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Evaluation of a Regional Retrofit Programme to Upgrade Existing Housing Stock to Reduce Carbon Emissions, Fuel Poverty and Support the Local Supply Chain

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Abstract: The first-ever legally binding global climate deal that will be adopted by 195 countries was introduced in Paris in 2015, highlighting that climate change is being recognised as a real and urgent global problem. Legislative interventions need to be accompanied by significant action across all sectors of the built environment through reducing energy demand, providing energy supply from low carbon sources and combining with this with energy storage to enable necessary targets to be met. Retrofitting existing buildings is critical to making these cuts as 80% of buildings currently in existence will still be present in 2050. These retrofits need to be undertaken rapidly using replicable and affordable solutions that benefit both the householder whilst significantly reducing emissions. This paper will present an evaluation of a £9.6 million regional scale retrofit programme funded under the Welsh Governments Arbed 1 Programme which aimed to reduce fuel poverty, reduce carbon emissions and support the energy efficiency and renewable supply chain and encourage recruitment and training in the sector. Results have been obtained from desk top data collection and energy modelling calculations. The evaluation work presents the technical, environmental and economic impacts of the programme and demonstrates lessons learnt to help improve the implementation of the other regional retrofit projects providing evidence of the impacts of a large scale retrofit programme that are necessary for the deep carbon reductions required in the near future.

Keywords: regional; retrofit; energy efficiency; Wales; renewable energy supply; reduce demand

1. Introduction

The first-ever universal legally binding global climate deal was introduced in Paris in 2015 highlighting that climate change is, at last, being recognised as a real and urgent global problem [1]. The agreement recognises that global emissions are yet to peak, but that this peak should take place as soon as possible, and be followed by rapid reductions. A total of 195 countries will adopt the Agreement which will enter into force in 2020, with national targets revised on a 5 yearly basis. This follows the EU commitment in 2007 to transform Europe into a highly energy efficient, low carbon economy where EU Governments agreed that emissions would be cut by at least 20% of 1990 levels by 2020 [2]. As a result of the EU Legislation, the Climate Change Act was introduced in the UK in 2008 presenting a new approach to managing and responding to climate change in the UK [3]. Targets were set to reduce carbon emissions by 80% by 2050 with 1990 as the baseline year with interim targets of 26% by 2020 [3]. Top down, legislative agreements need to be fully supported by significant action across all sectors of the built environment, through reducing energy demand, providing energy from renewable low carbon sources and storing energy where possible to minimise the use of fossil fuels.

Final energy consumption in EU28 in 2013 was 1103.7 Mtoe, with 26% of this total used in households [4]. In 2014 UK total greenhouse gas emissions were estimated to be 514.4 million tonnes

CO_2 equivalent in ($MtCO_2e$) [5]. Twenty nine percent of total final energy consumption in the UK is by housing, the highest of all sectors [6]. Figure 1 summarises the energy consumption of a typical home in the UK in 2009 and highlights opportunities to save energy through space and water heating. Significant changes are required in both lifestyle and to the current housing stock for these targets to be met.

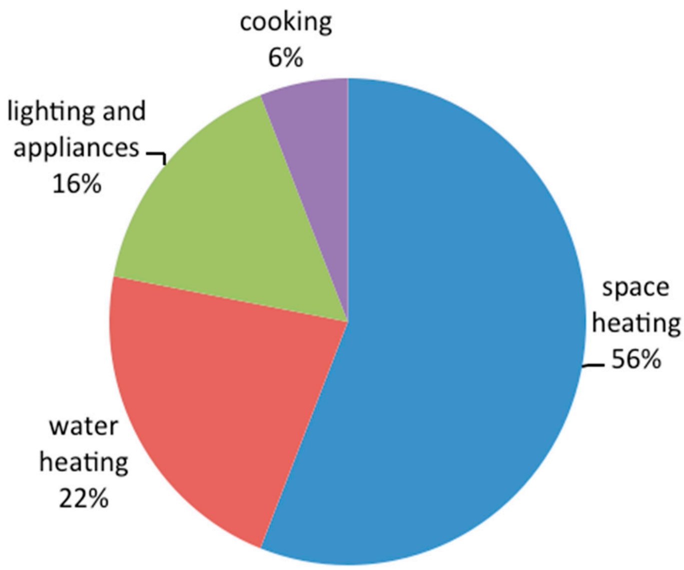

Figure 1. Energy consumption in a typical home in the UK [7].

Low carbon retrofit options can include: reduced demand—through fabric and form improvements such as increased insulation, installation of energy efficient appliances and considered layout; thermal and electrical energy storage and through generating energy from renewable energy sources. However, identifying the most appropriate combination of retrofit solutions required to meet targets can be extremely complex [8]. Many studies have been undertaken to provide methodologies to support the selection of appropriate retrofit solutions for domestic properties [9–13] but in practice it is proving difficult to implement these on a scale that will achieve the targets set due to the large number of barriers. Properties constructed during different time periods pose different retrofit challenges due to the materials available, construction methods and needs of the population at the time of construction and this is also true for dwelling in different locations. Decisions have to be made between taking the "whole house" approach on fewer dwellings or implementing one or two measures over a wider range of stock and these decisions are often influenced by the type of grant funding available. The favorable long term view should be to aim for a whole house approach [14–16] as this would provide a stock of properties that would perform as efficiently as possible, assuming the planning, design and construction of the works had been undertaken correctly and that maintenance procedures are put in place. By undertaking few measures to many properties, underlying problems may exist within properties that will prevent measures working efficiently. However, this approach would keep more householders satisfied with short term improved housing and may be dictated by funds available and political requirements.

Barriers preventing energy retrofits through improved energy efficiency and the application of renewable energy supply include a lack of consistent funds available to householders and government, knowledge regarding appropriate changes for housing type and the cost of "deep" retrofit where clear financial savings can be made on energy bills [8,10]. The European Directive 2010/31 [17] emphasizes that retrofitting of existing stock should aim to achieve "minimum energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels". With energy costs increasing and the introduction of further legislation to reduce carbon emission pressure to make changes to existing building stock is increasing.

To highlight the affordability problem, in 2009 over 5.5 million (approximately 21%) households in the UK were living in fuel poverty, spending more than 10% of household income on heating [18]. In Wales, UK it was estimated that 386,000 or 30% of all households were suffering from fuel poverty in 2012 [19], an increase from 134,000 in 2004 with 44% of these households living in social housing. The price of domestic gas and electricity has been relatively stable between 2010 and 2015 after increasing steadily through 2000–2008 [20]. As household incomes have generally fallen or levelled off since the economic downturn in 2008, the main way to reduce the impact of future price rises is to increase energy efficiency of homes and provide energy from renewable energy sources.

With a replenishment rate of just 1% per annum [21] and over 20 million existing homes in the UK [6,22], there is a significant challenge for householders, local authorities, businesses and communities to utilize limited funding and grants available on the homes most in need for retrofit whilst on a scale large enough to have long term impacts. The need for good quality retrofitting is essential to reach targets through the implementation of low carbon technologies to improve the existing housing stock through more energy efficient properties and providing energy from low carbon sources due to unnecessary demand for space heating. A range of funding streams and grants have been made available in the UK to attempt to reduce emissions from the domestic stock in the UK including Green Deal [23], Feed in Tariffs [23], Renewable Heat Incentives [24] and the New Fuel Poverty Scheme [19]. These are been available to different groups of the population and frequently change name and eligibility criteria which can be confusing and therefore have low uptake due to uncertainty of eligibility. Other issues that create a lack of motivation for such schemes include a lack of clarity on financial savings/payback time on investment and also a lack of community uptake which prevents the aesthetic benefits of the "blanket approach" that can be achieved through social housing investment. A key driver for social housing improvements and therefore the uptake of these grants in Wales, UK is the Welsh Housing Quality Standard (WHQS) [24] established in 2001 which requires that "everyone in Wales should have the opportunity to live in a good quality home within a safe and secure community". To help achieve this, the physical standard and condition of existing housing must be maintained and improved and that all social housing should reach a Standard Assessment Procedure (SAP) of 65 as an indication of "adequate fuel efficiency and insulation" with 2020 as the deadline for all social housing to meet the WHQS targets. In the private rented sector, a minimum Energy Performance Certificate (EPC) will be set for domestic rented properties in 2018 which will require an improvement to a specified minimum standard [23].

