SUSTAINABLE RETROFIT PLAN
PRE-1919 MID OF TERRACE HOUSE

Abstract

This paper explores, the challenge of reducing OC[1] emission in 95% from those of 1990 in the Wales housing old stock through different retrofit options for apre-1919 mid of terrace house, developing the most feasible and cost-effective of them. Furthermore, an analysis of a significant feature of the refurbishment is carried out, to understand the relation between the savings in OC when upgrading a building and the EC[2] emissions involved in that process.

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[1] Operational Carbon
[2] Embodied Carbon

1. Introduction

Currently, the levels of CO[2] in the atmosphere are 400 parts per million over the safe limit of 350 (Stevenson, 2020), and the construction industry is responsible of 39% of CE [1] in the world (Sassi, 2006). That is why regulations have set up very ambitious targets for cutting down the building carbon footprint[2]. Particularly, UK government aims to reduce at least 80% the emissions from 1990 levels, with a special emphasis in the domestic sector as it is responsible for 33% of the emissions. However Wales has committed to reach a 95% reduction, because although its domestic sector emissions are only a 21% of the total, this higher goal pursue to balance the industrial sector who is responsible for 55% of the CE in Wales against the 39% of the UK industry sector (Green, et al., 2019).

In addition to this challenge, Wales must also face that the 35% of the stock housing was built before 1919, owning one of the oldest housing stocks in Europe (Green, et al., 2019). Then, it is highly likely that additional upgrades are required against other stocks, which are to be essential as it is predicted that 90% of the actual stock will keep in use by 2050 (Green, et al., 2019).

On this ground, this paper aims to explore effective and feasible strategies for retrofitting a pre-1919 mid of terrace house (Figure 1) in order to reach the set target in Wales. Furthermore, it seeks a wider understanding of not only the OC[3] emissions of the building, but also its relationship with the EC[4] of the elements involved.

Figure 1. Front House View

2. Methodology

For that purpose, the research is diveded in two main sections: the exploration and development of a retrofit plan and the analysis of a significant element of the refurbishemnt. Therefore, an utter understanding is achieved of thre upgrade impact onto the total building carbon footprint. Inasmuch as , if it is true that OC has been higly reduce in the last years (Figure 2), the EC have been kept in the same levels. However, to reduced the carbon footprint further, more attention to EC[5] emmisions is essential and its understanding. (Banteli, 2020).

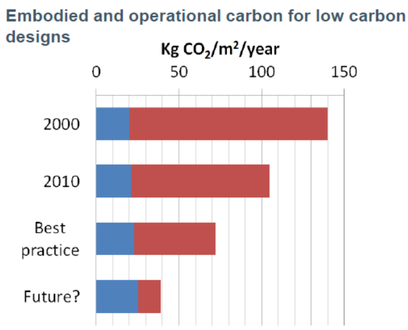


Figure 2. Embodied and OC for Low Carbon Designs. (Banteli, 2020)

First, the current stage of the house is analyze and its OC footprint is stablished as well as the principales to adress the problematic. Then, different options are modelled in the SAP tool (CRIBE, 2014) and analysed in terms of their feasibility and costs. To ultimately develop and detail the most efficent strategy to achieve the 95% target.

On the second part, the wall upgrade will be analysed in detail since it is the meassure wich will required more quantity of materials as shown later, which likely be translate in higher EC emissions. Whilst also, it is one of the most effcient measures to cut down the OC. With this purpose, two alternative systems are compared in terms of its EC, cradle to grave boundary[6]. Ultimately, the EC of the most suitable one is compared against the savings in OC emmisions due to the wall upgrade during its lifecycle.

[1] CE = Carbon Emissions

[2] Carbon Footprint = "A ‘carbon footprint’ is the total amount of CO2and other greenhouse gases, emitted over the full life cycle of a process or product.". (Stevenson, 2020)

[3] OC =Operational Carbon = Amount of the CO2 emissions related to the building in use during its full lifecycle. Such as those produced by heating or lighting. (Stevenson, 2020)

[4] Embodied Carbon = CE linked to the harvest, transport, manufacturing, installation, disposal and/or recycled of any product or process involved in the construction of the building. (Stevenson, 2020)

[5] EC = Embodied Carbon

[6] Cradle to Grave Boundary = Embodied carbon from a product or elements since it is harvested as raw material to the end of its lifecycle.

3. Domestic Retrofit – Operational Carbon

3.1. Base Case and approach.

The pre-1919 mid of terrace house is in King Street, Pentre (Wales), has north–south orientation and a refurbishment has already been carried out previously there, which resulted in a 56% reduction of its OC emissions. The main changes were as follows (Lannon, 2020)):

- 50 mm of insulation between the rafters - **6%** [1]
- New Double-glazed Windows, PVC frames and doors. U-value =3 - **2%** [1]
- Chimney removal- Air tightness improvement together with Windows and doors improvement – Airtightness = 10 m^3/m^2h (Normal Practice) **3%** [1]
- Gas Combi Boiler (90% efficiency) – **43%** [1]
- 100% Low energy Lights – **2%**[1]

Then, the strategy was based on an individual upgrade , the boiler, and the avoidance of high-risk interventions or the use of highly skilled workers. The result of that is the need of a "Fabric First approach"[2] (Lannon & Green, 2020) in the current refurbishment as it is the only route towards reducing heating demand thus emissions can be diminish further. Otherwise limited improvement can be achieved in regards with fuel type or heating system as it is evidenced in the option 4 from the modelled scenarios in the following section.

