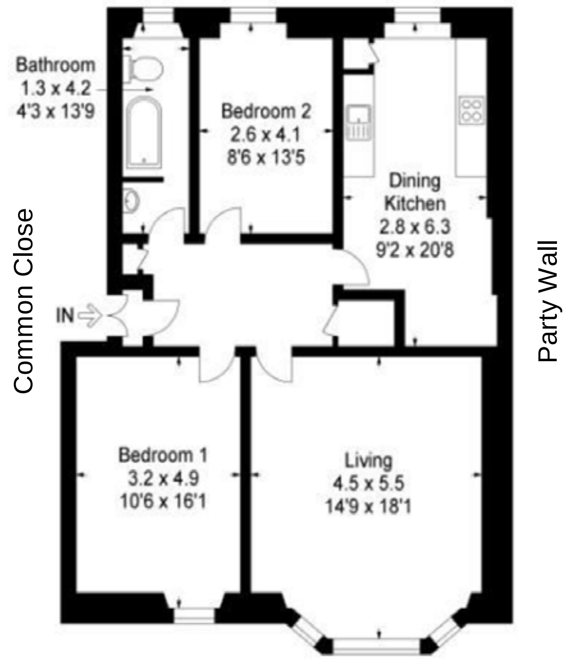
[3] From Table 21 of the Scottish House Condition Survey: 2015; Key Findings

[4] Common repairs of such closes are often excluded from current energy improvement funding as it's the freeholders, as a group, who own them - not any one individual household.

W/m²K[5]. Ground floor units typically have a suspended timber floor, and top-floor units typically have a wood-framed pitched roof. The U-values of roofs can be highly variable, but range between ~0.7 - 1.2W/m²K[6]. Most tenements are pre-1919, so the average internal floor area is taken as 70m[7].

Potential Suitable Measures

Tenements are generally not suitable for external wall insulation, due to the aesthetic appeal of the buildings and because an entire street would have to be insulated in order for the measure to be effective with minimal technical risk or disruption with neighbouring properties.



Internal wall insulation is possible, though there are geometric complications around bays and beneath and around windows where there is often traditional joinery and a significant air gap as well as traditional features such as shutter-boxes and cornicing. These areas are particularly difficult to treat, are a location of both thermal bridging and potential air infiltration, and the retention of traditional features can impact the property's value, so dismantling them or adversely impacting them for energy-saving benefits is often an unappealing option to owners. Furthermore, dry-lined solutions on top of lathe and plaster walls can carry some significant risks of interstitial condensation, and fully-adhered systems would require the full removal of the lathe-and-plater (including decorations), so there are some pragmatic issues with IWI.

Loft and underfloor insulation are suitable in the top and bottom floor units, respectably, with some caveats. It would potentially be advisable to insulate the common close floor and ceiling, to avoid driving a thermo-syphon in the close. The range of underfloor insulation should be examined to ensure it's appropriate for suspended timber floors in regards to vapour permeability and the nature of the heat loss being addressed (latent and convective heat, in this case, as opposed to radiant heat). A significant source of heat loss to the floor is air infiltration, which needs to be resolved to get the full benefit of the underfloor insulation. This can be achieved with specific products (spray-foam insulations, for example), though the majority of these are not all vapour-permeable, or via mechanically sealing the more significant air gaps using air-tightness tape and barriers. Applying sealant under the skirting boards is generally not advisable.

Secondary or double glazing is also feasible in these properties. And, secondary glazing in homes that already have first generation double-glazing is a feasible upgrade, as is the application of low-E film (many first generation double-glazing do not have a low-e coating to keep heat in the building). Chimney baffles are feasible where chimneys are still open.

Currently, there is no funding available for thermal upgrades to common areas of the building due to the fact that there's no one person to sign any funding contract in a building of free-holders, and the fact the common areas don't constitute a dwelling.

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5 U-Values and traditional Buildings, In-situ measurements and their comparisons to calculated values Technical Paper 10, Historic Scotland, January 2011 (p.21)

6 U-Values and traditional Buildings, In-situ measurements and their comparisons to calculated values Technical Paper 10, Historic Scotland, January 2011 (p.17)

7 Scottish House Condition Survey: 2015; Key Findings, Figure 2: Average Floor Area (m²) by Dwelling Type and Age, 2015

"4-in-a-block" or Cottage Flats

The second typology is so-called "4-in-a-block" flats, or cottage flats, which are found throughout Scotland in urban, suburban and rural areas.

General Construction

Cottage flats are generally post-war brick/block construction predominantly with masonry cavity-wall construction. These flats have no common stairwell, and each flat has its own external entry. As the buildings are stand-alone, they have a relatively higher proportion of external wall areas than tenements. They also have shorter (~2.4m) floor-to-ceiling heights and smaller windows, typical of post-war construction. They are typically 2- or 3-bedroom flats. Some have been converted from 2-bed to 3-bed by partitioning the living area.

Cottage flats are constructed with a range of methodologies, but they are predominantly rendered brick/block cavity construction with suspended timber floors and timber roofs. Earlier cottage flats will potentially have hard-to-treat and narrow cavities. The internal surfaces of occupied rooms in these cases are often plastered on the hard. Some have fireplaces/chimneys along the party wall. Ceiling heights are generally a more modern ~2.4m

These typologies are also constructed of a number of non-traditional construction methods, including system-built no-fines construction. These tend to be clustered in specific areas from particular historic construction programmes. Some of the non-standard and system-built construction may struggle to support the additional structural loading of significant retrofit measures without additional reinforcement or remedial works, or require other maintenance works to ensure significant retrofits can be safely undertaken.

Potential Suitable Measures

These properties can be suitable for a range of window and door upgrades, a range of draught-proofing options, loft and underfloor insulation, and chimney baffles where there are open chimneys.

In terms of wall insulation, there are a range of issues and options to consider. Cavity wall insulation (CWI) is the most obvious solution. According to the latest data, approximately 71% of Scottish homes with cavity walls were already insulated. One thing to be wary of with already-insulated cavity-wall properties is that junctions, corners and edges at floors, ceilings, party walls, windows and doors can experience exacerbated risks if multiple insulation measures are utilised to improve energy efficiency, and infiltration and thermal bridges are not robustly addressed and resolved.

In this form of construction, a vapour permeable CWI option would often be advisable, which is a non-standard solution, and some caution should be taken with any wet-applied insulation system, which could saturate the building fabric. It's also critical that any water ingress details such as flashings, eaves, and cills be carefully checked, and repaired or upgraded to ensure that the cavity remains free from excessive water ingress after insulating, which could then result in serious damp issues. The windows present a challenge as the internal cills, headers and jambs can be specific locations for thermal bridging and thus vulnerable to surface condensation after cavity insulation is installed. For this reason, a combined solution of CWI, with reveal-specific internal wall insulation solutions may be advisable in some cases to reduce the risk of thermal bridging around the window returns, down party-walls for 300mm is also advisable to reduce the thermal bridge with the adjacent unit. It's possible that CWI properties that have already had cavities insulated could benefit from a thin layer (~20mm) of surface adhered IWI.

A potential option is to externally insulate the entire building. This would enable some reduction in thermal bridging, however it would require the consent of all four freeholders in a building, and the works would have to all be done at the same time. Eaves would likely need to be extended to ensure the loft is still ventilated, though EWI would allow the cavity to still function to manage moisture transfer risk. Coordinating and agreeing a whole-building EWI programme in privately owned cottage flats is probably logistically difficult, though it would be more feasible in social housing. It would not be wise to insulate only one unit in a block of cottage flats. Half a cottage flat building (a ground floor unit and the above first floor unit) could potentially be insulated though may cause knock-on problems at the party wall for the uninsulated units.

Post-war terraces

The third typology is post-war terraces. These are found across Scotland, but the majority are located in urban areas (87%).

General Construction

Post-war terraces are typically masonry cavity-wall construction with suspended timber floors and timber-framed pitched roofs. They also have shorter (~2.4m) floor-to-ceiling heights and smaller windows, typical of post-war construction. They are typically 2- or 3-bedroom houses. The internal surfaces are often plastered. Most have fireplaces/chimneys along the party wall. Ceiling heights are generally a modern standard of ~2.4m, and the homes typically have shorter, punctured windows which are typical of this era. Terraces are typically rendered on the outside (with pebbledash or other), and may include features such as porch shed roofs, conservatories or roof dormers from loft extensions.

Potential Suitable Measures

These properties can be suitable for a range of window and door upgrades, a range of draught-proofing options, loft and underfloor insulation, and chimney baffles where there are open chimneys.

In terms of cavity wall insulation, these properties face similar issues to the cottage flats, only it's simpler to insulate individual homes. External wall insulation is highly appropriate, but needs proper resolution around garden walls, eaves, conservatories and other details.

Post-war, Timber-Framed Detached

These are a common house-type in Scotland, especially in rural areas, and notably problematic when it comes to energy efficiency. This construction typology has been specifically chosen due to being singled out by the Spéird Project as both common and vulnerable to fuel poverty, due to the larger size of the property, greater surface area exposure, and potentially larger family size. The 1945-1982 detached houses represent approximately 7% of the total stock, which will include some system-built or non-standard construction, so the exact proportion of timber-framed homes cannot be easily determined. The homes of this era are commonly single-storey bungalows; however some have had extensions or other alterations to the original layouts. Just over half (213,000) of all rural dwellings are detached. When the post-1982 homes are included, the detached typology represents ~16% of total housing stock. Detached homes built in the period 1945-1982 are recorded in the 2015 SHC to have an average floor area of 125m^2. Timber frame was also used in a number of semi-detached homes as well.