The UK economy is dependent on a strong construction industry, with 2.93 million people employed in the industry in the UK in 2013, with half involved in repair, maintenance and improvement [25]. The importance of good quality, well designed and properly implemented retrofitting will become more important as the building stock ages. This will require a significant step change in training, skills and investment if carbon reduction targets are to be achieved and the construction industry will need to adapt to suit these needs. Incorrect installation of low carbon measures can lead to detrimental impacts rather than improved conditions for householders and reduced CO_2 emissions.

Reducing emissions from retrofitting existing housing is relatively new to policy and action has therefore been relatively slow, particularly in regards to making "deep reductions" despite its inclusion the EU European Directive 2010/31 [2]. Small scale programmes are common involving less than 500 domestic properties but deeper retrofits which target a large number of properties are not typical, but are required to achieve the 80% target set for 2050. Smaller scale successful retrofits include the Sustainable Energy for Rural Village Environment (SERVE) in Ireland which saw 350 homes retrofitted to achieve a 40% energy savings as part of the EU Concerto Programme [26]. The retrofit of 100 detached dwellings in Karaburma in Serbia has resulted in 42% CO_2 reduction through external wall insulation (EWI), replacement window and roof insulation. Although such schemes are achieving significant reductions in CO_2, levels are not as high as they should be. However, these schemes are likely to be having a positive impact on fuel bills and quality and life and wellbeing of the householders which is very difficult to provide evidence of.

In an attempt to stimulate the uptake of new to the market technologies in the UK the Technology Strategy Board (TSB) launched the "Retrofit for the future" programme to take technologies and ideas that were available and try to address the broader barriers to increase uptake. This scheme illustrated that a "whole house" deep approach can provide huge financial, comfort, carbon and social benefits but that costs to undertake the retrofit works were still prohibitively high to undertake at scale [27].

There is therefore a need for rapidly employed large scale retrofit programmes to take place which improve the housing stock, reduce emissions, create employment and improve quality of life and wellbeing of residents' whist being at an affordable level. These retrofits need to be undertaken quickly using replicable and affordable solutions that benefit both the householder whilst significantly reducing emissions. Programmes should be well planned and managed to be environmentally, economically and socially effective as possible.

2. Materials and Methods

In order to evaluate the technical, environmental and economic impact of the implementation of the regional scale Arbed 1 retrofit programme, data was provided by Warm Wales (WW) and modelled energy calculations based on property types and ages was calculated. Interviews took place with staff involved in the Warm Wales Programme including both property owners and WW staff to reveal further information about the experience.

The retrofit programme, Arbed 1, was set up by the Welsh Government to take a "whole house" approach to install energy efficiency measures and renewables across Wales, UK. Arbed 1 was the Welsh Governments (WG) Strategic Energy Performance Investment Programme and included domestic properties owned by Registered Social Landlords (RSLs), Local Authorities (LAs) and owner occupied homes. The strategic objectives Arbed 1 were to reduce fuel poverty; reduce carbon emissions and support the energy efficiency and renewables supply chain and encourage recruitment and training in the sector. Properties were targeted in Strategic Regeneration Areas within Wales which were also believed to have low household incomes. Arbed 1 was established in 2009 and included 28 separate projects involving more than 6000 homes [28].

The amount of £60 million of funding was invested in Arbed 1, £30 million from the Welsh and UK Government, £10 million from energy suppliers and £20 million from RSLs and local authorities. A follow up, Arbed 2 took place between 2012 and 2015 with the same objectives as Arbed 1 with £45 million to improve energy efficiency in Welsh homes targeting solid wall, off gas properties in low income areas with a more even split of public/private households. A minimum target reduction of 11.6 KT CO_2 was set.

Warm Wales, a Community Interest Company, based in Port Talbot in South Wales was commissioned by five RSLs and two LAs to help deliver their Arbed 1 projects. Warm Wales' undertook scheme design, project management and provide design advice working alongside contractors, RSLs/LAs and energy suppliers. These 7 projects were part of the 28 projects funded by the WG and are summarised in Table 1. Each RSL/LA made the decision as to what properties to improve and what measures to implement during the application process to WG. Warm Wales oversaw the overall programme with two project managers who delivered the project. Energy wardens were recruited to act as a direct link with householders. A total of £9.6 million was invested within the Warm Wales programme and the work took place from 2010 to 2011.

The total number of properties included within the Warm Wales Programme was 1147. Fabric improvements involved the implementation of external wall insulation (EWI) to improve the internal thermal conditions. The improvement of windows was not included in the programme as many of the properties already have double glazed windows and upgraded boilers funded from alternative schemes as part of the WHQS [24]. Heating modifications took place where new boilers were installed where fuel switching took place and Air Source Heat Pumps (ASHP) were implemented in a small selection of flats. These were limited due to the element of risk perceived by the RSLs. Solar PV, fuel switching, solar thermal and air source heat pumps were installed to provide more efficient energy supply system resulting in reduced energy costs and emissions.

Table 1. Key characteristics of each of the Warm Wales Arbed 1 projects.

RSLs/Local Authorities	Location	Total No. of Units Managed by RSL	Main Type of Properties Included in Arbed	Arbed Grant	Main Measures
Charter Housing	South East Wales–Newport area	5500	2 and 3 bed terrace built pre 1919	£1.6 million	EWI, Solar PV
Melin Homes	South East Wales–Pontypool area	3000	1/3 pre 1919 solid wall, 2/3 post 1980 cavity wall houses	£1.0 million	EWI, Solar PV ASHP
Family Housing	South Wales area–Swansea area	2300	Pre 1919 solid wall	£1.0 million	EWI, Solar PV
Coastal Housing	South Wales–Swansea area	5500	1/2 pre 1919 solid wall, 1/2 post 1980 cavity wall	£1.3 million	EWI, Solar PV
City and County of Swansea	South Wales–Swansea area	Over 13,000	Post war semi-detached housing and some 1980s terraced	£2.5 million	EWI, Fuel switching, Solar PV, Solar thermal
Tai Ceredigion	Mid-West Wales–Aberystwyth area	2200	Flats and semi-detached houses built between 1965 and 1980	£600,000	EWI, Fuel switching

EWI: External Wall Insulation; PV: Photo Voltaic.

One of the main objectives of Arbed 1 was to reduce emissions to assist in meeting the targets set by Welsh and UK Government. In this evaluation CO_2 savings and SAP improvements have been calculated using information regarding the measures implemented and the types of properties on a property by property basis using the Energy and Environmental Prediction (EEP) Model [29,30] using "as built" U-values of the different aged properties and fabric [31] used in the calculations. The "as built" U-values are based on construction type and have been extracted from the UK Building Regulations [29] which have changed over time to help improve the energy efficiency of housing. Properties within the EEP model are clustered into 100 groups based on bandings of property age, heated ground floor area (m^2), façade (m^2), window to wall ratio and exposed end area (m^2) as these features of domestic properties have the largest impact on energy use and information can be collected relatively quickly and easily through maps and "drive by" surveys without the need to enter the property which can be disruptive to the householder and slows down the data collection process significantly [29,30]. The SAP ratings calculated have since been validated with actual SAP calculations and have been found to be representative. The EEP Model was developed and tested in the County Borough Council area of Neath Port Talbot in the UK which is representative of the housing stock of South Wales [30], with many of the properties involved in the Warm Wales programme being located within this local authority area.