Nevertheless, the previous retrofit is still an advantage from a cost point of view too(Figure 3) as to reach the final goal of 95% reduction at once might end up on average around £800/ m^2, while the savings will not rises that much, so reasonable payback periods are difficult to achieve (Jones, et al., 2013). Then, retrofitting in two phases to reach the 95% reduction is more beneficial for the owners.

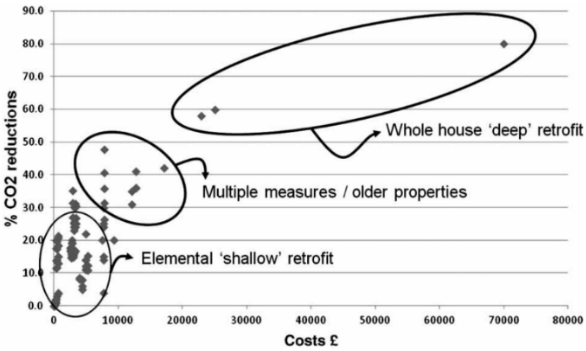


Figure 3. Summary of Costs versus savings for different retrofit strategies.

3.2. Contemplated Scenarios. Feasibility and costs.

Following the "First Fabric" approach, different scenarios (Table 1) have been conceived and complemented using renewable energies as suggested in most of the literature such as McCaig, et al. (2018) and study cases. For example, 15 Passmore street (Westminster City Council, 2013) or in high number of cases on "Homes of today for tomorrow" (Green, et al., 2019).

In order to assess the options, all are modelled in the SAP tool (CRIBE, 2014) and 4 main characteristics are studied individually and as a part of each scenario: intensity, contribution to the carbon reduction, feasibility and cost (Tables 2-5).

ANALYSED SCENARIOS											
OPTION	FABRIC				HEATING SYSTEM	INFILTRATION RATE	MVHR	RENEWABLES		Number Actions	SAP MODEL LINK
	WALLS	FLOOR	ROOF	WINDOWS				SOLAR THERMAL	PHOTOVOLTAIC		
1	X	X				X	X	X	X	6	http://bit.ly/2TPybxA
2	X	X	X			X	X	X	X	**7**	https://bit.ly/3drMHU6
3	X	X	X			X	X		X	**6**	http://bit.ly/33lwevW
4	X	X	X	x	X	X	X		X	**8**	https://bit.ly/33zhjhK#
5	X	X	X					X		5	https://bit.ly/2Wv8LXD
6	X	X	X			X	X	X		7	https://bit.ly/3bjh25r
7	X	X	X					X		**5**	https://bit.ly/2xhJlg5
8	x	x	x			X		x	x	**6**	https://bit.ly/3aecSLS
9	X	X	X			X			X	**5**	https://bit.ly/2Dz0066

Table 1

[1] **X%** = percentage of emission reduction due to each upgrade
[2] First Fabric Approach = It consists in the massive improvement of the building fabric to diminish the energy demand for heating as much as it is possible.

Overall, examining the results carefully the most cost-effective options are those with a whole fabric upgrade but not extremely low values as it is observed that under 0.15-0.20 W/ m^{2}K, there is little or no improvement and technically it is to be difficult of achieve. Furthermore, it can be appreciated the high contributions of photovoltaic panels, 10-13%(Table 3) and how their prices have decrease along the years (Table 5) making them cost effective.

However, making the "First Fabric" approach feasible can be a little intricate (Table 4) due to site dimension constrictions, the high disturbance for occupants or the need of high skilled workers (McCaig, et al., 2018). That is why is crucial to complement this measures with others which do not add further risks. Then, options that contemplates MVHR, PV arrays over 2 kWP or emerging technoloigies are rule out (Table 4). Finally, option 8 stands out as the most suitable option because is intensively based on a "Fabric First" approach, but within the constrains limits, and supported by reliable renewable technology. The specific features of the retrofit are developed on the next point.