General Construction

Mid-century timber frame homes generally have masonry plinths, either suspended timber floors or slab-on-ground, and timber trussed roof. The windows can be of variable sizes typical of the era of construction. Floor to ceiling heights are of a more modern standard and can be assumed to be ~2.4 meters. The homes can have 2-4 bedrooms. The construction can be quite draughty, depending on the external treatment of the walls and openings.

Potential Suitable Measures

These properties can be suitable for a range of window and door upgrades, a range of draught-proofing options, loft and underfloor insulation, and chimney baffles where there are open chimneys.

In terms of cavity wall insulation, these properties can potentially accept cavity wall insulation, depending if a cavity is present, suitable and clear. External wall insulation is potentially appropriate, but needs proper resolution around garden walls, eaves, conservatories and other details, as eaves and guttering would likely need to be extended.

Scottish Building Context: Non-domestic Stock Analysis

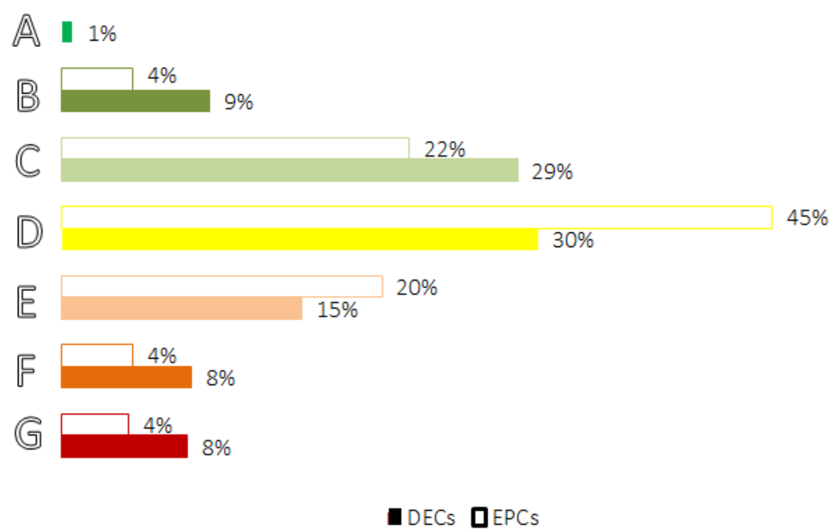

Figure 1 – Percentage distribution of the Scottish non-domestic building stock by EPC and DEC as on Jan 2017 (Source: DCLG's OpenDataCommunities.org)

Data available on the Scottish non-domestic building stock has proven to be sparse and of a largely disparate nature, with the above graphic based on a total of 1,088 lodged non-domestic EPCs and 406 Display Energy Certificates (DECs) as available via the DCLG open data portal accessed January 2017. The most indicative information available on typology and construction was on estate agent websites. The Section 63 reports are not readily available and searchable online, making it difficult to assess the current state of the non-domestic stock and provide some contextual details for the type and size of non-domestic buildings currently operational in Scotland. As an aside to this study, this would be worthwhile remedying – making *a searchable, anonymised database of non-domestic buildings in Scotland*, which includes searchable traits such as; building typology and use (e.g. school, hospital, GP Surgery, retail store, office, etc.), energy rating, age and general condition. Coupled with the key outputs from the "Action Plan", this would help identify market size for various products, and attract business and investment in these areas to serve the market needs. Such a database could begin to be populated by the gathering and publishing of ESOS Scotland data. Without more precise data, it is difficult to determine benchmarks and to quantify improvement potential.

Taking Edinburgh as a small representative of Scotland, research conducted by Chetbout et al., (2015) on buildings owned by City of Edinburgh Council reveals that:

- **Educational buildings** emerge as the predominant cluster both in terms of number of premises (70%) and floor areas (72%).
- Approximately 25% of schools were built prior to 1919, and 57% before 1964.
- The end-use thermal energy consumption of schools averages at 186 kWh/m^{2}year, 86% higher than the European average, accounting for 68% of the sample overall CO2 emissions.
- **Offices** are the second cluster, responsible for 8% of thermal and 17% of electricity or 180.6 kWh/m^{2}year.
- **Commercial properties** such as hospitality (guest houses, B&B's, some pubs, etc) may best fall into the guidance and notes for domestic stock, as these buildings are often of a similar construction and typology and would benefit from similar measures and approaches. Likewise, there are a number of commercial property areas in Scotland which are integral to buildings such as tenements (where there may be retail units on the ground floor, or converted townhouses/terraces) which could similarly be grouped with their domestic counterparts.

Schools

The total number of schools in Scotland is published in an annual report by Scottish Government[8]. From this data, it was clear there that ELC (Early learning and childcare) and Primary were the two largest portions of the school building stock. There was little published information available on the size of ELCs, however, there was a reasonable amount of summary information on primary schools, which could be used to infer an indicative building typology. The average floor area for primary schools was calculated using Aberdeenshire's published data on primary school size (GIFA)[9], which was calculated as 2,761m^2. Using Edinburgh as example[10] on construction typology, approximately 25% of schools were built prior to 1919, and 57% before 1964. So, for the purposes of the assumed case study a single-storey, typical mid-century construction of cavity wall masonry construction is assumed, with slab-on-grade floor, timber truss roof and natural ventilation. The pupil/teacher ratio for primary schools is 16.6, as of 2016 published data.

Table 2.1: Schools, pupils, teachers and pupil teacher ratios (PTR) for all publicly funded schools by school sector, 2010 to 2016

	2010	2011	2012	2013	2014	2015[(2)]	2016
Schools							
ELC[(1)]	2,586	2,553	2,551	2,504	2,449	2,492	2,514
Primary	2,099	2,081	2,064	2,056	2,048	2,039	2,031
Secondary	372	367	365	364	362	361	359
Special	163	158	155	149	145	144	141

(1) ELC centre count includes local authority and partnership centres, and ELC teacher figures include ELC home visiting. 2010, 2011, 2012 ELC and primary figures were revised in 2013. See background note 4.
(2) 2015 primary school and pupil figures were updated in February 2016. See background note 2 for details.

Offices

No specific information could be found which could help identify or specify a representative office building in Scotland. They are of a wide range of construction typologies, ages, and design. Many commercial properties share the same construction methodologies and materiality issues identified in the domestic stock assessment. It's recommended a simple 4-story office block be considered with floorplates in the range of ~500-600m^2 each.

Industrial Warehouse

For the sake of an exemplar building, it may be useful to consider an industrial warehouse, as Scotland has a fair number of industries and infrastructure. These are not necessarily fully heated, but often use convective fan-heaters to off-set external temperatures. These are predominantly large steel portal framed industrial units under a profiled metal clad roof. They can be assumed to have block/brick dado walls and profiled metal cladding. The wall head can be assumed at approximately 6.5m (roughly the height of a 2-storey building, only without the second floor) and a floor area of ~800m^2. They also often have roof lights, though few have significant window openings. The external loading door is often a significant source of heat loss.

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8 Summary statistics for schools in Scotland No. 7: 2016 Edition; http://www.gov.scot/Resource/0051/00511490.pdf
9 Gross Internal Floor Area of Primary Schools - Aberdeenshire http://www.aberdeencity.gov.uk/nmsruntime/saveasdialog.asp?lID=53378&sID=23620
10 Chetbout et al., (2015)

Energy efficiency

Scope for this study

Energy efficiency has been designated a 'National Infrastructure Priority' and has catalysed the 15 to 20 year SEEP programme. 'Energy efficiency' can refer to a broad range of technologies that can reduce energy use in a building, whilst providing a similar standard of performance. Recognising the complementary SEEP studies on 'Smart' and 'Heat Generation' technologies, for the purpose of this study, energy efficiency technologies have been narrowed down to fabric energy efficient technologies. Energy efficiency technologies that have been omitted include low energy lighting, energy efficient pumps, fans, cooling systems and appliances, and also systems such as waste water heat recovery, flue gas heat recovery and interventions such as lagging of primary heating system pipework. These were excluded from the study because they are either already well established, with a strong business case already driving uptake (e.g. LED lighting and efficient pumps and fans), or they cut across the research themes (e.g. flue gas heat recovery and pipework insulation relating just as much to heat generation as it does with energy efficiency).

Informed by the research presented on Scottish domestic and non-domestic buildings, the technologies reviewed include innovative:

- Insulation technologies and techniques:
  - Ground/basement floor insulation
  - Wall insulation
  - Roof insulation
- Shading and glazing systems:
  - Windows and curtain walling
  - Doors
  - Shading systems and glare control
- Air tightness and ventilation systems:
  - Airtightness interventions
  - Ventilation systems

Each technology area identified provides energy efficiency improvements to Scottish buildings through upgrade of the building fabric. During the study, the technologies have been grouped based on the building element that they are applicable to. For example, solid floor, suspended floor and perimeter insulation technology solutions are all intervention categories that fall under the ground/basement floor insulation element.

It is widely acknowledged that it is better to reduce energy demand wherever possible, before then designing and specifying heating, cooling, ventilation systems and any supporting renewable energy systems. Reductions in energy demand should typically target the highest energy loads in a building, typically the provision of space heating. In addressing the building fabric to reduce such space heating losses, not only is the fabric and the health of the building improved, there is also a knock-on benefit/opportunity to deliver improved indoor air quality, occupant health, wellbeing and productivity.

Double glazing is a common example of where the majority of homes have been retrofitted with an energy efficiency measure. Replacing single glazing for double glazing improves the quality of life for tenants through reduced noise pollution, improved security and aesthetics, whilst the greater thermal resistance (rate at which heat is lost from a building) ensures comfortable room temperatures can be achieved and maintained by using a fraction of the energy.