These calculations are based on the database of property plans provided to Warm Wales by each of the RSLs/LAs which included data on property age, type and other property based information. There were however, inconsistencies and gaps in this dataset, particularly regarding age of properties. Where gaps were present, information has been obtained using digital maps including Google map. This has enabled SAP ratings, CO_2 emissions and energy saving calculations to be made to demonstrate the improvements as a result of the Warm Wales programme. Gas has been assumed to the primary fuel apart from properties where fuel switching or ASHP have been installed where electrical heating was assumed to be the original heating fuel.

3. Results

Results presented below include the types of properties included in the Programme, the measures installed, CO_2 savings as a result of the measures, supply chain up-skilling and expenditure on the measures.

40% of properties improved within the Programme were built before 1919, therefore having solid wall construction, as shown in Figure 2. Almost a quarter of the properties improved were built during the period of rapid house building of 1945–1964. This included properties of non-traditional construction which were built quickly following serious housing shortages after World War 2 when a surplus of steel and aluminium production following the war drove construction to pre-cast and in-situ prefabrication [32]. Twenty percent of the properties were built between 1965 and 1980 and the same number were constructed after 1980.

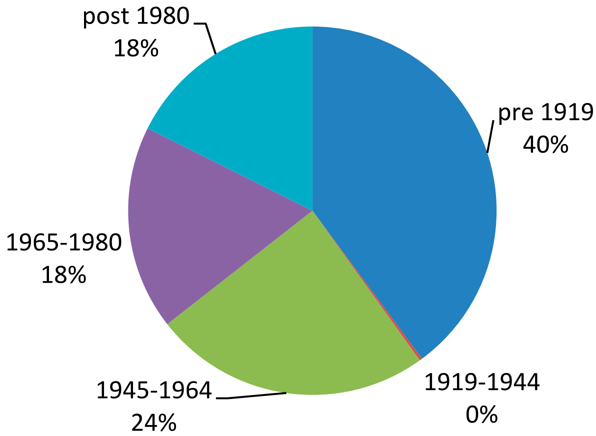

Figure 2. Ages of properties improved within the Warm Wales Arbed 1 Programme.

Almost half the properties improved as part of the programme were either semi-detached or end terraced properties. For this evaluation, these have been grouped together as they have three exposed walls and therefore similar heat loss characteristics. Almost 30% of the properties were mid terrace houses and 21% were flats. It was agreed that very few bungalows and detached properties would be treated as part of the programme in order to concentrate resources, these property types are not well represented within the social housing sector.

57% of the properties improved under the Warm Wales Programme were owned by RSLs, almost a quarter of the properties were owned by LAs, with 20% being owner occupied. Due to the short turnaround time for the Programme, owner occupier recruitment proved difficult, due to the additional time required to reassure and support householders. Despite the introduction of such Government led initiatives such as the Green Deal.

A total of 1391 measures have been installed as part of the Programme, the measures selected to be implemented were based on the types of properties to be included in the programme, the level of funding available and the ability to apply the measures at a practical level. A total of 905 properties received 1 measure, 240 received two measures and 2 properties received three measures. This illustrates that although the Arbed 1 Scheme was aiming to take a whole house approach, the projects within the Warm Wales Programme took more of a blanket approach improving a greater number of properties with fewer measures. EWI was the most common measure installed, with 648 properties receiving this measure. A total of 414 properties received solar PV, 46 solar thermal, 241 switched fuels and 42 had air source heat pumps installed, the proportions of which is shown in Figure 3. Figure 3 also illustrates the types of measures installed within the different aged properties. EWI was targeted towards solid wall properties as this was believed to have the highest improvement in emissions and comfort in this type of housing. Fuel switching was predominant in both the 1945–1964 and 1965–1980 age bands. This is likely to be the case as these properties are remotely located and densely grouped in estates making fuel switching a relatively straightforward option with the funding available.

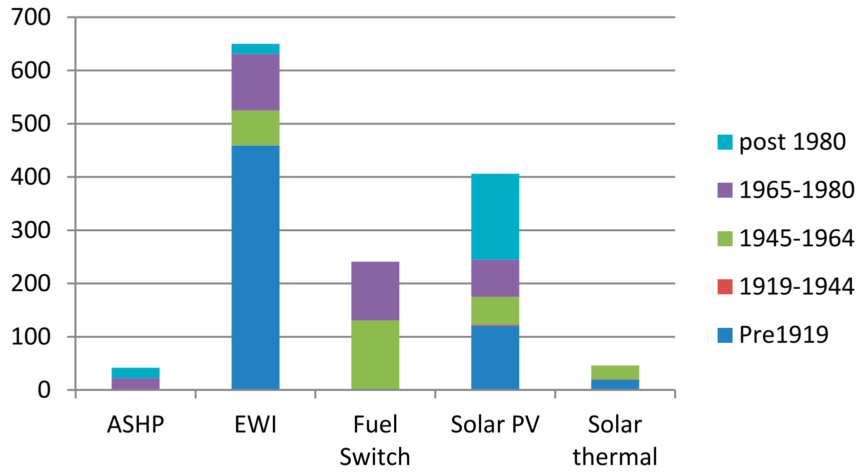

Figure 3. Measures installed in different aged properties. ASHP: Air Source Heat Pumps; EWI: External Wall Insulation; PV: Photo Voltaic.

Solar PV was the most common measure within the post 1980s properties. ASHP were only applied to properties in the 1965–1980 and post 1980 age groups, these were applied to flats on both occasions as illustrated in Figure 4.

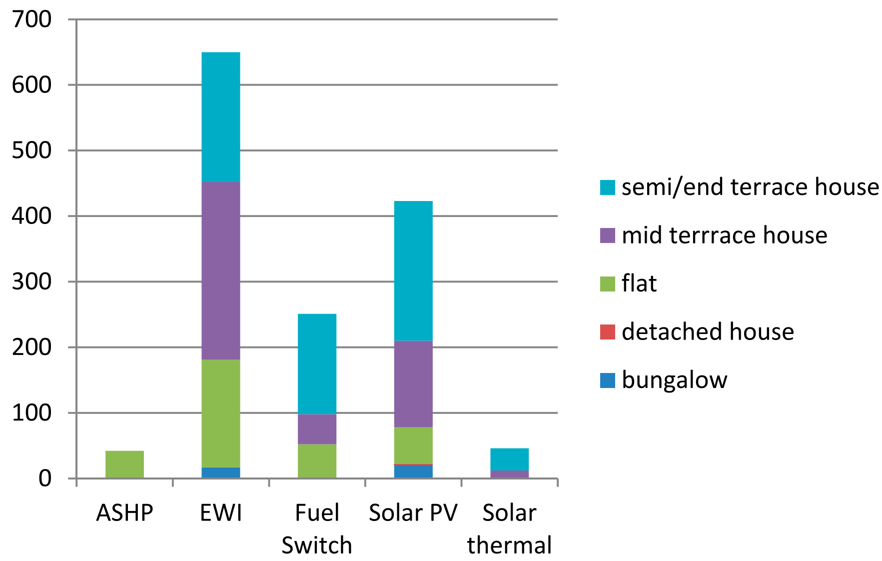

Figure 4. Measures installed in different types of property.

Table 2 illustrates the types and ages of the properties included within the Warm Wales Programme, together with the measures installed within these properties. For each of the types of property, SAP calculations before and after have been made together with CO_2 savings. All calculations have been made using the SAP calculator based on the BRE SAP Procedure 2009 [31].

Properties with the highest CO_2 savings are those which have undergone fuel switching and are relatively large in area. Large CO_2 savings are associated with the change from electricity (Economy 7) to gas as the main heating fuel.