INTENSITY OF THE MEASURES									
OPTION	FABRIC				HEATING SYSTEM	INFILTRATION RATE	MVHR	RENEWABLES	
	WALLS	FLOOR	ROOF	WINDOWS				SOLAR THERMAL	PHOTOVOLTAIC
Base Case	2.1	2	0.6	3	Gas	normal practice	NO	NO	NO
1	0.3	0.25				3m3/m2h	YES	6sqm	2Kwp
2	0.3	0.3	0.35			3m3/m2h	YES	4sqm	2Kwp
3	0.25	0.14	0.25			3m3/m2h	YES		2.5KWP
4	0.1	0.1	0.1	1.2	HEAT PUMP	3m3/m2h	YES		1kwp
5	0.6	0.2	0.2					2.5 kwp + 6m2 PV-T Panels	
6	1	0.45	0.2			3m3/m2h	YES	2.5 kwp + 6m2 PV-T Panels	
7	0.25	0.15	0.25					2.5 kwp + 3m2 PV-T Panels	
8	0.2	0.15	0.2			5m3/m2h		4sqm	2Kwp
9	0.2	0.15	0.2			5m3/m2h			3kwp

KEY - Intensity
Low
Medium - Low
Medium
Medium -High
High

Table 2

EFFICIENCY OF THE MEASURES										
OPTION	FABRIC				HEATING SYSTEM	INFILTRATION RATE	MVHR	RENEWABLES		
	WALLS	FLOOR	ROOF	WINDOWS				SOLAR THERMAL	PHOTOVOLTAIC	CO2 kg yearly
1	8%	10%				2%	3%	6%	10%	336
2	**10%**	**10%**	**1%**			**2%**	**2%**	**4%**	**10%**	400
3	**10%**	**10%**	**2%**			**1%**	**3%**		**13%**	352
4	**10%**	**10%**	**2%**	**4%**	**5%**	**1%**	**2%**		**5%**	376
5	8%	9%	3%					6%	13%	400
6	6%	7%	2%			2%	3%	6%	13%	376
7	**10%**	**10%**	**2%**					**4%**	**13%**	400
8	**10%**	**10%**	**2%**			**1%**		**5%**	**11%**	400
9	**10%**	**10%**	**2%**			**1%**			**16%**	376

KEY - Efficiency
1-5%
6-9%
>10%

Table 3

FEASIBILITY *									
OPTION	FABRIC				HEATING SYSTEM	INFILTRATION RATE	MVHR	RENEWABLES	
	WALLS	FLOOR	ROOF	WINDOWS				SOLAR THERMAL	PHOTOVOLTAIC
1	High Disturbance. House unoccupied is required. Limitations in ceiling heights to be considered for floor insulations. Reductions in volume because of IWI*1					✓ very high skilled work forced required	✓ LIMITATIONS in Floor to ceiling height h=2.5m	✓ 20sqm Available. Limited space	
2			✓					✓	✓
3			✓						✓
4			✓	✓	✓ under staircase				✓
5			✓					✓ Emerging technologies	
6			✓				✓Limitations in Floor to ceiling height h=2.5m		
7			✓						
8			✓			✓ very high skilled work forced required		✓	✓
9			✓						✓ 20sqm Available. Limited space

KEY - Feasibility
Easy to do
Moderate
Difficult to do

Table 4

OPTION	FABRIC: WALLS	FLOOR	ROOF*2	WINDOWS*3	HEATING SYSTEM	INFILTRATION RATE*	MVHR	RENEWABLES*7: SOLAR THERMAL	PHOTOVOLTAIC	TOTAL COSTS
APPROXIMATE CAPITAL COST £ - (based on Lee Wakeman cost consultants) * *5										
Base Case			830	4500	5100	415				**10845**
2	1958	2076	830			415	1760	3000	5000	**15039**
4	1958		830		11600	415	1760		5000	**21563**
7	1958	2076	830					8000		12864
8	**1958**	**2076**	**830**			**415**		**3000**	**5000**	**13279**

OPTION	FABRIC: WALLS	FLOOR*10	ROOF*2	WINDOWS	HEATING SYSTEM	INFILTRATION RATE*	MVHR*12	RENEWABLES*7: SOLAR THERMAL	PHOTOVOLTAIC	TOTAL COSTS
APPROXIMATE CAPITAL COST £ - (Westminster City Council)* *6										
Base Case		875	352	3450	2550	250				**7477**
2	5600	917	352			250	1760	5000	13000	**26879**
4	8500		352		11600	250	1760		13000	**35462**
7	7050	917	352					18000		26319
8	**7050**	**917**	**352**			**250**		**5000**	**13000**	**26569**

Table 5

3.3. Retrofit "8". – Strategy:

This retrofit (See table 6) diminishes the OC up to the 95% required as shown in the SAP model (Appendix B), which means 5kg CO_2/m^2 emissions per year, and considering the total area of the house is 80 m^2, then the total OC is to be 400 kg CO_2 a year against the current 3256 Kg CO_2 or the 7400 Kg CO_2 equivalent to the levels of 1990 (CRIBE, 2014). In order to materialized that, the different elements of the refurbishment are further detailed below.