To that end, fabric energy efficient technologies provide the staple building block to any sustainable future. Existing low cost, and low disruption technologies have begun to be common place – with 71% of cavity walls being insulated, for example.

This study has sought to go beyond established technologies and identify innovative energy efficiency technologies in the sector that can offer the Scottish building stock a step change in energy efficiency performance, as well as offering a commercial exploitation opportunity for Scotland. Innovation in this context can range from new and emerging materials and technologies, through to more efficient and less disruptive means of installing and delivering more established, well understood solutions.

Methodology

Basic approach

The following sets out the workflow adopted in undertaking the energy efficiency technology landscaping study:

1) Research innovative fabric energy efficient technologies for non-domestic and domestic buildings
2) In parallel, review Scottish housing stock and identify archetypal buildings
3) Shortlist those technologies that are 'near market' – either innovative (TRL 8/9) or installed innovatively
4) Preliminarily score each technology/technique against an agreed scoring matrix covering the categories:
    a. Technical
    b. Environmental
    c. Policy / Regulatory
    d. Financial / Monetary
    e. Capacity / Supply chain
    f. Consumer
    g. Opportunities / Risks
5) Rank technologies by each element, undertaking desk based research into each technology and peer review
6) Through an external workshop, identify additional innovative technologies and review the preliminary scoring
7) Score additional technologies following workshop, ensuring applicable energy efficiency technologies for the main energy loads for each building type have been reviewed
8) Comment on the applicable context for leading technologies for each building element group, and building type

Literature review

Previous studies have identified that the current government's model of subsidised retrofit measures has gone some way to upgrade the building stock. This has typically been through cavity wall and loft insulation subsidies, with 71% of cavity walls now insulated and at least 100mm of loft insulation installed in an estimated 92% of lofts. Whilst such subsidies have encouraged positive action, this piecemeal approach has tended to create a perception that there is little more that can or should be done to further improve building fabric energy efficiency.

The wide reaching 'Retrofit for the Future' study[11], amongst other similar whole house retrofit pilot projects, concluded that the best results are achieved through integration, where multiple interdependencies are considered and their

[11] https://retrofit.innovateuk.org/documents/1524978/2138994/Retrofit%20for%20the%20future%20-%20A%20guide%20to%20making%20retrofit%20work%20-%202014

needs and details balanced. During the Retrofit for the Future study, 86 properties were holistically retrofit to reduce their carbon usage by 80%. The majority of projects insulated all external building elements to maintain a continuity of insulation. Practically, the study identified numerous installation best practice advice to ensure optimal performance.

The Passivhaus Institute has established EnerPHit[12], to certify domestic retrofits that have used Passivhaus components and principles. The cost however, continues into the hundreds of thousands, with strict U-value and air tightness criteria. Whilst effective at improving fabric energy efficiency, it is inaccessible for many due to the price point.

Further, national networks such as SuperHomes have emerged[13], where residents who have demonstrated a 60% reduction in carbon dioxide emissions from retrofits, form a peer-to-peer advice network. Many of the SuperHome owners have carried out much of the work themselves; therefore retrofit costs were significantly reduced against whole-house retrofit alternatives. With NEF managing the SuperHomes open days, many of the technologies and approaches used across the country have come across our desks.

Work by Saint Gobain and University of Salford[14] explored individual measures against whole-house retrofit solutions. Against a baseline of 100mm loft insulation and 90's double glazing, individual measures (loft insulation, glazing and SWI upgrades) saved 4%, 7% and 46% respectively. Fabric efficiency savings (and carbon savings) of 63% were delivered by the whole-house retrofit, with savings made up of 6% loft insulation, 11% floor insulation, 11% glazing upgrade and 72% solid wall insulation. This shift towards deep-whole house retrofit has led to specialist multi-trade teams, overseen by specifically qualified retrofit coordinators[15].

Although central to any low-energy building future, for the most part, insulation materials are not novel. The notion of insulating buildings is as old as buildings themselves. There are a limited number of innovative insulation materials however these are typically too expensive to achieve broad viability. Rather, the trends in fabric energy efficiency innovation (as well as the move to whole-house retrofit) have centred on improving installation efficiency, to reduce disruption, deliver a better finished product (performance and aesthetics), and reduce waste. These installation improvements target better accuracy and in-use performance enhancement. This is often achieved through a combination of laser scanning, measurement, offsite manufacturing and rapid (sometimes robotic) installation. With respect to a better finished product, numerous innovations build upon existing insulation technologies to diversify the supplementary benefits offered, such as improved moisture resistance, breathability or appearance.

Technology Readiness Levels

The scope of this study targeted assessment of 'near-market' technologies. In this report, this has been defined as technologies that are high on the technology readiness level (TRL) scale (Figure 2), predominantly levels 8 and 9. It was deemed technologies of this level offer SEEP the optimal blend of innovative, yet commercially available technologies, capable of delivering energy efficiency and economic benefit to the Scottish building stock.

Technologies lower down the TRL scale carry higher uncertainty as to whether they will achieve commercial viability. A number of technologies were reviewed that could be considered established or incumbent technologies. These were included where innovative elements had recently been developed, for example, uPVC double glazing units continuing to be enhanced through multi-chamber frames and glazing units with warm edge spacers and low thermal conductivity gas fills. As a result, the technologies covered provide SEEP with a thorough analysis of available technologies.

[12] http://www.passivhaus.org.uk/filelibrary/Passivhaus%20Standards/EnerPHit_Criteria_Residential_EN.pdf
[13] http://www.superhomes.org.uk/
[14] http://www.salford.ac.uk/__data/assets/pdf_file/0008/563165/pdf4-saint-gobain_energy_house_leaflet_high_res_v8.pdf
[15] https://www.retrofitacademy.org/programme/retrofit-coordinator/

Figure 2 - TRL breakdown as used by the European Commission.

Assessment criteria

To enable comparative assessment of technology impact potential, against SEEP objectives the following assessment criteria matrix has been used for each of the three SEEP studies. Where possible each technology has been assessed on simple Likert 1 to 5 score for each criterion. Comments by the research team have also been added to offer qualitative context for each score. The quantitative scoring is useful for 'at-a-glance' comparing of technologies, however investigation into the qualitative context is advised before conclusions are drawn.

Table 2 outlines each criteria and the quantitative scoring range. The agreed criteria are the product of initial criteria outlined in NEF's proposal, subsequently reviewed, discussed and agreed between the three collaborating consultancy teams.

The **technical** section covers areas of technical performance, where high efficiency, reliability, compatibility and adaptability are all advocated. **Environmental** scores carbon saving potential and cradle to grave whole-life impact. **Policy / Regulatory** criteria score compatibility with the existing frameworks underpinning Scottish legislation. The **monetary** section assesses the financial impacts of each technology; capital costs, and a measure of cost/carbon saving benefit i.e. pound per tonne of CO_2 saved. **Capacity / Supply Chain** criteria measure the capability within Scotland to exploit the opportunities afforded by the technology; be that through national job creation or international trade. The final quantified category, **Consumer**, scores impacts and benefits of the technology on the consumer; measures include disruption, quality of life improvements, usability, savings and protection. **Opportunities** and/or **Risks** are evaluated qualitatively to note watch points and guide further work and guidance for the implementation of SEEP.

To enable high-level comparison between the technologies, assessment criteria have been scored on a 1 (poor performance) to 5 (good performance) Likert scale. The definition of 1 and 5 vary depending on criteria, for example a low efficiency technology would score 1 (for Efficiency), however the same technology with a low risk of unintended consequences would score 5 (for Risk), as this is the desirable (good performance) end of the scoring scale. In the score cards and technology summaries colour coding further aids comparison, where a score of 5 is coloured green, and a 1 red. There are a total of 27 scored assessment criteria for each technology and a further three qualitative criteria.

The following brief definitions offer a guide to how each assessment criteria has been applied:

Technology readiness measures the commercial availability of the innovation based on defined levels from idea (level 0) through to commercially available product (level 9).

Efficiency (product / technology efficiency) assesses the energy efficiency of a technology against other technologies available. For example, insulating plaster is considered against alternative wall construction products, therefore will likely score lower than the best insulation materials, but higher than a non-insulating material.

Reliability considers the technology's relative vulnerability and likelihood for necessary corrective measures during the product life.

(level of) Compatibility with existing systems assesses the relative applicability of the assessed technology to seamlessly operate with its surrounding technologies upon retrofit. For energy efficiency technologies most will be applicable where designed, but will be limited to that application.

Complexity of systems/ their integration assesses the difficulty and number of stages required to retrofit a technology. For example, retrofitting double glazing is compatible with surrounds, where the old glazing is removed, therefore scores highly; however the introduction of new glazing to a solid wall is compatible, but may require significant structural work to enable installation, thus scoring more lowly.

Risk/severity of unintended consequences considers relatively, how likely a technology would cause unexpected problems. For example, inappropriate insulation on a vapour open is likely to cause moisture related issues such as mould and damp over time.

(in-use) carbon saving potential assesses the relative ability for a technology to reduce carbon emissions during the technology's lifetime, against equivalent technologies. For example, draught proofing reduces the heating demand on a boiler, therefore saves the equivalent carbon emissions. 1 would consider its saving potential non-existent, or no better than the status quo, 3 would offer carbon savings, 5 would offer exceptional carbon savings, against the status quo, and better than the majority of equivalent technologies.

Whole life environmental impact considers both the relative manufacturing emissions, in-use emissions and end-of-life emissions. Technologies with high levels of recycled content, such as cellulose insulation, or biodegradable content will score 5. Those technologies with energy intensive manufacturing or polluting waste products will score 1.