Table 2. Property types, measures and emission savings associated with retrofitted properties.

Type of Property	Age Band	Measures			No. of Props	SAP before	SAP after	SAP Change Per Property	CO_2 before (kg/Year)	CO_2 after (kg/Year)	CO_2 Saving Per Property (kg/Year)	% CO_2 Saving	Total CO_2 Savings for Prop Type
no data	no data				11								
Flat	pre 1919	EWI	solar PV		7	60	70	10	5147	3646	1500	29%	10,503
Flat	pre 1919	EWI			94	60	70	10	5147	3646	1500	29%	141,039
mid ter house	pre 1919	EWI	solar PV		62	58	75	17	8081	4768	3313	41%	205,428
mid ter house	pre 1919	EWI	solar thermal		10	58	71	13	8081	5290	2791	35%	27,913
mid ter house	pre 1919	EWI			190	58	69	11	8081	5689	2393	30%	454,650
mid ter house	pre 1919	solar PV			23	58	64	6	8081	7161	920	11%	21,171
mid ter house	pre 1919	solar thermal			2	58	60	2	8081	7683	398	5%	797
semi/end terrace	pre 1919	EWI	solar PV	solar thermal	1	58	75	17	6765	3948	2817	42%	2817
semi/end terrace	pre 1919	EWI	solar PV		22	58	73	15	6765	4343	2422	36%	53,275
semi/end terrace	pre 1919	EWI	solar thermal		4	58	70	11	6765	4699	2065	31%	8261
semi/end terrace	pre 1919	EWI			69	58	68	9	6765	5094	1670	25%	115,258
semi/end terrace	pre 1919	solar PV			6	58	64	6	6765	6013	751	11%	4507
semi/end terrace	pre 1919	solar thermal			2	58	61	2	6765	6370	395	6%	790
semi/end terrace	pre 1919	fuel switching			1	43	58	15	15,704	6765	8939	57%	8939
semi/end terrace	1919–1944	solar PV			2	61	66	5	4292	3816	476	11%	952
semi/end terrace	1919–1944	solar thermal			1	61	64	3	4292	3919	373	9%	373
Flat	1945–1964	EWI			11	51	59	8	6030	4939	1091	18%	12,000
semi/end terrace	1945–1964	EWI	solar PV		2	62	75	13	4951	3180	1772	36%	3543
semi/end terrace	1945–1964	EWI			22	62	70	8	4951	3772	1179	24%	25,939
semi/end terrace	1945–1964	EWI	Fuel switching		31	55	70	15	11,415	3772	7643	67%	236,930
semi/end terrace	1945–1964	fuel switching	solar thermal	solar PV	1	55	70	15	11,415	3971	7444	65%	7444
semi/end terrace	1945–1964	solar thermal	solar PV		7	62	70	8	4951	3971	980	20%	6863
semi/end terrace	1945–1964	fuel switching	solar PV		2	55	68	13	11,415	4359	7056	62%	14,113
semi/end terrace	1945–1964	solar PV			40	62	68	5	4951	4359	592	12%	23,699
semi/end terrace	1945–1964	fuel switching	solar thermal		8	55	65	10	11,415	4563	6852	60%	54,814
semi/end terrace	1945–1964	solar thermal			10	62	65	3	4951	4563	388	8%	3879
semi/end terrace	1945–1964	No measures			80	62	62	0	4951	4951	0	0%	0
semi/end terrace	1945–1964	fuel switching			88	55	62	7	11,415	4951	6464	57%	568,821
bungalow	1965–1980	EWI			17	59	62	3	4570	4131	439	10%	7465
Flat	1965–1980	ASHP			22	62	81	20	6419	3023	3396	53%	74,719
Flat	1965–1980	EWI	Fuel switching		52	62	69	7	6419	2405	4014	63%	208,718
mid ter house	1965–1980	EWI			4	65	70	5	7344	6209	1135	15%	4542
mid ter house	1965–1980	solar PV			4	65	71	6	7344	6318	1026	14%	4105
mid ter house	1965–1980	fuel switching	solar PV		23	57	71	14	16,717	6318	10,399	62%	239,179
mid ter house	1965–1980	fuel switching			13	57	65	8	16,717	7344	9373	56%	121,847
semi/end terrace	1965–1980	EWI			33	66	70	4	5266	4506	760	14%	25,082
semi/end terrace	1965–1980	fuel switching	solar PV		12	60	72	12	11,982	4525	7457	62%	89,480
semi/end terrace	1965–1980	solar PV			31	66	72	6	5266	4525	741	14%	22,959
semi/end terrace	1965–1980	fuel switching			10	60	66	6	11,982	5266	6716	56%	67,161
bungalow	post 1980	solar PV			4	66	74	8	2332	1813	518	22%	2074
Det house	post 1980	solar PV			1	66	74	8	2332	1813	518	22%	518
Flat	post 1980	ASHP			20	60	82	22	6101	2662	3439	56%	68,776
Flat	post 1980	solar PV			49	66	74	8	2352	1833	518	22%	25,403
mid ter house	post 1980	EWI			5	66	67	1	2352	2262	90	4%	451
mid ter house	post 1980	solar PV			20	66	74	8	2352	1833	518	22%	10,368
semi/end terrace	post 1980	EWI			14	66	67	1	2352	2262	90	4%	1261
semi/end terrace	post 1980	solar PV			87	66	74	8	2352	1833	518	22%	45,103
semi/end terrace	post 1980	No measures			18	66	66	0	2352	2352	0	0%	0

SAP: Standard Assessment Procedure.

The average SAP rating before works across the properties was 60 and ranged from 43 to 66. Virtually all properties were therefore below the WHQS recommended SAP of 65 [24]. The target set by the WHQS is very ambitious as the average SAP rating for a British home is 51.6 [33]. Figure 5 illustrates SAP ratings before and after the measures were installed. The average SAP rating following the works was 69, with a range from 58 to 82 with only 231 properties falling below the WHQS of 65.