RETROFIT "8"										
FABRIC: WALLS	FLOOR	ROOF	WINDOWS	HEATING SYSTEM	INFILTRATION RATE	MVHR	RENEWABLES: SOLAR THERMAL	PHOTOVOLTAIC	Number Actions	
x	x	x			X		x	x	**6**	
INTENSITY										
FABRIC: WALLS	FLOOR	ROOF	WINDOWS	HEATING SYSTEM	INFILTRATION RATE	MVHR	RENEWABLES: SOLAR THERMAL	PHOTOVOLTAIC		
0.2	0.15	0.2			5m3/m2h		4sqm	2Kwp		
EFFICIENCY										
FABRIC: WALLS	FLOOR	ROOF	WINDOWS	HEATING SYSTEM	INFILTRATION RATE	MVHR	RENEWABLES: SOLAR THERMAL	PHOTOVOLTAIC	CO2 kg yearly	
10%	**10%**	**2%**			**1%**		**5%**	**11%**	400	
FEASIBILITY *										
FABRIC: WALLS	FLOOR	ROOF	WINDOWS	HEATING SYSTEM	INFILTRATION RATE	MVHR	RENEWABLES: SOLAR THERMAL	PHOTOVOLTAIC		
High Disturbance. House unoccupied is required. Limitations in ceiling heights to be considered for floor insulations. Reductions in volume because of IWI*1		✓			✓ very high skilled work forced required		✓	✓		
APPROXIMATE CAPITAL COST £ - (based on Lee Wakeman cost consultants) * *5										
FABRIC: WALLS	FLOOR	ROOF*2	WINDOWS*3	HEATING SYSTEM	INFILTRATION RATE*	MVHR	RENEWABLES*7: SOLAR THERMAL	PHOTOVOLTAIC	TOTAL COSTS	
1958	**2076**	**830**			**415**		**3000**	**5000**	**13279**	

Table 6

3.1.1. Fabric Insulation:

It is essential that all insulation is added at the same time to make sure joints between the different elements are executed properly and in coordination with the introduction of permeability measures, commented afterwards. Furthermore, overheating must be considered when u-values are this lo. However according to SAP (CRIBE, 2014), in this case, it can be overcome by "opening the windows half time" (Appendix B) rather than installing shading elements with an over cost associated.

In regard to the walls, because of the historic value and to keep consistency along the street, IWI is added at the Front and back walls, but also because it tends to be cheaper than EWI[1] (Westminster City Council, 2013).

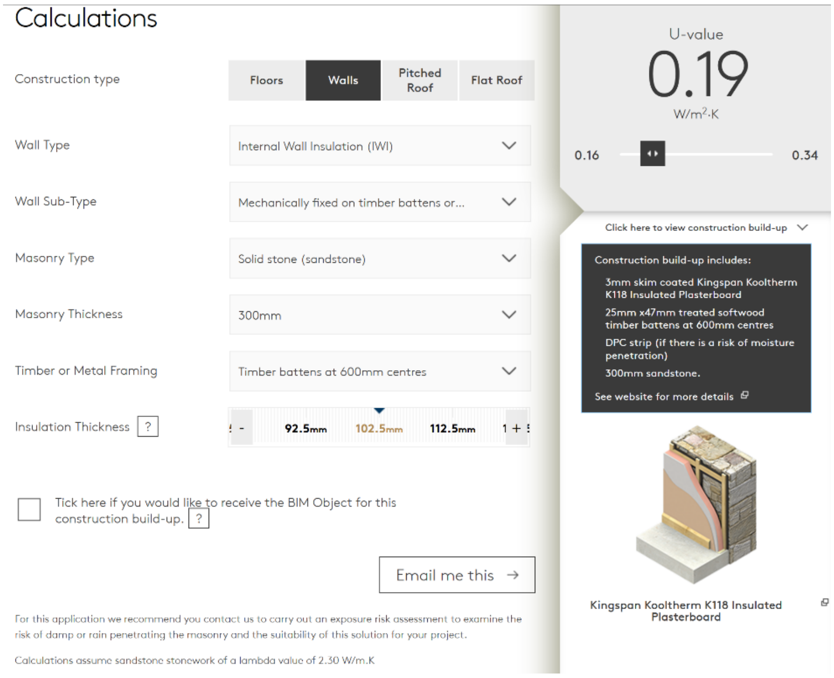
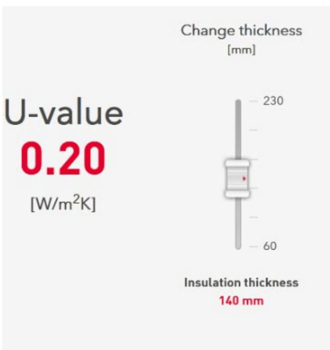


Figure 4. Wall Built-up. Phenolic Insulation. (Kingspan , 2020)

The same report, advices also a breathable solution for the walls upgrade as would reduce the risk of damp issues, particularly in historic buildings. Then, a timber frame cavity wall upgrade with rockwool insulation (Figures 5) is considered. However, another option (Figures 4)is contemplated because of space constrains, phenolic insulation with a vapour barrier as the overall thickness will be reduce from 227'5 mm[2] (Rockwool, 2017) to130'5 mm (Kingspan, 2020). So, while the breathable option will reduce the floor area of each storey by 2.3 m^2 , the phenolic insulation would only take 1.3 m^2.