Compatibility with Scottish policy assesses the alignment between the technologies energy efficiency improvement and elements of the Scottish policy. As the technologies have been initially filtered to, at least partially, contribute towards reducing building energy demand, most technologies have scored highly.

Compatibility with current regulation considers how relatively aligned the technologies are with current building regulations, for example fire safety. Most TRL 9 technologies will score highly otherwise they would not be viable commercial products. It can be harder for less developed technologies to demonstrate high levels of compatibility.

Compatibility with current assessment methodologies considers how simply a given technology can be modelled using existing software. Scores of 5 are awarded to technologies that can be assessed in rdSAP, SAP or iSBEM. Moderate scores (3 or 4) are awarded where technologies can be modelled in existing DSM packages. Low scores (1 or 2) are awarded where CFD or bespoke definition of elements is required to build up a model.

Capital costs rewards low cost technologies with 4 or 5, relative to other available measures for the property. Costly measures will score lowly. Since different technologies are extremely different in costs, scoring was a relative capital cost, i.e much cheaper than equivalent (5), or similar costs (3) or more expensive (2).

Life cycle costs broaden the cost category to consider the long-term cost-benefit of the technology, including manufacture and disposal. Strong cost-benefit will score highly, and vice versa, compared to an equivalent or incumbent technology; therefore, (1) much more costly, to (5) much less costly.

Carbon cost effectiveness (£ per tCO_2 saved) assesses how much carbon is saved over the lifetime of the product, for every pound spent purchasing, installing and maintaining the product. This measure is key to prioritising technologies to be meet carbon goals cost efficiently.

(Potential for) economy of scale (to drive down costs) measures the relative likely impact that selling more products would significantly reduce the cost of the technology. Newer technologies and those with complex manufacturing processes commonly benefit more from economies of scale.

Applicability considers the breadth of the Scottish building stock that a technology could be installed in and bring energy efficient benefit. Where a technology only benefits a small portion of the stock, it will score lowly.

Existing Scottish capacity/skills assesses how capable trades people of Scotland are already at installing and maintaining similar technologies.

Scottish content assesses how much of the technology supply chain, from raw materials, through processing, manufacturing, installation, maintenance, and disposal, is currently based within Scotland. This impacts the economic impact potential of promoting a given technology.

Potential for cross-sector involvement/benefit considers what benefits there could be to other sectors, outside of the building and manufacturing industries.

Scottish economic impact potential compiles a number of factors and offers a judgement call on the likely relative ability to create Scottish jobs and exports.

User friendliness / practicality metric review how difficult it is to use the product. Products that are passive and require no interaction after installation score highly, then simple intuitive interaction, down to highly complex systems.

Disruption assesses the likely inconvenience caused through installation and operation of a technology. For example, external wall insulation can largely be fitted without the occupant needing to clear or move any of their belongings, thus scoring highly. However glazing replacement requires occupants to move furniture to provide access, scoring moderately, whilst some wall cassette systems require occupants to move out entirely for a number of weeks, thus scoring poorly.

Customer acceptance considers the opinion in society for the technology, whether it is the 'must have' item for every building, such as LED lighting, or is reluctantly installed as a last resort. For novel technologies a judgement call has been made based on general sector opinions and the position the new technology would be taking in the sector.

Savings on bills assesses the impact on users' finances. If the technology will save a relatively high amount from the energy bill it will score highly.

Maintenance requirements considers how often maintenance is required, how expensive it is to maintain and how complex. Low maintenance scores highly.

Health/wellbeing/comfort assesses the impact (negative or positive) the energy efficient technology has on the occupants' wellbeing. Typically this is through changes to thermal comfort (temperature and humidity), lighting levels or visual impact.

Existing consumer protection? (Adequacy?) considers what insurance or guarantees are provided with the technology. Long comprehensive guarantees score highly.

Critical success factors/watch points offers a commentary on relevant elements that should be monitored to determine the future viability of the technology.

Other relevant considerations/risks/opportunities offers further commentary on the pros and cons of each technology that are worth mitigating or leveraging as the technology markets develop.

Adaptability / future proofing considers, through comment, how suitable a technology is to changing occupant or building needs. Changes can be triggered by the building users, community impacts or national or global affects such as climate change.

Table 2 overleaf outlines the scoring scale for each assessment criteria. Sub-totals (for the criteria groupings) and an overall total for each of the 27 the technologies scored. Again, colour-coding has been used to indicate a good performing (green) and a poor performing (red) technology, against the assessment criteria.

Table 2 - Scoring Matrix

Technical	**Scoring**
Technology readiness	TRL score 1-9
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score
Reliability	1 (low) to 5 (high) score
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score
complexity of systems/ their integration	1 (complex) to 5 (simple) score
risk/severity of unintended consequences	1 (high) to 5 (low) score
Environmental	**Scoring**
(in-use) carbon saving potential	1 (low) to 5 (high) score
whole life environmental impact	1 (high) to 5 (low) score
Policy / Regulatory	**Scoring**
compatibility with Scottish policy	1 (low) to 5 (high) score
compatibility with current regulation	1 (low) to 5 (high) score
compatibility with current assessment methodologies	1 (low) to 5 (high) score
Monetary	**Scoring**
capital costs	1 (high) to 5 (low) score
life cycle costs	1 (high) to 5 (low) score
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score
Capacity/ Supply Chain	**Scoring**
applicability	1 (low) to 5 (high) score
existing Scottish capacity/skills	1 (low) to 5 (high) score
Scottish content	1 (low) to 5 (high) score
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score
Scottish economic impact potential	1 (low) to 5 (high) score
Consumer	**Scoring**
user friendliness / practicality	1 (low) to 5 (high) score
disruption	1 (high) to 5 (low) score
customer acceptance	1 (low) to 5 (high) score
savings on bills	1 (low) to 5 (high) score
maintenance requirements	1 (high) to 5 (low) score
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score
Opportunities / risks	**Scoring**
Critical success factors/watch points	List/Describe
other relevant considerations/risks/opportunities	List/Describe
adaptability / future proofing	List/Describe

Scoring methodology

Throughout this study, NEF experts have relied on a combination of sources to identify innovative technologies and approaches. Initially, in-house sector expertise has been utilised, expertise that has been built through combined experience on the Retrofit for the Future programme, Building Performance Evaluation programme, Saint Gobain's Energy House and SuperHomes, to name a few. This expertise has been supplemented through manufacturers' technical specifications, online technology databases (e.g. greenspec) and where possible third party, peer reviewed and/or independent evaluation studies. Due to the innovative nature of the technologies evaluated, highly reliable performance data has not always been available to evaluate technologies. In these instances expert judgement has been applied, however it is still advised that where these technologies have scored highly and are taken forward, that independent trials are conducted on archetypal buildings to validate performance. Despite making best efforts to use the best data available to them, there may be instances where new data comes to light that adjusts the assessors view sufficiently to moderate the score.

Where third party verified assessment has been found there is a high confidence in the scores apportioned. Where reliant on manufacturers' materials there is a medium confidence behind the scores. Where expert judgement alone has been relied upon there is a medium to low confidence in the scores, depending on familiarity with the technology.

Scoring of each technology, for each assessment criteria has been considered on a relative basis, against alternative measures available, for example, PCM windows has been considered against alternative opaque glazing/wall solutions. For each score (and scorecard) the research team have sought to find sufficient evidence to make a relative judgement for the given technology.

Against each technology and technology area the following approach was taken.

1) Researched the broad technical landscape – such as comprehending the current state of IWI – to provide a relative canvas on which to judge a specific innovative technology against.
2) Researched the specific technology being assessed, to obtain sufficient understanding to score the relative performance of the technology, against the assessment criteria.
3) Complete the score card by scoring and commenting on the specific technology, against each assessment criteria.
4) Moderated the score cards, section by section, to ensure continuity across the assessors.

The scorings are useful for high-level comparison between technologies and to prioritise areas of development. For example, a technology might show significant promise technically and environmentally, but be poor performing commercially. Priority can therefore be given to improving the commercial viability of a technology to ensure the benefits available are realised across the Scottish building stock.

The ***numerical scoring should not be used in isolation*** or as a mark simply of whether a technology is good or not, nor should it be subsidised or invested in or not. Scoring poorly on this assessment reflects only against the assessment criteria applied and the information available to the researchers at the time of the study.

Alongside the scored performance, a technical commentary has been offered on technology categories, further illustrating the benefits and drawbacks of each technology, against the assessment criteria. In the scorecards, the three qualitative criteria are commented on, as well as supplementary comments alongside most quantitative criteria, generating a brief commentary against the 30 assessment criteria per technology.

Full commentary can be found in the associated score cards PDF. These comments have been further summarised for high scoring technologies in the relevant technology sections of this report to give useful insights for readers.

Market testing

Market testing was conducted via a stakeholder workshop. The full programme is available in Appendix A: Workshop Programme.

The workshop engaged leading practitioners and researchers in the field of retrofit in Scotland. Through the session delegates were:

- Informed about the study and our work in profiling the Scottish building stock.
- Reviewed the scope of available technologies, specifically inputting into the list of emerging fabric energy efficiency, airtightness and ventilation technologies, and identifying any relevant missing areas of innovation.
- Inputted into the process of scoring and ranking the identified technologies with regards to impact potential, Scottish economic growth opportunities, risks, watch-points and further research requirements.
- Directed on how to keep the matrix up to date and track future innovation in Scotland.

Workshop outputs

The workshop provided a positive space for discussion, with regard to technologies and materials that could underpin the SEEP objectives. The stakeholders were knowledgeable of both the Scottish building and SEEP policy landscape, therefore provided a market experts overview.

Following a briefing on SEEP and the Scottish building profiling work to date, the delegates were invited to recommended suitably innovative technologies that should be captured in our analysis. This was conducted prior to briefing them on the existing technologies assessed to test the suitability of the technologies to date.