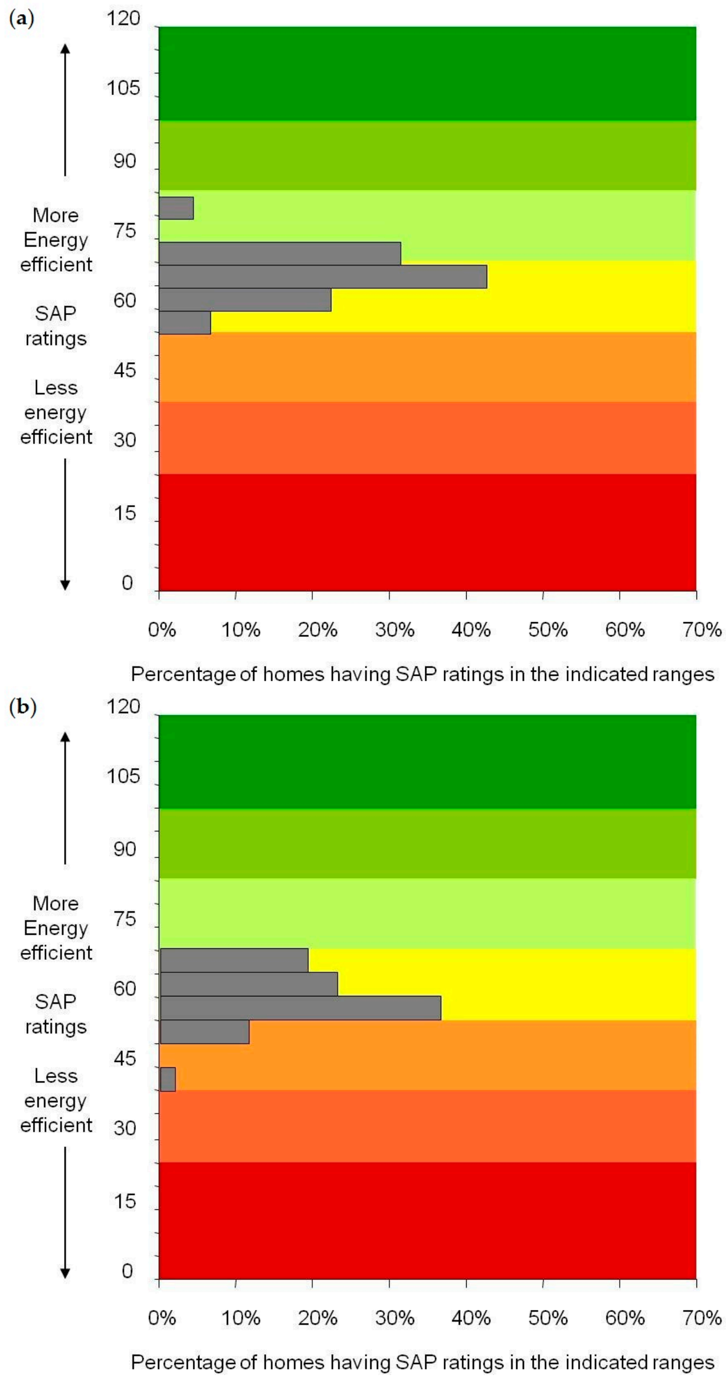

Figure 5. Standard Assessment Procedure (SAP) ratings of properties (**a**) before and (**b**) after measures were installed.

Total CO_2 savings for the Programme have been calculated at 3025 tonnes per year. The average UK household emits 6000 kg of CO_2 per year [6]. More than 30% of the properties saved more than

3000 kg/year CO_2. Almost 1/3 of the properties save more than 40% of CO_2 emissions when looking at the percentage of CO_2 saved compared to the CO_2 emissions before the work was undertaken (Figure 6).

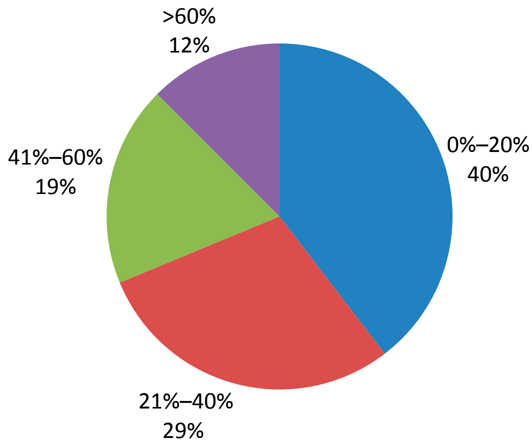

Figure 6. Percentage of CO_2 savings per property.

The greatest percentage of CO_2 savings are achieved when fuel switching is undertaken due to a lower emission factor associated with gas compared to other heating fuel sources as illustrated in Table 3.

Table 3. CO_2 emissions for different heating fuels [34].

Heating Fuel Source	Kg/CO_2/kWh
Gas	0.19
Coal	0.33
Oil	0.28
Electricity from grid	0.55

Arbed 1 sought to stimulate economic regeneration, create employment opportunities in local areas, whilst also increasing capacity in the manufacture of low carbon technologies in Wales utilizing all grant assistance available to bring maximum benefit to low household income areas. Training requirements were set as part of the funding criteria for Arbed 1. Training opportunities included initiatives such as "Job Match", a Welsh Government, Department for Work and Pensions and local authority backed initiative offering support to help people to overcome barriers to employment and "Beyond Bricks and Mortar" to help with social and physical regeneration were used to recruit appropriate staff. The majority of trainee opportunities were provided via subcontractors and ranged from short term trainee positions to 3 and 4 year apprenticeships. The aim was 1308 training weeks and this was exceeded by over 25%, achieving a total of 1704 training weeks. Training opportunities were provided in carpentry, plumbing and heating, electrical, construction skills and plastering.

Fifteen Community Energy Wardens were employed to work with Warm Wales and the main contractor to support community engagement, installation of measures and provide an aftercare service to residents. This supporting role included being on hand to discuss and support residents in understanding information related to the programme, benefits of individual measures and potential impacts throughout the installation process. Energy Wardens were trained and supported to deliver Home Energy Assessments, basic energy advice and installation of Real Time Displays. All fifteen received significant training and work experience to improve their long-term work prospects.

The total cost of the works implemented through the Warm Wales Programme was £9,658,509 as illustrated in Table 4.

The total cost of the measures implemented to RSL/LA properties utilising Arbed 1 funding through the Warm Wales Programme was £6,372,155. Of this, £5,580,367 was provided from grant support mechanisms. RSLs/LAs contributed £791,789 towards the direct cost of the Arbed 1 works undertaken to RSL/LA properties, which equates to 12.4% of the expenditure. £2,141,104 additional funding was provided to undertake leverage measures by the RSLs/LAs on their properties. This included additional works such as replacement of eaves, electrical upgrades and general making good, together with making use of facilities such as scaffolding whilst on site to reduce future disruption. A total of £1,145,250 has been invested on EWI and new heating systems within privately owned dwellings.

Table 4. Funding allocation through Warm Wales Programme.

Funding Allocation	Contribution
Warm Wales Programme—RSL/LA properties	£6,372,155
Leveraged measures on RSL/LA properties	£2,141,104
Warm Wales Programme—privately owned properties	£1,145,250
TOTAL	£9,658,509

Average actual costs per measure can be seen in Table 5. These are the average direct costs charged by the contractor to undertake the works including enabling works which varied according to the measure being installed.

Table 5. Actual cost per measure installed during the Warm Wales projects.

Measure	Average Cost	Note	No. of Measures Installed
EWI	£7730	Inc enabling works and 5% VAT	648
Fuel switching	£3126	Inc 20% VAT	241
Solar PV	£4988	Inc enabling works	414
Solar thermal	£4393	Inc enabling works	46

When considering the supply chains involved in the Programme, four of the seven manufacturers are located in Wales including Envirowall, Rockwool, Sharp and Wetherby. Twenty contractors/subcontractors were involved in the programme. Of these 16 were based in South Wales which strongly supports the aim of the scheme to increase local employment. The lead contractor that was recruited was predominantly based in Cardiff and supported in part from Birmingham.

4. Discussion

The technical, environmental and economic benefits, barriers and problems that have arisen during large scale retrofit being evaluated are presented.

The benefits of EWI over internal wall insulation include no loss of internal space, less disruption to householders and less cost due to rewiring and removal of fittings and fixtures and allowances for redecoration and floor coverings. EWI also has the benefit of permitting total coverage if installation is undertaken correctly. However, incorrect installation of EWI can result in thermal bridging when the external surface is not fully covered or gaps remain which can create internal draughts and potential condensation issues. However, it is generally accepted by OFGEM that thermal bridging may exist around windows, doors and at roof and floor junctions when EWI is installed but this should be reduced if reasonably practical and cost-effective to do so. Problems in the Arbed 1 Programme were experienced with difficult detail issues that had to be solved on site (Figure 7), poor workmanship and difficulties experienced when dealing with too many properties being retrofitted simultaneously. The following examples illustrate the need for good planning and workmanship and the need for manufacturers to provide detailing solutions for the problems that might arise on site. There is a balance that needs to be met between specifying high quality design, completing works on time with less disruption to residents and cost.

(**a**) (**b**)

Figure 7. Difficulties when dealing with solid walled properties with intricate detailing. (**a**) Stone front façade to remain, with EWI having to be cut around detailing on side aspect; (**b**) Poor detailing around roof/wall junction.

If detailing is not specified during the scheme design stage, they have to be resolved on-site which delays progress. Although properties do vary, particularly older properties which have been extended over time, the provision of generic solutions for such issues from manufacturers and at the design stage would ensure that solutions provided are technically robust. EWI systems typically do not have ready answers to awkward detailing and this therefore merits further special attention.