Manufacturer	Name	Thickness [m], number	Lambda [W/(mK)]	Q	R [m²K/W]
Rse					0.0400
Generic Buildi	Stone Wall Thickness = 0.3 m / Lambda =2.3 (Kingspan 2020). - R= 1/U = 0.13			D	~~0.1325~~
	automatic disregarding acc. BRE 4.4.3)				
Online	Low E Breather Membrane R=0.77m²K/W	0.0500	0.065	E	0.7700
BS EN 12524	Plywood [500 kg/m³]	0.0095	0.130	D	0.0731
Inhomogeneous material layer	consisting of:	0.1400	ø 0.049		2.8426
ROCKWOOL Ltd Online	Flexi 140mm - 200mm	85.00 %	0.035	E	-
Air gaps	Level 0: dU" = 0.00 W/(m²K)				
BS EN 12524	Softwood Timber [500 kg/m³]	15.00 %	0.130	D	-
Inhomogeneous material layer	consisting of:	0.0250	ø 0.040		0.6217
BS EN 12524	Softwood Timber [500 kg/m³]	08.33 %	0.130	D	-
[illegible]	Breathable plasterboard & Finished (left out of preliminary calculations. Very limited contribution for U-value.	[illegible]	[illegible]		~~0.0658~~
[illegible]					~~0.0053~~
Rsi					0.1300

Figure 5. Wall Built-up. Rockwool Modified. Bre

Furthermore, floor insulation (Figure 6) is to be added over concreate slab, for this the floor finish and skirts must be removed, as well as any inner plaster finished in walls for the earlier commented upgrade. Afterwards, 100 mm of K103 floorboard insulation (See figure 6) will be place after tackling any moisture issues (McCaig, et al., 2018) and must be consider the possibility of having to change doors because of new floor height.

Besides, 50 mm of insulation will be added under the roof rafters (Figure 7), in addition to the exiting 50 mm, to fully achieve the U-values required. Being this the easiest measure, only must be consider the joints with the walls. (Westminster City Council, 2013).

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[1] EWI = External Wall Insulation

[2] Note, the breathable option is not standard Rockwool, neither the stone wall so values have been modified according to BSN ISO 6946 (BSI Standards Institution, 2017).

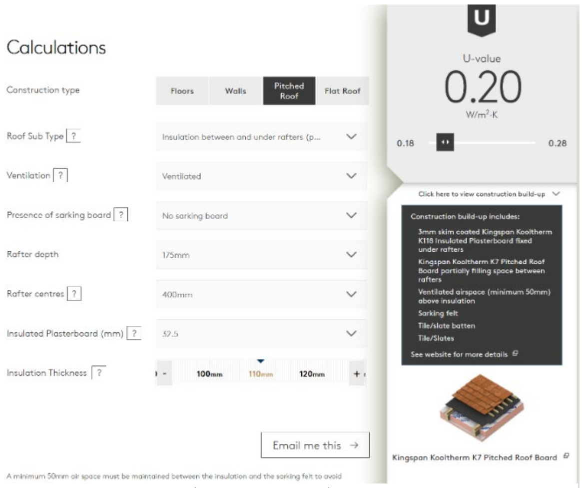

Figure 7 . Roof Built-up. (Kingspan , 2020)

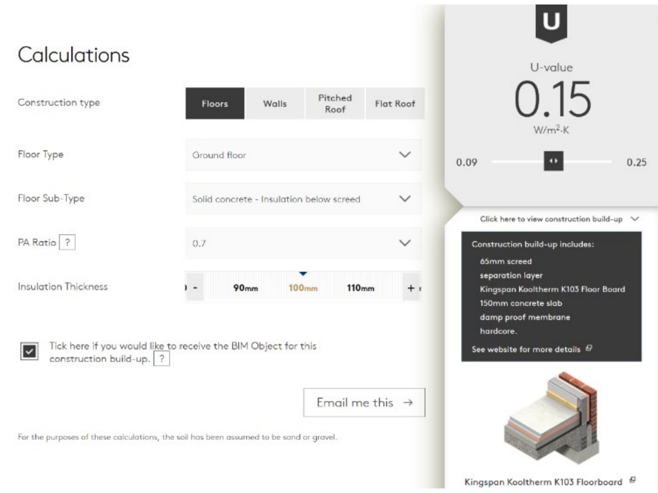

Figure 6 . Floor Built-up. (Kingspan , 2020)

3.1.2. Airtightness:

At the same time, the required measures for the reduction of air permeability to 5 m^3/m^2 must be set in place to create a consistent and continues fabric. However, this is a very difficult measure to quantify beforehand and only with a blower-door test[1] can be checked after the implementation of the retrofit.

Nevertheless, there is extended literature and study cases which shows the successful measures to achieve the 5 m^3/m^2h infiltration rate. Sturgis Carbon Profiling LLP (2013) explains detailed measures to diminished permeability and are meant to be applied in this case:

- Closing existing holes in building walls with insulant and draught stripping at all the apertures
- Closing holes around pipes penetrating the envelope and any holes in the roof or eaves area
- Draught striping loft hatches

Furthermore, a vapour permeable membrane can be added to walls and roof and a "Lime lite" renovating plaster might be added as it limits the air permeability at the same time is a breathable material, reducing the moisture risk. This solutions have been already successfully implemented in "Solcer Retrofit King Street (Social housing)" (Lannon & Green, 2020) achieving up to 0.9 $^3/m^2$.hr @ 50 Pa.