43 technologies were identified by the gathered experts. Following the workshop these were cross referenced against NEF's existing technology list, with 14 recommended technologies subsequently added to NEF's assessment.

These included alternative insulation materials such as cellulose fibreboard and sheep wool composites, amongst others. Others subsequently added to the analysis included; glazing variants (ventilated, water filled and PCM filled) and honeycomb style shading systems. Further details of the suggested technologies can be found in Appendix B: Workshop Activity 1 – Outputs.

Having tested the technologies to be assessed, the workshop delegates assessed the review methodology by scoring 16 industry recommended technologies, against a reduced set of assessment criteria. Following clarification questions the method was accepted by the stakeholders. After the workshop, the industry outputs were used as a guide for informal cross-checking the bulk NEF scoring.

Additional comments identified; the importance of health criteria (humidity, acoustics, ventilation, etc.) to be included in the full assessment procedure, that thermal comfort is more than airtightness and low U-value products, and the perverse unintended consequences that can arise from:

- Over insulation → more air conditioning → more carbon emissions
- High air tightness→ poor air quality → illness → cost to NHS and occupant wellbeing

A number of exemplar buildings, projects and resources were also put forward. The recommended resources below informed the analysis but also provide wider guidance for SEEP as a whole.

- Retrofit for the Future, Sweett Group Report – *contains useful cost analysis data* https://retrofit.innovateuk.org/documents/1524978/1866952/Retrofit%20for%20the%20Future%20-%20analysis%20of%20cost%20data%20report%202014
- Energy-efficient new housing, Policy Review Paper, Prof P. Banfill – *critique of UK policy* https://researchportal.hw.ac.uk/en/publications/energy-efficient-new-housing-the-uk-reaches-for-sustainability

- HES Sustainable retrofit project case studies, - *contains case specific retrofit solutions and learnings* https://www.historicenvironment.scot/about-us/news/hes-leads-climate-change-initiative/
- Zero Carbon Britain Report, Centre for Alternative Technology – *provides a plan for decarbonising Britain* http://www.zerocarbonbritain.org/images/pdfs/ZeroCarbonBritain-MakingItHappen.pdf
- Project Drawdown, Paul Hawkens *et al. – provides global strategies for carbon reduction* http://www.drawdown.org/

The technologies

Technology categories

Energy efficient fabric technologies improve the thermal efficiency of the building envelope, thus reduce the amount of energy needed to heat the building. As highlighted in the Scottish plan, reducing space heating demand is key to Scotland meeting their carbon reduction targets. Improving the energy efficiency of the building fabric, through insulation and airtightness upgrades, is the best way to deliver this objective.

Weather conditions and building use are always changing; therefore careful selection of complementary technologies is required when considering whole-building retrofit, to avoid unintended consequences such as overheating or poor indoor air quality (IAQ). Insulation and airtightness concepts have been used in construction for centuries, and many materials are incumbent parts of modern building design.

For the purpose of evaluation, each technology has been grouped by the building element they're a part of. The following section gives an overview of the innovations reviewed in each building element category. The overview includes the quantitative scores and a short commentary of the main considerations in the category with regard to opportunity areas. Full scorecards on each technology assessed can be found in the associated Energy Efficiency Scorecards document. Further, a searchable spreadsheet is available for further investigation.

Recognising the extensive range of energy-efficient fabric interventions already available the following sections focus on reviewing applicable innovative technologies for building retrofit against the criteria. Innovations cover anything from novel installation methods to fundamental material breakthroughs.

Ground floors

Up to 15% of heat can be lost through uninsulated floors. Retrofitting underfloor insulation is typically disruptive due to difficulty of access and space constraints both above and below the flooring. Predominantly two floor constructions exist in the Scottish building stock; solid and suspended floors.

Solid floor insulation

Retrofit insulation for solid floors is restricted to adding insulating materials above the solid floor layer, thus raising the floor level and often effecting stair treads and door threshold levels. Such interventions therefore can cause high levels of disturbance and are only applicable where sufficient ceiling height permits. Innovations have tended to focus on ultra-thin insulating layers, such as aerogel backed floor panels (E_a01) or vacuum insulation floor panels (E_a02). Due to the advanced materials, core to the insulation, cost is the largest hindrance to widespread application. Economies of scale, or equivalent economic forces, to lower the cost manufacture of materials would benefit these interventions. Whilst it is necessary for the property or room being treated to be vacant of furniture and possessions, it is not dissimilar to having new floor coverings installed and as an intervention; it is far less disruptive than full replacement of the existing floor slab.

Perimeter floor insulation

Alternatively, where internal floor insulation is unsuitable, insulation may be applied to the floor perimeter. Such measures can be effective since heat loss through the floor is concentrated at the perimeter; however they require excavating around the property and installing external wall insulation at the footings (E_a03). Material costs can be saved, however installation can be labour intensive. Innovation in installation approaches would reduce costs. However, access to external footings is required, thus applicability will remain limited and often external services such as drains, gas and electric can be troublesome to work around.

Suspended floor insulation

Suspended floors may be constructed from timber or concrete and traditional insulation materials may be retrofitted beneath the floor deck. Innovation lies in the installation methods so as to reduce occupant disruption and the specification of the correct materials for optimal moisture management and performance for a given thickness. Assessed were technologies that could be installed via sprayed, blown or pumped mechanisms – either manually or robotic. Each of the technologies assessed scored well, yet they all require care at installation stage to ensure a uniform fill to deliver energy efficient performance. Improved customer protection would help mitigate the potential long term in-use performance risks.

Table 3 - Floor Technology Scores

Ref#	Intervention	Technology	Total score (/139)	Technical (/34)	Environmental (/10)	Policy / Regulation (/15)	Monetary (/20)	Supply Chain (/25)	Consumer (/35)
E_a01	Solid Floor Insulation	Ultra-thin aerogel backed floor panels	106	29	8	15	14	16	24
E_a02	Solid Floor Insulation	Vacuum insulation panels	93	23	7	14	13	13	23
E_a03	Perimeter Insulation	Closed cell EWI perimeter insulation to footings	105	29	5	15	12	18	26
E_a04	Suspended Floor Insulation	PU Spray Foam Systems	103	26	6	14	15	18	24
E_a05	Suspended Floor Insulation	Foamed glass pumice under floor void	105	29	7	14	15	15	25
E_a06	Suspended Floor Insulation	Blown/loose fit suspended floor insulation	105	27	8	14	17	15	24

External walls

Heat loss through uninsulated and draughty walls can account for up to 35% of building heat loss. Three intervention areas have been reviewed cavity, external and internal wall insulation (CWI, EWI and IWI). The building construction, availability of floor space and planning regulations will influence which technologies are most suitable. Further, following recent events, fire resistance of materials and products is rightly in the spotlight and factors such as fire resistance and toxicity should both be key considerations.

Cavity wall insulation (CWI)

CWI is widely accepted as external aesthetics and internal space is maintained, whilst fabric efficiency is upgraded but it requires there to be a suited vacant cavity in the wall build-up. As outlined, 71% of Scottish domestic cavity walled properties have CWI installed. The remaining, often narrow, hard-to-treat, cavities require innovative installation solutions. Further, advances in material mixes has bought vapour-permeable insulants (E_b02) to the market, as well as improved the utilisation of natural materials, such as cellulose (E_b03). Further roll out of CWI in difficult to treat cavities is required, as well as consideration of the need for insulation with good moisture management properties.

External wall insulation (EWI)

To date, EWI has seen lower market uptake due to prohibitive aesthetic and space implications. Innovations therefore include material improvements, to improve technical performance; and system improvements, to reduce disruption and improve customer acceptance. Insulated renders have been most commonly adopted (E_b04, E_b08) but they provide limited benefit for conservation buildings, where restrictions to appearance apply. By utilising offsite manufacturing (E_b07), improvements in continuity and installation time can be delivered, however challenges lie in integrating multiple stakeholders to deliver the wide-reaching system. Further innovation and widespread application of safe solutions is required.

Internal wall insulation (IWI)

To date, IWI has been limited due to the loss of internal space where applied as well as due to concerns of how well IWI systems may cause issues with the transport of moisture through the wall build-up. Innovations therefore include material improvements, to improve technical performance; and system improvements, to reduce disruption and improve customer acceptance. Narrow profile (E_b15) or building material integrated (E_b12) insulation innovations offer the most likely technologies for widespread applicability. Cost of advanced materials requires attention to improve uptake.

Table 4 - Wall Technology Scores

Ref#	Intervention	Technology	Total score (/139)	Technical (/34)	Environmental (/10)	Policy / Regulation (/15)	Monetary (/20)	Supply Chain (/25)	Consumer (/35)
E_b01	Cavity Wall Insulation	PU Spray Foam Systems	99	26	6	11	15	17	24
E_b02	Cavity Wall Insulation	Blown bonded EPS bead based systems	113	30	8	14	17	14	30
E_b03	Cavity Wall Insulation	Loose blown material blends	115	29	10	13	18	17	28
E_b04	External Wall Insulation	Vapour open wet render systems	114	28	9	14	16	18	29
E_b05	External Wall Insulation	Insulated rain screen cladding systems	110	28	7	15	15	18	27
E_b06	External Wall Insulation	Dynamic External Wall Insulation	83	21	5	10	12	13	22
E_b07	External Wall Insulation	Off-site manufactured cassette systems	112	27	9	14	15	19	28
E_b08	External Wall Insulation	External paints, plaster and renders	82	25	4	8	11	14	20
E_b09	Internal Wall Insulation	Offsite Manufactured (OM) Cut Panel Systems	103	28	7	15	16	11	26
E_b10	Internal Wall Insulation	Vacuum wall panel insulation	93	23	7	14	13	13	23
E_b11	Internal Wall Insulation	PU Spray Foam Systems	100	26	6	11	15	18	24
E_b12	Internal Wall Insulation	Internal insulation stud systems	108	25	8	15	17	18	25
E_b13	Internal Wall Insulation	Internal paints, wall paper and plaster coatings	73	23	2	7	8	14	19
E_b14	Internal Wall Insulation	Phase Change Materials	90	27	5	9	14	13	22
E_b15	Internal Wall Insulation	Ultra-thin insulation for hard-to-treat areas	108	29	8	12	13	19	27

Roofing and lofts

Uninsulated roofs can account for up to 25% of building heat loss. Loft insulation has been a longstanding retrofit measure installed in homes. Harder to treat roofs have led to roof-type specific innovations. In addition technologies for enhancing the energy efficiency of roofs beyond traditional loft insulation have been considered.