Shortcomings in workmanship where time has been lost due to other technological issues can also create water penetration problems. In Figure 8, the bottom track at floor level has not been terminated with a capping piece which prevents render adhering to the EWI. The problem is made worse as the vertical corner bead has not been continued down to the bottom track. This would be resolved by the introduction of a stop end or cutting a 45° cut into the end of the trim to enable the track to return into the door reveal.

Figure 8. Detail at floor level.

Window sills provide a challenge when installing EWI. It is common for uPVC sills to be fitted over existing sills, which can leave opportunity for water penetration if not finished correctly with sealing by end caps (Figure 9.)

Figure 9. Fitting a new sill over existing sill.

The need to maintain dwellings further than simply installing low carbon measures is demonstrated in Figure 10 where the addition of the EWI has resulted in damage to the head of the window. Additional budgets should be incorporated into low carbon programmes to rectify direct problems that will reduce the benefit investments made.

Figure 10. Damage to window head during the installation of EWI.

There is a need to provide a well prepared timetable for subcontractors to work to. Figure 11 illustrates problems that occur where programmes are poorly timed. In this example the heating system was installed after the EWI had been fitted. As a consequence the heating engineers cut a hole in the EWI for the flue which resulted in insulation being stuffed into the hole once the flue had been installed. This resulted in the EWI installers having to return to the property to re-insulate and re-render the area around the flue, taking additional time and cost.

When adjacent properties do not have works undertaken problems occur with the implementation of fixtures. In Figure 12 the differing profiles of guttering would lead to leaks during heavy rain which was rectified by providing new matching guttering even though the resident was not involved in the Warm Wales Programme.

Figure 11. Poor timetabling resulted in damaged EWI.

Figure 12. Undertaking works on adjacent properties.

In many of the situations described above it is the time aspect which causes issues, with subcontractors wanting to get works completed as quickly as possible. This demonstrates the necessity of quality control via agreed samples for larger scale initiatives and site supervision. Reliance on manufacturer warranties is a poor substitute to insisting on appropriate design solutions and good quality workmanship during installation. The level of EWI product knowledge and experience is not high enough to allow large scale initiatives to take place. The Arbed 1 Scheme has shown the need for up-skilling to ensure that sufficient levels of labour are available. It is also important that, where possible, schemes are well planned to enable consistency in employment rather than ad-hoc work dependent on funding streams. The 15 month gap between Arbed 1 and Arbed 2 demonstrates the problem in retaining skills.

The Programme has made a significant improvement to the aesthetics of communities, particularly those that have had EWI installed. Figure 13 provides evidence of visual improvements. These are likely to have a significant impact on the quality of life and wellbeing of the wider community in providing a more pleasant environment to live in.

Figure 13. Aesthetic improvement of housing as a result of retrofitting. (**a**) Block of flats prior to retrofit; (**b**) The same flats post retrofit; (**c**) Single storey housing prior to retrofit (**d**) The same single storey housing post retrofit.

A comparison has been made of the CO_2 savings made per pound spent on the different measures for a semi-detached/end terrace pre-1919 house, illustrated in Table 6. The highest CO_2 savings are made when fuel switching takes place, resulting in a CO_2 saving five times greater than the other measures for this type of property. This assumes that the original fuel source is economy 7 electrical heating which is the highest emitter of CO_2.

Although CO_2 savings associated with fuel switching are in the magnitude of those required to achieve long term targets set, opportunities for fuel switching to gas are limited. The current fuel mix for domestic energy consumption in the UK is 1% coal, 21% electricity and 69% gas [35] which means that only around 22% have the opportunity to make this relatively cheap but significant change. CO_2 savings are higher for EWI than for solar PV and solar thermal and prove to be better value for money with a lower £ per kg CO_2 per year.

Table 6. Illustration of the CO_2 savings made per £ spent for a semi/end terraced house.

Measure	CO_2 Savings (kg/Year)	£ Per Measure	£ Per kg CO_2 Per Year	% CO_2 Saving (kg/Year)
EWI	1670	£7730	£4.63	25
Fuel switching	8939	£3126	£0.35	57
Solar PV	751	£4988	£6.64	11
Solar Thermal	395	£4393	£11.12	6

Figure 14 demonstrates that fuel switching provides the best CO_2 savings per £ than any of the other measures (based on electricity being pre works heating fuel source).

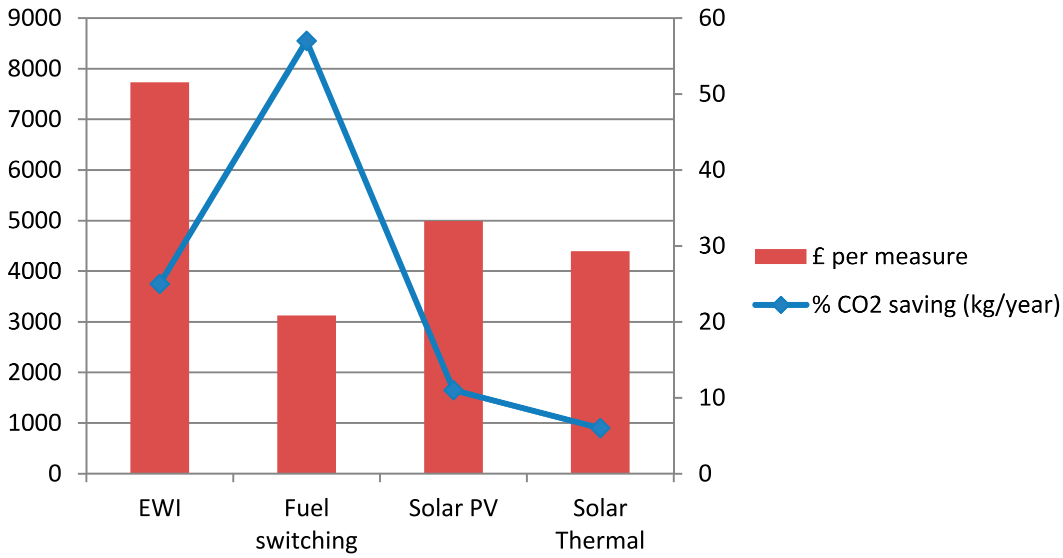

Figure 14. Comparison of CO_2 savings and £ per measure for a pre-1919 semi/end terrace house.

The average annual energy bill before the works were undertaken was approximately £990. This corresponds to the estimated UK domestic fuel bill of £1032 per year as calculated by OFGEM [36] based on a typical consumption of 16,500 kWh per year of gas and 3300 kWh per year of electricity.

Assuming the behaviour of the residents remained similar, the average household energy cost after the works has been calculated to be £774 therefore saving £216 per year on energy bills. The greatest energy bill savings have been calculated for a 1980s flat that has received ASHP with a saving of over 50%. Forty percent energy cost savings were calculated for a mid-terrace pre 1919 house that had EWI and solar PV installed, with annual energy bills potentially being reduced by over £550. It has to be acknowledged that an element of this saving could be used to increase temperatures for increased comfort rather than the householder benefitting financially.

Figure 15 demonstrates the percentage of savings to householders' energy bills as a result of the works undertaken. This illustrates that 50% of the households involved in the scheme could save more than a 20% of their annual energy expenditure assuming behaviour remains the same following the retrofitting work.