3.1.3. Renewable Energies:

Finally . the "Fabric focus" measures are complemented with the installation of renewable systems on the 16 sqm of suitable[2] roof area will be occupied with 4 m^2 of thermal solar panels connected to the Combi boiler and 10 m2 of PV-array 2 KWp made up of 5 "UKSOL 380-400W MONO HALF CELL" panels 400Wp (Appendix C) of 1990x992mm. As shown in the table 6, this will add up 16% CO^2 reductions to the 23% savings by the fabric improvements, achieving the 95% as show in Appendix C.

4. Wall Upgrade– Embodied Carbon:

Regarding the EC of the elements that are involved in the refurbishment, and as explained earlier, the walls upgrade is analysed as the most representative feature of the retrofit. For that purpose, the two systems, already introduced in section 3.1.1 are analysed. Prior to that, assumptions for both scenarios are taken in order to achieve efficient and realistic results at the same time calculations are simplified:

- EC[3], kg CO2 per Kg of are taken by default from "The Carbon Calculator" (Enviromental Agency, 2007) but in the cases there is not existing data. Then EC values are from ICE (BSRIA, 2011) or the manufacturer specifications.

[1] Blower-door Test= measure of flow necessary to raise interior of a dwelling by 50 Pa Q_{50} (McMullan, 2012)
[2] 80% of the total roof area available- (Energy Saving Trust, 2015)
[3] EC=Embodied Carbon

- "The Carbon Calculator" results have minor rounder errors as it is developed for mayor developments.
- Wall Areas has been worked out from Appendix A and Assignment Brief. To simplify calculation small walls of the single storey extension at the back have not been considered. Then, 4 wall areas of 5.1*2.8 m are to be considered.
- When EC boundary is "Cradle to gate", transport to site, removal and disposal are calculated separately to achieve the "Cradle to grave" boundary required.
- Local providers have been chosen if available, in order to diminish further EC.
- When possible local recycle industries have been used. Otherwise, the Lamby Way Landfill has been selected as the as they use all non-recyclable materials for producing energy, Landfill gas (LFG), with the aim of reducing the systems footprint as much as possible.
- Average use of 20KWh per day in the worksite and a duration of works up to 2 weeks have been considered.
- An additional 10% of each material had been taken in account as "Waste on site" (Stevenson, 2020)
- The personnel travel is not accounted for the total EC by "The carbon Calculator" in the results shown in Appendix D by an error of the Excel, although they appear in the subtotals.

Then, the next two sections detail the systems and show the quantity of each materials that composed them, the manufacturers chosen and their location, the waste treatment method and any other relevant observation related to their EC emissions. Ultimately, the total EC of each system is stated. and the report from the carbon calculator with further details.

10.1. Solution 1. Non-Breathable Wall Upgrade

Option 1. KINGSPAN - PHENOLIC INSULATION - NON-BREATHBLE CONSTRUTION							
Material	Manufacture	Location	Transport (Km)	Observations	Waste Treatment Method	Location	Transport (Km)
DPC Strips	Visqueen	Lundholm Rd, Ayrshire, Stevenston KA20 3NQ	721	B/ timber battens & stone wall. EC (BSRIA, 2011).	Landfill	Lamby Way Landfill. Rumney, Cardiff CF3 2HP	44.9
screws	Evolution	2A & 2B, Clyde Gateway Trade Park, Dalmarnock Rd, Rutherglen, Glasgow G73 1AN	661.4	600 mm centres. Stainless Steel Multi-Fix. Ref. A4CSK6.3-57-GP. Size:6.3 x 57mm. Assumed Steel General UK Average.	Recycle	Metal + Waste Recycling. Lightmoor Rd, Telford TF4 3QN	175.4
Timber Battens Vertically	A1 Timber Frame	Unit 43 Endeavour Cl, Purcell Ave, Port Talbot SA 12 7PT	38	600 mm centres	Recycle	Reseiclo Community Wood Recycling, The Woodstore, Harlequin Trading Estate, Alderney Street,, Newport NP20 5NH	51.5
Timber Battens (Horizontal)	A1 Timber Frame			Bottom/ top	Recycle		
K118-Koltherm Insulation	Kingspan		-	Plasterboard and vapour barrier included . Embodied carbon from "Appendix No.ENP500at" (BRE,2020)	Landfill	Lamby Way Landfill. Rumney, Cardiff CF3 2HP	44.9
Windows Reveals. K118-Koltherm	Kingspan		-	Embodied carbon from "Appendix No.ENP500at" (BRE,2020)	Landfill	Lamby Way Landfill. Rumney, Cardiff CF3 2HP	44.9
Drywalls screws	Evolution	2A & 2B, Clyde Gateway Trade Park, Dalmarnock Rd, Rutherglen, Glasgow G73 1AN	661.4	300 mm centres along the perimeter of the boards. Min. depth 102.5+25mm. Number subjected to Insulation panel units per wall. Carbon Steel. Ref. DWSZ150. Size= 4.8*150mm. Assumed Steel General UK Average	Recycle	Metal + Waste Recycling. Lightmoor Rd, Telford TF4 3QN	175.4
Flexible polyutherane foam and flexible sealant	Flowstrip	Markham House, Atkinsons Way, Foxhills Industrial Park, Scunthorpe DN15 8QJ	402.3	Gun Grade Expanding PU Foam. Product Code: FAS0909. Expansion is about 50 times. Joints between insulation board 10 mm and Lengths (refer to Kingspan data sheet). EC from ICE (BSRIA,2011)	Landfill	Lamby Way Landfill. Rumney, Cardiff CF3 2HP	44.9
Gyproc Drywall sealer	British Gypsum	Barrow Works, Loughborough LE12 8GB	280	Additional moisture resistance. 1l/ 11sqm required. 2 layers. 5l required. WATER VAPOUR CONTROL. Density approx. = to general paint density.	Landfill	Lamby Way Landfill. Rumney, Cardiff CF3 2HP	44.9
White Clay Paint - Finished	Earthborn	Frodsham Business Centre, Bridge Lane, Frodsham, Cheshire WA6 7FZ	250	Lifestyle Paint. Water Based 6l /60 sqm	Landfill	Lamby Way Landfill. Rumney, Cardiff CF3 2HP	44.9