Cold roofs

Cold roofs insulate at the ceiling layer, creating a cold air barrier between the uppermost heated space and the roof. Common loft insulation is an example of such technology. Innovative material mixes (E_c01) provide a comparative technology, particularly suitable, through blown installation, for treating hard to reach portions of a loft space, such as the eaves. Such interventions score highly due to the simplicity of installation, energy saving impact and broad applicability to the Scottish stock. Alternatively, PCM materials embedded into insulant layers or ceiling tiles (E_c02) can provide tempering of the space or reduce overheating. Due to the limited for overheating mitigation in the Scottish stock, these innovations have scored more lowly.

Warm roofs

Warm roofs insulate at the roof layer, with heated liveable spaces directly below the roof. The applicable technology depends on the building form. In buildings with pitched roofs there are a variety of insulation systems (E_c03) that insulate between the rafters to minimise heat loss through the roof. These are particularly applicable to buildings with occupied loft spaces. Care should be taken during installation to allow required ventilation pathways at the eaves.

In non-domestic atrium spaces, ETFE roofing (E_c04) can be used to create a solar heated air gap between ETFE layers, thus insulating the occupied space below the warm roof. Such roofs are particularly suited to spaces with a large roof span; however are custom made, therefore incur relatively high design and installation costs.

Flat roofs

On a domestic level, flat roofs have received far less insulation than pitched roofs. Systems to reduce thermal gain from external additions include laying green roofs (E_c05) or applying reduced albedo coatings (E_c06). Green roofs require careful design before application to ensure the structural capability of the building with the additional material and potentially held water. More broadly applicable, offsite manufactured cassette systems (E_c07) provide wrap around insulation added to the roof surface. The technology adds height to the flat roof, which includes insulation and an air gap for improved thermal performance.

Other roofing interventions

Beyond insulating materials alone, active thermal mass additions (E_c08) can be introduced to temper internal room air, either as chilled or radiant beams. Such technology is applicable to non-domestic buildings and requires careful integration with existing HVAC strategies.

Photovoltaic (PV) roof tiles (E_c09) offer a further energy efficiency improvement, by offering energy generation. Whilst additional roof panels and tiles have been on the market for over 10 years, novel glass tiles offer an integrated technology for roofs with conservation orders to become energy generating systems. The technology is still at early demonstration stage. Enabling a Scottish import and delivery supply chain could create a new market within Scotland.

Table 5 - Roof Technology Scores

Ref#	Intervention	Technology	Total score (/139)	Technical (/34)	Environmental (/10)	Policy / Regulation (/15)	Monetary (/20)	Supply Chain (/25)	Consumer (/35)
E_c01	Cold Roofs	Blown/loose fit cold roof insulation	114	30	9	13	18	17	27
E_c02	Cold Roofs	PCM Ceiling Tiles / Ceiling Void additions	96	27	7	11	12	13	26
E_c03	Warm Roofs	Warm roof insulation systems	110	27	8	13	15	20	27
E_c04	Warm (Large Span) Roofs	ETFE Roofing	96	25	8	13	14	11	25
E_c05	Flat Roofs	Green Roofs	97	26	8	12	15	15	21
E_c06	Flat Roofs	Reduced albedo (paint / materials)	80	24	6	6	10	15	19
E_c07	Flat Roofs	Offsite Manufactured (OM) Cut Cassette Systems	106	28	8	14	15	14	27
E_c08	Thermal labyrinths	Chilled Beam Ceilings	90	23	6	12	12	15	22
E_c09	Pitched Roofs	Glass PV roof tiles	110	28	9	10	16	19	28

Glazing and shading

Glazing can account for 10 to 25% of fabric heat loss, depending on the building glazing ratios. Typically the building openings (windows, doors, etc.) are also vulnerable to unmetered air infiltration (draughts) and thermal bridging. Double glazing has become a mainstay retrofit technology across the built environment; however it is not always applicable, for example in conservation buildings.

Windows

Innovation has therefore arisen in glazing that aims to; improve the applicability (e.g. thin profile glazing (E_d02)), reduce thermal transmittance (e.g. vacuum glazing (E_d02) or photo-sensitive glazing (E_d06)), or harness energy (e.g. building integrated PV glazing (E_d10) or water-filled glazing(E_d07)). Glazing solutions remain a relatively high-cost fabric improvement as most are custom built for each application. Innovation opportunities remain in the glazing installation process, to minimise cost, disturbance and risk of unintended consequences.

Thin profile (E_d02), secondary glazing (E_d01) and window films (E_d05) can be applicable for improving the thermal efficiency of glazing in conservation buildings. Light pipes (E_d16) offer natural lighting to internal spaces, indirectly improving the energy efficiency by reduced electrical demand from lighting.

Shading

For buildings with high south-facing glazing ratios, where overheating is a significant risk, innovations in shading are applicable. Shading can be effectively applied internally (E_d12), integrated in the glazing (E_d09 or E_d11), or externally. Suitable systems should be specified after consideration with the HVAC and occupancy schedules of the building. Integration with building management systems can provide further benefits from control.

Other walling and openings

Curtain walling provides a mechanism for adding functionality to the building skin. Systems are costs and require significant redesign of the building, but can deliver significant benefits. For example, building integrated PV cladding (E_d13) can make use of wall area to generate electricity, whilst double skin glazed facades (E_d14) can be used to gather preheated inlet air to HVAC systems or simply as a thermal buffer from outside temperatures. Each requires careful design and installation, accruing associated costs. The technologies are effective but applicability is low due to cost and typology constraints, more commonly in non-domestic buildings. Ventilated glazing (E_d08) applies similar concepts of double skin facades to individual window fittings, more broadly applicable, but less proven.

Table 6 - Glazing Technology Scores

Ref#	Intervention	Technology	Total score (/139)	Technical (/34)	Environmental (/10)	Policy / Regulation (/15)	Monetary (/20)	Supply Chain (/25)	Consumer (/35)
E_d01	Windows	Secondary glazing including plastic films	98	27	6	12	14	15	24
E_d02	Windows	Thin profile vacuum glazing	95	24	7	14	10	15	25
E_d03	Windows	Low E Double Glazing	101	25	7	13	13	18	25
E_d04	Windows	Low E Triple Glazing	103	26	7	13	12	20	25
E_d05	Windows	Window films	100	28	4	14	14	12	28
E_d06	Windows	Spectrally selective glazing	96	28	6	10	12	16	24
E_d07	Windows	Water filled double glazing	61	17	6	6	7	10	15
E_d08	Windows	Ventilated windows	90	21	9	8	14	16	22
E_d09	Windows	PCM filled glazing	89	24	8	8	11	15	23
E_d10	Windows/Curtain walling	BIPV glazing	85	27	6	11	11	11	19
E_d11	Shading Systems / glare control	Dynamically selective glazing (electro & photo sensitive glazing)	82	24	6	9	8	11	24
E_d12	Shading systems	Insulating cellular blinds / shades	103	27	7	12	14	17	26
E_d13	Curtain Walling	PV integrated facades, cladding, windows	100	28	7	14	13	13	25
E_d14	Curtain Walling	Double skin facades	81	22	6	9	11	13	20
E_d15	Doors	High performance doors	103	29	7	13	10	16	28
E_d16	Daylighting	Light pipes, light shelves; diffraction glazing	98	27	8	10	13	16	24

Ventilation and Airtightness

Beyond fabric insulation, uncontrolled ventilation and infiltration can account for up to 35% of building heat loss. Passive natural ventilation strategies are common in historic buildings, largely due to the ways in which they were constructed, with chimneys, suspended timber floors and vapour open wall construction. However, for many buildings the consideration of air tightness and dedicated ventilation technologies is a growing area of innovation. Where high levels of insulation and airtightness are sought, there is a requirement for ventilation systems that are effective, efficient, user friendly and controllable. In existing buildings such solutions can be extremely difficult to identify and install and the interrelationship between insulation, airtightness and ventilation cannot be overstressed.

The technologies captured in this final grouping are therefore deemed both necessary and also complementary to the fabric energy saving technologies detailed above.

Airtightness

Although it may help improve the overall airtightness of a building, insulation itself is unable deliver the standards of airtightness required to deliver significant energy savings and comfort benefits. There are therefore a range of innovative products and solutions in the market place that seek to help improve building airtightness. The E_e01 scorecard item seeks to encapsulate many of these products which include solutions such as chimney balloons which offer a reversible means of reducing heat loss up disused chimneys, through to very specialist draught stripping profiles, airtightness tapes and sealants. Some of these may be installed in isolation or indeed as part of a wider whole house retrofit.