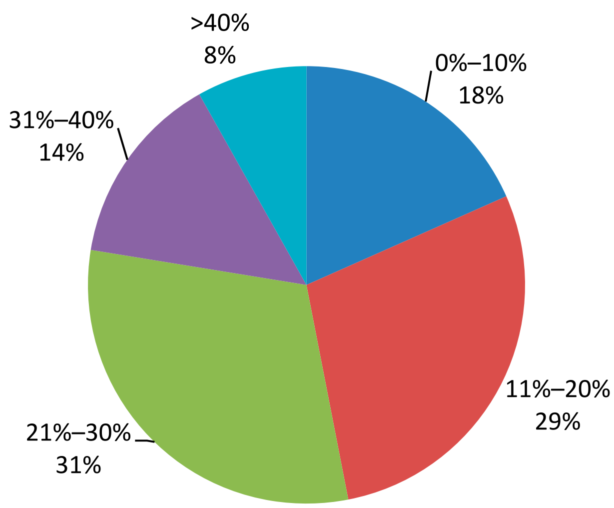

Figure 15. Percentage of potential financial savings on energy bills as a result of the Warm Wales Programme measures installed.

The combined potential financial savings for all households involved in the Warm Wales Programme is £285,000 per year.

The investment involved in the Warm Wales Programme of £9,658,509 equates to a payback period of 33 years across the whole the programme. This does not take into account the added property value which will have been enhanced as a result of the improved condition of the housing standard, the improved comfort for householders (which is likely to have an impact on health and well being), improved aesthetic value of the communities and likely increased energy costs over time.

5. Conclusions

The evaluation of the Warm Wales component of Arbed 1 was undertaken to provide evidence of the impacts of a large scale retrofit programme. Technical, environmental and economic impacts of the Programme have been evaluated to demonstrate the positive and negative aspects of the programme in order to assist with improving the implementation of other large scale retrofit programmes that are necessary for the deep carbon reductions required in the near future. This evaluation has highlighted key factors involved in the successful delivery of large scale low carbon retrofitting of housing in programme. Key drivers of a large scale retrofit programme have been identified to include the involvement of a contractor who is efficient, organised, and resourced to take "well-planned" risks; which should be supported by large scale funding programmes, such as Arbed, which at an average rate in excess of 80% grant, which enables retrofit works to be undertaken creating employment opportunities and allowing low level risks to be taken using technologies that had not been used in the past by RSL's/LAs.

A number of barriers to large scale roll out have been identified through the evaluation process, including:

- Cost evaluation should include better control of capital costs together with long term operational costs including enabling works, maintenance and project management. This can be managed by the Programme administrator and the project management team.
- Rectifying detailing due to small variations in properties took time and additional expense on site which was inefficient. Detailing solutions provided by manufacturers, agreed with approved installers at the outset, would minimise this problem.
- Different products require different detail, which involves a lot of new information to be learnt and to trust. There is a need to reliably share information at all levels to ensure a high level of installation to reduce long term efforts and cost with maintenance.
- Additional planning time could have allowed more appropriate solutions to be have been identified. Due to the quick turnaround time specified by the Arbed Programme there were instances of a lack of time for appropriate planning, particularly at the initial site set up stages and for selection of appropriate measures.
- Lack of experience and available local skills caused problems in implementation preventing works of a satisfactory standard being delivered.

To resolve these issues the following recommendations are made for large scale retrofit programmes:

- An accurate survey of properties should be undertaken as early as possible, together with validated computer based modelling to identify property appropriate and cost effective measures, supported by findings from the "Retrofit for the Future" programme [27]. Although this is will take additional planning time and therefore have implications on the cost of the retrofit, it will reduce complexity and opportunity for errors to be made during the construction stage which could be more costly and will have a greater impact on the householder. Responsibility for this should be clearly allocated so that it is undertaken in advance of works, and in sufficient detail to allow on site-works to be as efficient as possible to minimise disruption to the resident and to keep installation costs down. The improvement measures to be delivered and the approach to be taken should be confirmed, with a clear rationale of either "whole house" or "blanket"? The intention of the Arbed programme was to be "whole house", but time constraints restricted this to a "blanket approach".

- The most appropriate combination of measures for the building, the locality and the residents, fully utilizing the funds available, considering long term maintenance should be adopted. This should consider fabric, form, system and appliances. Generally, fabric improvements are favoured by householders and property owners as appearance is improved and long term maintenance is minimal if detail is specified correctly during installation. However, fewer difficulties were experienced during the installation of renewable energy supply systems—provided that on-site timetabling was addressed.
- Data collection such as existing detailed building layouts (as built and modifications), occupier details, energy bills, detailed as retrofitted plans, basic monitoring and warrantees is usually very variable in quality and accuracy. Consistent methods of data collection and storage simplify the surveying and planning process and aid the collation of evidence that improvements are making a difference which enables lessons to be learnt for future experiences. This would have to fit in with the existing processes of the organisation managing the retrofit scheme whilst taking into consideration the roles of other stakeholders such as the building owners and their needs. Monitoring of works before and after would allow for a better evaluation of success to provide evidence that the measures are performing as expected.
- Costs of work need to be carefully planned to reduce levels of uncertainty. Cost evaluation should include more emphasis on fixed and measured capital costs at the outset together with allowance for expected operational costs including enabling works, long term maintenance and the cost of project management.
- The potential social impacts of the scheme such as householders' behaviour during and after works and impact on broader community also needs to be better understood in order to optimise the benefits that can be provided from such schemes.
- The supply chain should be carefully evaluated before large Programmes are initiated. Local subcontractors on existing frameworks can often provide the benefit of continuity and experience of the types of properties involved. Local manufacturers can be involved to adapt measures as required and provide suitable product warrantees. Main contractors should underwrite compliance with product specifications to provide those assurances of long term performance.

There is a significant need for large scale deep retrofits to take place across Europe to achieve the 2050 target of 80% emission reductions to be achieved [3]. The Arbed 1 Programme has demonstrated that large scale retrofits can be implemented with significant benefits therefore demonstrating the need to act rather than to model and to undertake very small scale retrofit programmes. Lessons have been learnt from the programme as presented above which can be used to inspire further regional programmes to take place. The Arbed programme has provided the RSLs and LAs with confidence to try out new technologies and establish new relationships with local suppliers and installers. The programme has illustrated that there is a need for good scheme design and contract planning and workmanship. There is also a need for the supply chain to provide flexible and adaptable solutions for problems that might arise. A balance needs to be met between high quality design, meeting tight deadlines and cost in order to complete works that will deliver the CO_2 targets necessary. Around 20,000 properties are owned across the seven organisations involved in the Warm Wales component of Arbed 1, with a range of measures implemented on different aged and types of properties. The large range of housing across all seven projects provided the opportunity for the RSLs involved to share findings from the implementation of Arbed 1 on different types and ages of properties in order to improve a broader range of their housing stock in the future.

There is potential for retrofits to not deliver as expected including inadequate analysis, inappropriate design decisions, supply chain obstacles, poor quality installation practices on site or ineffective occupier engagement and handover regimes. There is a need for the implementation of regional scale retrofits to be well managed throughout the entire programme of works, including into the operational phase. As a result of the Retrofit for the Future programme [27] the TSB have developed a framework of six key components to ensure successful implementation of a domestic retrofit which are required for a successful "whole house" retrofit. This highlights the need for planning and the involvement of key stakeholders including the householder.

Above all both capital and operational costs have to be favourable to enable retrofit works and the broader value of undertaking a "whole house" retrofit has to be clear. Jones et al. [14] have recently undertaken deep whole house retrofits and although this work illustrates that the cost is declining, further reductions are still needed to make retrofitting more attractive.