Option 1. KINGSPAN - PHENOLIC INSULATION - NON-BREATHBLE CONSTRUTION												
Material	Width (mm)	Thickness (mm)	Lengths (mm)	Units	Volume (m3)	Density (tonnes/m3)	Mass (tonnes)	Waste (tonnes)	Total (tonnes)	Boundary	CO2e (Kg CO2 / Kg).	C02e (Kg C02 / Kg). Related to boundary.
DPC Strips	47	0.5	134400.0	36	0.1137	0.92	0.1046	0.0105	0.1151	Cradle to gate	4.45	0.5120
screws				208	0.0004	7.8	0.0030	0.0003	0.0033	Cradle to gate	1.46	0.0048
Timber Battens Vertically	47	25.0	2800.0	36	0.1184	0.5	0.0592	0.0059	0.0651	Cradle to gate	0.31	0.0202
Timber Battens (Horizontal)	47	25.0	5100.0	8	0.0479	0.5	0.0240	0.0024	0.0264	Cradle to gate	0.31	0.0082
K118-Koltherm Insulation	1200	102.5	2400.0	20	5.9040	0.035	0.2066	0.0207	0.2273	Cradle to site	5.8	1.3184
Windows and door reveals. K118-Koltherm	450	32.5	30400.0	-	0.4446	0.035	0.0156	0.0016	0.0171	Cradle to site	5.8	0.0993
Drywalls screws				584	0.005	7.8	0.039	0.0039	0.0427	Cradle to gate	1.46	0.0624
Flexible polyutherane foam and flexible sealant	103	10	168000	-	0.0344	0.025	0.0009	0.00009	0.0009	Cradle to gate	4.06	0.0038
Gyproc Drywall sealer					0.005	1.2	0.006	0.0006	0.0066	Cradle to gate	0.13	0.0009
White Clay Paint - Finished					0.006	1.2	0.0072	0.00072	0.0079	Cradle to gate	2.54	0.0201

Table 7

Sub-totals	tonnes CO_2e	%
Quarried Material	0.0	0%
Timber	0.0	1%
Concrete, Mortars & Cement	0.0	0%
Metals	0.1	2%
Plastics	0.0	0%
Glass	0.0	0%
Miscellaneous	1.9	67%
Finishings, coatings & adhesives	0.0	1%
Plant and equipment emissions	0.0	0%
Waste Removal	0.1	2%
Portable site accommodation	0.1	4%
Material transport	0.0	0%
Personnel travel	0.6	22%

Table 8. "The Carbon Calculator" (Enviromental Agency, 2007)

Overall, this wall upgrade system based on phenolic insulation with 60 yeas of lifecycle is responsible for 2800 kg of CO^2 from cradle to grave (Appendix D). Being a half of the emmisions due to the insulation, having an enourmous impact, due to its artificial composition including plastics and the imposibility of recycle. Therefore, as there is not more sustainable insulation with the same properties the option to dinimish the EC of this systems are very limited.