Natural Ventilation

With a building being made more airtight, it becomes necessary to provide ventilation either by natural or mechanical means. The appropriate solution will be entirely case specific but as a rule of thumb, natural ventilation is well suited to buildings with only moderate levels of airtightness >5 air changes per hour (ACH). In this category, our evaluation considers passive stack heat recovery (E_e08), passive wall ventilation labyrinths (E_e09), automated windows (E_e05) and trickle vents (E_e04) as well as mixed mode ventilation (E_eo6) and hybrid solutions (E_e07).

Mechanical Ventilation

Although invariably some cross-over with the provision of heat (see heat generation technology landscaping study), mechanical ventilation systems with built-in heat recovery elements have also been evaluated. Specifically, mechanical ventilation is required in buildings where the air tightness is less than 5 ACH or where both heating and cooling may be required in the form of a building wide HVAC system. The systems we have evaluated here are Mechanical Ventilation Heat Recovery (E_e02) which is extremely complex and difficult to install as a retrofit solution. We also reviewed single room heat recovery (SRHR) ventilation (E_e03) which shows great promise.

Table 7 – Ventilation and Airtightness Technology Scores

Ref#	Intervention	Technology	Total score (/139)	Technical (/34)	Environmental (/10)	Policy / Regulation (/15)	Monetary (/20)	Supply Chain (/25)	Consumer (/35)
E_e01	Airtightness	Draught stripping - novel profiles, tapes and sealants	114	28	8	13	18	20	27
E_e02	Ventilation	Mechanical Ventilation Heat Recovery (MVHR)	95	23	6	13	13	17	23
E_e03	Ventilation	Single Room Heat Recovery (SRHR) Ventilation	101	27	5	11	14	18	26
E_e04	Ventilation	Automated trickle ventilation systems	102	27	7	11	14	18	25
E_e05	Ventilation	Automated window opening / closure	92	22	7	10	14	16	23
E_e06	Ventilation	Mixed mode ventilation (using thermal mass)	102	26	8	12	14	17	25
E_e07	Ventilation	Hybrid Ventilation	91	21	8	11	12	15	24
E_e08	Ventilation	Passive Stack Heat Recovery	99	25	7	11	13	18	25
E_e09	Ventilation	Insulation with passive wall ventilation labyrinth	92	20	6	14	15	16	21

Energy efficient lighting and HVAC

Throughout the study we were aware that two major energy loads that may not be covered by any of the three studies were lighting and HVAC. Especially in the retail sector, great energy efficiency savings can be made through installation of modern energy efficient alternatives.

On lighting, most incumbent lighting solutions can be replaced with modern LED products. Systematic research to ensure the right tone of lighting is maintained is required for each context; however up to 75% lighting savings have been identified in UK retail retrofit. With such exceptional energy and cost savings available, and the lowering LED lighting costs, the business case for LED retrofit, especially when rolled out as part of a retailers standard retrofit programme, offers payback of no more than five years, and generally less than two years. Due to the strength of the business case, it is reasonable to consider that there are sufficient market forces in place to drive lighting retrofit, and therefore specific focus within SEEP is unnecessary to catalyse up take.

On HVAC, innovative retailers are looking for solutions to reduce demand, especially with regard to in-store chillers and freezers. Modern advancements in sensor and control technology are enabling much of this work. The area of refrigerants and refrigeration cycles continues to attract focus for innovation. Although the scope of this work did not cover HVAC innovation, it is recommended that SEEP consider a bespoke piece to assess the emerging systems and subsequently support development in this area.

Closing remarks and opportunities

This study has identified a total of 55 leading innovative fabric technologies that could improve the energy efficiency of both domestic and non-domestic Scottish buildings. It is hoped that these findings will provide a framework for the SEEP to prioritise technologies that provide strong energy efficiency benefits, as well as commercial opportunities. The quantitative scores presented are intended as a guide and should *not* be considered in isolation.

Applicable contexts

Of the total of 55 technologies, 44 (80%) are deemed suitable to domestic applications, 45 (82%) applicable to community buildings, 49 (89%) to public buildings, 46 (85%) applicable to commercial buildings and just 21 (38%) deemed applicable to industrial building types. This universal applicability of many of the identified energy efficiency technologies bodes well for Scotland and the opportunity for supply chain stimulation, job creation and economic impact potential. The limited applicability to industrial buildings is less of a surprise given that many such buildings tend to be conditioned with low grade heat with limited need for efficiency gains in the form of building fabric upgrades.

Innovations

With regards to the nature of innovation, this study has been unable to identify any notable new materials that stand to offer a step change in the way that we insulate and improve the fabric energy efficiency of the existing building stock. Instead, we see a landscape where incremental enhancements are being made across the board. For example:

- Material enhancement – the full spectrum of natural, recycled material and petrochemical based insulants have been covered by our research. Other than the gradual introduction of vacuum panels, aerogel based boards and quilts, we see that enhancements are simply being made to the overall durability, robustness, rot resistance, moisture management properties and fire proofing of the existing, well established materials. Provided the materials are specified correctly for a given application, stability in the types of materials being used may be regarded as good news for the existing established installer base.

- Novel systems – where we see a considerable level of innovation is in how the above insulation materials are being used to form whole-system based solutions. For example, in using off-site panel system manufacturing techniques to deliver 'ready insulated' panels and cassettes to site. Similarly, internal wall insulation system providers are embedding well established insulants within systems that comprise of thermal bridge free studwork, vapour control layers and airtightness grommets and sealants.

- Innovative surveying and installation – for almost all technologies, surveyors, manufacturers, suppliers and contractors are increasingly working to high tolerances in the way that they measure, manufacture and install components. Technologies such as 3D scanners, theodolites and laser measuring devices are being used to minimise waste and speed up the process of installing interventions on site. Off-site manufacturing and even the use of robots appear to be increasingly commonplace, again in a bid to reduce the time and effort required on-site and make the install process more tolerable for building occupants and users.

- Performance risk management – there is growing recognition to the fact that buildings require solutions that are tailored to their built characteristics and context and that if incorrectly specified, the installation of certain technologies can lead to sizeable unintended consequences. Manufacturers and suppliers appear increasingly conscious of this, notable in the sheer range and diversity of technologies that are available in the market place; each claiming to suit a particular need or building type. Whilst our landscaping study picks up on many of these technology options, we strongly recommend that the SEEP programme should also focus effort in ensuring technologies are properly specified, designed, implemented and then verified through testing and evaluation wherever possible.

Next step opportunities

This study, we hope, is just the beginning of a much larger exercise of not only helping to ensure the early phase of SEEP chooses to support the right measures but also in serving to inform areas of further research and evaluation. As has already been acknowledged; there are considerable benefits in recognising not just the scale of the opportunity in relation to delivering energy efficient retrofit as a national infrastructure priority but in then also translating this into the true needs of the Scottish Building stock and how existing Scottish supply chains, know-how and IP may be maximised.

It must also be recognised that this landscaping study has been conducted within a limited timeframe and that it has not been possible to ensure that all manufacturers and suppliers have had the opportunity to forward put their perhaps less well known innovations. A potential solution for this could be to transpose the work of the three landscaping studies into a live database which the whole supply chain could add to, continually review and build-upon. Such a database could potentially be used by building owners/occupiers, specifiers and installers alike, perhaps encouraging not only the adoption of the most effective solutions but also a preference for the 'made in Scotland' solutions.

This study has only focussed in on those innovative technologies that are (or close to being) commercially available today and, although more taxing, it would also be particularly interesting to see what less well developed technology concepts and innovations may be available to the Scottish market place in the medium to long term.

Glossary

Terms

Air-tightness/Infiltration – refers to how much unwanted air enters or leaves the building, and materials that limit this unwanted air exchange

Building envelope – comprising of the walls, roof, etc., it provides the separation between internal and external spaces.

Cassette systems – a technology comprising of multiple sections to be fitted together

Cavity wall – wall constructions with an air gap between external and internal façades

Cill/Sill – the area beneath a window, where the window connects with the wall

Cold roofs – where the space below the roof is unheated

Continuity of insulation – maintaining an insulating layer around the whole internal heated space, in all walls, roofs, floors and junctions

Domestic – residential buildings, e.g. terraces, flats, etc.

Eaves – the lower side of the roof that connects with and overhangs the building walls

Fabric – the building materials that make up the structure of the building, (e.g. walls, roof, windows, etc.) and their components, (e.g. bricks, tiles, glass)

Fabric energy efficiency technologies – a technology or system that is applied to the structure of a building to reduce the amount of energy used by occupants using the building

Flashings – material layers applied around junction details to avoid the ingress of water, e.g. lead flashing to weatherproof the seam between chimney and roof

Glazing ratio – the ratio of glazing to non-glazing of external wall, typically presented in percentage terms

Heat loss – typically unwanted, transfer of heat or hot air from internal rooms

Holistic/whole-house/deep retrofit – the upgrade and replacement of multiple energy efficient measures across a building, typically including at least wall, roof and opening upgrades

Interstitial condensation – moisture that accumulates between construction layers of a building, e.g. between insulation and external brick

In-use performance – the energy efficiency of a product when used in-situ

Lathe and plaster – traditional building material for constructing internal wall layers, made up of vertical studs, horizontal batons and skinned with plaster

Low-E – low emissivity materials, typically referring to glazing that reduces the heat transfer of radiant heat

Non-domestic – any non-residential buildings, such as schools, hotels, offices, warehouses, etc.

Offsite manufactured – refers to any building component that is constructed in a factory, transported to site as a unit to be fitted with adjacent units and for the complete construction. The method aims to reduce onsite activity, offering faster and more precise builds.