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Abbreviations

The following abbreviations are used in this manuscript:

ASHP	Air Source Heat Pump
EEP	Energy and Environmental Prediction (model)
EPC	Energy Performance Certificate
EU28	28 European member countries.
EWI	External Wall Insulation
Fuel poverty	Spending more than 10% of household income on heating
LA	Local Authority
$MtCO_2e$	Million tonnes CO_2 equivalent
Mtoe	Million tonnes of oil equivalent
PV	Solar Photovolatic
RSL	Registered Social Landlord
SAP	Standard Assessment Procedure
WG	Welsh Government
WHQS	Welsh Housing Quality Standard
WW	Warm Wales

References

1. United Nations. Paris Agreement. 2015. Available online: http://ec.europa.eu/clima/policies/international/negotiations/paris_en (accessed on 20 September 2016).
2. European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions—20 20 by 2020—Europe's Climate Change Opportunity. Available online: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52008DC0030 (accessed on 20 September 2016).
3. Department of Energy and Climate Change. *The Climate Change Act 2008*; The Stationary Office: London, UK, 2008.
4. European Environment Agency. Final Energy Consumption by Sector and Fuel. Available online: http://www.eea.europa.eu/data-and-maps/indicators/final-energy-consumption-by-sector-9/assessment (accessed on 28 October 2016).
5. Department of Energy and Climate Change. 2014 UK Greenhouse Gas Emissions, Final Figures. Available online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/496942/2014_Final_Emissions_Statistics_Release.pdf (accessed on 11 January 2016).
6. Palmer, J.; Cooper, I. United Kingdom Housing Energy Fact File. 2013. Available online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/345141/uk_housing_fact_ file_2013.pdf (accessed on 11 January 2016).
7. Department of Trade and Industry. Energy Consumption in the UK-2009. Available online: https://data.gov.uk/dataset/energy_consumption_in_the_uk (accessed on 8 January 2016).

8. Baeli, M. *Residential Retrofit 20 Case Studies*; RIBA publishing: London, UK, 2013.
9. Dineen, D.; Rogan, F.; O'Gallachoir, B.P. Improved modelling of thermal energy savings potential in the existing residential stock using a newly available data source. *Energy* **2015**, *90*, 759–767. [CrossRef]
10. Jones, P.; Lannon, S.; Patterson, J. Retrofitting existing housing: How far, how much? *Build. Res. Inf.* **2013**, *41*, 532–550. [CrossRef]
11. Geyer, P.; Schlüter, A.; Cisar, S. Application of clustering for the development of retrofit strategies for large building stocks. *Adv. Eng. Inform.* **2016**. [CrossRef]
12. Albatici, R.; Gadotti, A.; Baldessari, C.; Chiogna, M. A decision making tool for a comprehensive evaluation of building retrofitting actions at a regional scale. *Sustainability* **2016**, *8*, 990. [CrossRef]
13. Šijanec Zavrl, M.; Stegnar, G.; Rakuščček, A.; Gjerkeš, H. A bottom-up building stock model for tracking regional energy targets—A case study of kočevje. *Sustainability* **2016**, *8*, 1063. [CrossRef]
14. Jones, P.; Li, X.; Patterson, J.; Coma Bassas, E.; Lannon, S. Preparation for an energy positive community in the UK: Modelling-led innovative housing practice in Wales. In Proceedings of the 36th International Conference on Passive and Low Energy Architecture—Cities, Buildings, People: Towards Regenerative Environments, Los Angeles, LA, USA, 11–13 July 2016.
15. Elsharkawya, H.; Rutherford, P. Retrofitting social housing in the UK: Home energy use andperformance in a pre-Community Energy Saving Programme (CESP). *Energy Build.* **2015**, *88*, 25–33. [CrossRef] [PubMed]
16. National Energy Foundation. *Breaking Barriers—An Industry Review of the Barriers to Whole House Energy Efficiency Retrofit and the Creation of an Industry Action Plan*; National Energy Foundation: Salt Lake City, UT, USA, 2014.
17. European Union. *Directive 2010/31/EU on the Energy Performance of Buildings (Recast)—19 May 2010*; Official Journal of the European Union: Brussels, Belgium, 2010.
18. Department for Energy and Climate Change. Annual Report on Fuel Poverty Statistics 2011. Available online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48138/2181-annual-report-fuel-poverty-stats-2011.pdf (accessed on 10 January 2016).
19. Welsh Government. Wales Fuel Poverty Project Tool—2011 and 2012 Report. Available online: http://gov.wales/docs/caecd/research/130430-wales-fuel-poverty-projection-tool-2011-12-report-en.pdf (accessed on 8 January 2016).
20. Dempsey, N.; Barton, C.; Hough, D. *Energy Prices—Briefing Paper*; House of Commons Library: London, UK, 2016.
21. Department of Energy and Climate Change. 2010 to 2015 Government Policy: Low Carbon Technologies. Available online: https://www.gov.uk/government/publications/2010-to-2015-government-policy-low-carbon-technologies (accessed on 23 March 2016).
22. Utley, J.; Shorrock, L. *Ninety Years of Housing, 1921–2011: Trends Relating to Living Standards, Energy Use and Carbon Emissions*; IHS BRE Press: Watford, UK, 2012.
23. Department of Energy and Climate Change. *Energy Act 2011*; Department of Energy and Climate Change: London, UK, 2011.
24. Welsh Assembly Government. *The Welsh Housing Quality Standard—Revised Guidance for Social Landlords on Interpretation and Achievement of the Welsh Housing Quality Standard*; Welsh Assembly Government: Cardiff, UK, 2008.
25. Department for Business Innovation and Skills. UK Construction—An Economic Analysis of the Sector. Available online: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/210060/bis-13-958-uk-construction-an-economic-analysis-of-sector.pdf (accessed on 10 January 2016).
26. North Tipperary County Council. Deliverable No. D1.142011 Eco-Building Retrofitting-Final Report: Sustainable Energy for the Rural Village Environment. Available online: http://servecommunity.ie/wp-content/uploads/2010/08/SERVE-D1.14-Eco-Building-Retrofitting-Final-Report-Final1.pdf (accessed on 28 October 2016).
27. TSB (Technology Strategy Board). *Retrofit for the Future—Reducing Energy Use in Existing Homes—A Guide to Making Retrofit Work*; Technology Strategy Board: Swindon, UK, 2014.
28. Welsh Government. Arbed-Strategic Energy Performance Investment Programme: Background. 2014. Available online: http://gov.wales/topics/environmentcountryside/energy/efficiency/arbed/?lang=en (accessed on 8 January 2016).

29. Jones, P.; Williams, J.; Lannon, S. Planning for a sustainable city: An energy and environmental prediction model. *J. Environ. Plan. Manag.* **2000**, *43*, 855–872. [CrossRef]
30. Jones, P.; Patterson, J.; Lannon, S. Modelling the built environment at an urban scale—Energy and health impacts in relation to housing. *Landsc. Urban Plan.* **2007**, *83*, 39–49. [CrossRef]
31. BRE (Building Research Establishment). *The Government's Standard Assessment Procedure for Energy Rating of Dwellings*; BRE: Watford, UK, 2009.
32. BRE (Building Research Establishment). *Non-Traditional Housing in the UK—A Brief Review*; BRE: Watford, UK, 2002.
33. Palmer, J.; Cooper, I. Great Britain's Housing Energy Fact File. 2011. Available online: http://www.midlandsenergyconsortium.ac.uk/NewsArchive/2011/3224-great-britains-housing-energy-fact-file-2011.pdf (accessed on 11 January 2016).
34. Carbon Trust, CTL153 Conversion Factors Fact Sheet. 2011. Available online: https://www.scribd.com/document/209092374/Ctl153-Conversion-Factors (accessed on 11 January 2016).
35. Department of Energy and Climate Change. Energy Consumption in the UK-2011. Available online: https://data.gov.uk/dataset/energy_consumption_in_the_uk (accessed on 5 January 2016).
36. OFGEM (Office of Gas and Electricity Markets). Typical Domestic Energy Consumption Figures—Factsheet 96. Available online: https://www.ofgem.gov.uk/ofgem-publications/76112/domestic-energy-consump-fig-fs.pdf (accessed on 11 January 2016).