Party-wall – an internal wall separating two, typically independently owned, occupied, heated and managed, spaces e.g. between two houses in a terrace

Passivhaus – a leading energy-efficient building design philosophy where high levels of insulation and air-tightness are achieved to minimise the space heating demand

Primary heating fuel – refers to the main source of space heating, e.g. gas boiler

Solid wall – wall constructions without a cavity between external and internal walls, typically found in older buildings (pre-1930)

Suspended (timber) floor – ground floors that have an air gap beneath the floor trusses and floor boards

Thermal bridge – a highly conductive material that connects cold and warm environments, creating an easy passage for rapid heat transfer, e.g. metal door handles / mechanisms

Thermal comfort – the perception of comfort by occupants, dependent on temperature, humidity, air movement, occupant dress and occupant activity

Thermal labyrinth – dense material, such as concrete, with a maze of air or water channels embedded to move heat in and out of the material

Thermal mass – the use of thermally dense materials (materials that can store high levels of heat for small volumes) for the purpose of heat storage to offset heating demand or temper inlet or internal space temperatures.

Thermal transmittance – the rate at which heat is transmitted from a surface

U-value – a measure of how fast heat flows through a material or multiple building materials making up a whole wall, or building, measured in W/m2K.

Vapour-permeable – building layers that allow moist air to pass through, avoiding accumulation of interstitial condensation

Warm roofs – where the space, commonly a loft, below the roof is heated

Acronyms

BIPV – Building integrated photovoltaic

CWI – Cavity wall insulation

ELC – Early learning and childcare

EPC – Energy performance certificate – given to every building, based on simple assessment, conveying a measure of the building energy efficiency

ESOS – Energy saving opportunity scheme

EWI – External wall insulation

HVAC – Heating, Ventilation and Air Conditioning

IWI – Internal wall insulation

LED – Light emitting diode

NEF – National Energy Foundation

PCM – Phase change materials

PV - Photovoltaic

SAP – Standard assessment procedure – the modelling method used to generate EPCs

SEEP – Scotland's Energy Efficiency Programme

TRL – Technology readiness level – a scale of 0-9 that denotes how commercially ready a technology is, e.g. whether it is an early prototype or commercially viable system

Appendix A: Workshop Programme

Energy efficiency technologies available to deliver Scotland's Energy Efficiency Programme (SEEP): Stakeholder Engagement Workshop

Edinburgh Centre for Carbon Innovation (ECCI), High School Yards, Infirmary Street, Edinburgh, EH1 1LZ (Directions)

Friday 26th May, 12.00pm till 2.30pm. Tea, Coffee and Lunch provided.

The Scottish Government's Programme for Government "A Plan for Scotland – The Government's Programme for Scotland 2016-17" announced that the new Scotland's Energy Efficiency Programme (SEEP) will commence in 2018 with substantial annual public funding coupled with new powers for the Scottish Parliament over the regulated energy suppliers. SEEP will be a coordinated programme to improve the energy efficiency of existing homes and buildings in the commercial, public and industrial sectors.

ClimateXChange and the National Energy Foundation (NEF) are currently working together on behalf of the Scottish Government's SEEP policy team to map out near-term emerging fabric energy efficiency, airtightness and ventilation technologies* (TRL level 8 or 9). The purpose of this work is to both identify the key emerging retrofit technology options that may be supported by SEEP and to also inform the longer term programme of investment into further research and development.

*Heat generation technologies and smart energy solutions are being investigated by separate research teams.

Why attend?

The aim of this workshop session is to engage leading practitioners and researchers in the field of retrofit in Scotland. The session will provide an opportunity to:

- Hear more about the study and our work in profiling the Scottish building stock
- Have your say in scoping the recommended technologies. Review and input into the list of emerging fabric energy efficiency, airtightness and ventilation technologies. Have we missed any key areas of innovation?
- Input into the process of scoring and ranking the identified technologies with regards to impact potential, Scottish economic growth opportunities, risks, watch-points and further research requirements. How might we keep the matrix up to date and track future innovation in Scotland?
- Network with leading practitioners and key decision makers

Agenda

1) Lunch and networking on arrival
2) SEEP and the direction of travel + brief project introduction (ClimateXChange)
3) Early Findings Presentation (NEF) – Profiling the Scottish building stock and overview of identified technology innovation areas
4) Workshop Activity 1 – New and emerging energy efficiency technologies – your views
5) Workshop Activity 2 – Technology scores and ranking – what's hot and what's not
6) Concluding remarks and next steps

Appendix B: Workshop Activity 1 – Outputs

Grouping *What group does it fall in to?*	**Innovation** *Briefly describe the innovation*	**Product Examples** *Are there any existing products or services which utilise the innovation?*	**Retrofit Applications** *Which buildings is it suitable for?*		
			Domestic	**Public/ Commercial**	**Industrial**
Phantom loads – elec. doing nothing - 15% UK energy consumption - EU directive			y	y	y
Air tightness	Near Perth - breathing membrane and seals building on outside & put render on top	Procter Ltd, but moisture issues? (Roof Shield)	y	y	y
Modular roofing systems & replace cold roof with warm roofs - take off roof and create additional living space	solution for flat roofing	Offsite cassette system for roofs	y	y	y
Non-dom controls - openings of public buildings	Fly open doors / why not have a lobby	Revolving doors (B / W - fire escape??) Flip flap doors at person height		Y	
Solar shading for domestic			y		
Wall coating	Nano-technology coating using hollow glass beads in a coating (liquid paint 0.75 mm), applied to any surface, water based		y	y	y
Glazing	Water filled double glazing		y	y	y
Insulation	Wood fibre wall/floor/ceiling insulation		y	y	y

Insulation	Cellulose		y	y	y
Thermal mass (Roofs)	PCM ceiling tiles	BRE Innovation Park - Ravens Craig		y	
Doors	High-velocity air curtains			y	
Ventilation	Positive input ventilation (PIV)		Y		
Ventilation	Negative pressure ventilation		Y		
Walls	ICYNENE - different densities on sold stone walls and as the plaster	Got one in Perth Hist. Env. Scotland Technical Paper			
Floors/Walls - cavity	LECA - volcanic material	Like perlite / pumice has air in it (helps moisture problems)			
Ventilation / Glazing	Denmark - triple glazed with vents at top and bottom (can clean it) -	Sandy Halliday with send something, air is warmed			
Breathing wall	Vent on outside and inside	Kingdom innovation show case (Lomand Homes) Jon Stinson patent			

Breathing wall	Trombe - version of trombe - black glazing put on outside - preheat air before it goes into building	UK research Sand Haliday			
Glazing (2ndry)	Poly carbonate strips with magnetic frames	Jon Stinson (DIY store) - lots of companies in Scotland (South Seeds glazing & Leaflet - Kate Chan)			
Insulation	Thermashield - insulates windows, reconstruction of sash and case windows and insulate behind (at the plaster and wall) internal glazing. Laser Measurement (John Stinson - do offsite and reduce waste)	David Sommerville patented to Adam Dudley (wife now has the patent) - 5 joinery companies have license - can use ventrolla (seal and upskill)			
Walls	Un-glazed solar air collection - transpired	e.g. SOLARWALL		Y	y
Walls	Microbead technology (behind lathe & plaster) - filling void behind lathe and plaster versus more intrusive IWI. Good for historic properties		Y	Y	
Windows	Movable insulation (simple product)	e.g. DVETTE blinds (saving 30% overnight) - honey comb double layer principle - low-e enhancement potential	Y		
Windows	Window integrated solar air collectors (same principle as air supply windows - pre-heat of supply air)	RD&D but no manufactured product known	Y	y	y
Glazing	Phase change, translucent, U = 0.5W/m2K	Glass x Crystal e.g. WinterThur, CZ	Y	y	
Glazing	Air-supply windows (outer single - good for exposed sides, addresses airtightness failures due to wind		Y	y	

	pressure)				
Insulation	Blown fibre cellulose (recycled newspapers) better thermal regulation	Ecocel (www.ecocel.ie) Also used by MAKAR (Inverness) to fill naturally structurally insulated panels (NSIPs)	Y	y	
Walls	Solar honeycomb' principle (pre-fab panels) variable U-value	e.g. DIESEL WEG retrofit, GRAZ	Y	y	
Insulation	Sheeps wool / PET mixes	Thermafleece	Y	y	
Floors / Walls	Different applications of autoclaved concrete - precast in situ - low conductivity 0.14W/mK or less	Neil Burfords self-build prototype - Dundee Botances (in-situ deep slab Dundee Uni)	Y	y	y
Thermal mass	Thermal regulation, (solid, water, phase change, offiste covered water stores)	Sue Roaf or Sun amp	Y	y	y
Thermal mass	PCM (related heating controls)	Dupont Energain	Y	y	
Floor Insulation	Solid floor insulation - Foamed glass / Plecca pellets				
Floor Insulation	Timber floor insulation - Blown cellulose / Wood fibre board	Warmcell / FAVATHERM			
Wall Insulation	External - insulated lime render	Eden Lime			
Wall Insulation	Internal - insulated lime	Eden Lime	Y		

	plaster				
Wall Insulation	Internal - FOAM - ICYNENE	Kishorn Insulation	Y		
Wall Insulation	Internal - Aerogel	Proctor Group	Y		
Roof Insulation	Wood fibre				
Roof Insulation	Cotton waste				
Ventilation	HR from vents (chimneys)	Passivent			
Ventilation	Traditional stack ventilation	Trad. details for CUPOLAS, Stairwells, humidity based vents, Sun Amp			
Glazing	Vacuum glazing, Slim profile DG, Storm Glazing, Insulated Blinds,	Pilkington Spacia, histoglass, ravensby, Knaufman (enternal)			

Appendix C: Full score-cards

Available as a separate PDF download with contents page containing links to individual score cards.