10.2. Solution 2. Breathable Wall Upgrade

Option 2. Rockwool - BREATHABLE CONSTRUCTION							
Material	Manufacture	Location	Transport (Km)	Observations	Waste Treatment Method	Location	Transport (Km)
Breather Membrane	Protect	002 Brooklands Station Approach, Cheshire, Sale M33 3SS	326	Low E Breather Membrane R = 0.77 m²K/W. Protect TF200 Thermo. Extruded Polypropylene. EC from ICE (BSRIA,2011)	Landfill	Lamby Way Landfill. Rumney, Cardiff CF3 2HP	44.9
Plywood	A1 Timber Frame	Unit 43 Endeavour Cl, Purcell Ave, Port Talbot. SA 12 7PT	38	11kg/m2*10mm(Environmental Agency, 2007)	Recycle	Reseiclo Community, Harlequin Trading Estate, Alderney Street., Newport NP20 5NH	51.5
Screws	Evolution	2A & 2B, Clyde Gateway Trade Park, Dalmarnock Rd, Rutherglen, Glasgow G73 1AN	661.4	300 centres along timber battens/ two rows at 400 centres to battens (service void)/ 300 centres along wood wool panels Ref. WST4035. 4.0 x 35mm.	Recycle	Metal + Waste Recycling. Lightmoor Rd, Telford TF4 3QN	175.4
Timber Battens Vertically	A1 Timber Frame	Unit 43 Endeavour Cl, Purcell Ave, Port Talbot. SA 12 7PT		400 mm centres	Recycle	Reseiclo Community Wood Recycling, The Woodstore, Harlequin Trading Estate, Alderney Street., Newport NP20 5NH	51.5
Timber Battens (Horizontal)	A1 Timber Frame		38	Top/ Bottom			
Timber Battens (Horizontal)	A1 Timber Frame		38	service Void 25 mm - 5 horizontal battens - Wood wool boards fixed on to them			
Rockwool Flexi Insulation	Rockwool	Irrelevant	-	Between studs- 85% of Wall area	Recycle	Rockwool Recycling Facility	
Option B- Wood wool boards	CELENIT	JRM5+38 Tombolo, Province of Padua, Italy	-	Celenit N. EC from Specifications. (Celenit S.p.A., 2020)	Landfill	Lamby Way Landfill. Rumney, Cardiff CF3 2HP	44.9
Breathaplasta	Adaptavate*	Unit 10 button Mills Industrial Estate, Lower Mills, Stonehouse, Gloucestershire, GL10 2BB	112.2	Lime based product. Lime plasta Finished. 4mm Thickness - 20kg - 5 sqm (57 sqm to cover). Embodied Carbon of Lime from ICE (BSRIA,2011)	Landfill	Lamby Way Landfill. Rumney, Cardiff CF3 2HP	44.9

Option 2. Rockwool - BREATHABLE CONSTRUCTION												
Material	Width (mm)	Thickness (mm)	Lengths (mm)	Units	Volume (m3)	Density (tonnes/m3)	Mass (tonnes)	Waste (tonnes)	Total (tonnes)	Boundary	CO2e (Kg CO2 / Kg)	CO2e (Kg CO2 / Kg). Related to boundary.
Breather Membrane	5100	0.5	2800.0	4	0.0274	0.33	0.0090	0.0009	0.0100	Cradle to Gate	4.98	0.0496
Plywood	5100	10.0	2800.0	4	0.5712	0.55	0.3142	0.0314	0.3456	Cradle to Gate	0.45	0.1555
Screws				1772	0.0031	7.8	0.0243	0.0024	0.0267	Cradle to gate	1.46	0.0390
Timber Battens Vertically	22	140.0	2800.0	52	0.4484	0.5	0.2242	0.0224	0.2466	Cradle to Gate	0.31	0.0765
Timber Battens (Horizontal)	22	140.0	5100.0	8	0.1257	0.500	0.0628	0.0063	0.0691	Cradle to Gate	0.31	0.0214
Timber Battens (Horizontal)	47	25.0	5100.0	20.00	0.1199	0.500	0.0599	0.0060	0.0659	Cradle to Gate	0.31	0.0204
Rockwool Flexi Insulation		140.0			6.230	0.0	0.280	0.0280	0.3084	Cradle to grave	1.2	0.3701
Option B- Wood wool boards	600	15	2400	39	0.8424	0.53	0.4465	0.04465	0.4911	Cradle to site	1.38	0.6777
Breathaplasta	600		4				0.228	0.0228	0.2508	Cradle to Gate	0.76	0.1906

Table 9

Sub-totals	tonnes CO_2e	%
Quarried Material	0.2	8%
Timber	1.0	40%
Concrete, Mortars & Cement	0.0	0%
Metals	0.0	2%
Plastics	0.0	2%
Glass	0.0	0%
Miscellaneous	0.1	6%
Finishings, coatings & adhesives	0.0	0%
Plant and equipment emissions	0.0	0%
Waste Removal	0.4	16%
Portable site accommodation	0.0	0%
Material transport	0.0	0%
Personnel travel	0.6	26%

Table 10. "The Carbon Calculator" (Enviromental Agency, 2007)

In this option, the extremely low EC of the rockwool insulation, due to its natural condition and the possibility of recycling, (138 Kg CO_2) makes possible a reduction overall of 400 kg CO_2 from the previous system, with a total EC of 2400kg CO_2. However, the savings are not larger due to the greater use of wood to create a self-supported frame and the use of plywood on the outer side and the inner wood board, which altogether produces 40% of the total EC. However, for future retrofits an alternative use of cork (0.19 kg CO2/Kg (BSRIA, 2011)) and 0.24 Tonnes/m3 instead of plywood; or a Lime Breathable plasterboard from Adaptavate (2020) has potential to reduce further the EC of this system. The last elements is not as yet in the market but it has been use on "The UK Green building Council" where EC was reduced by 22% from the standards (Adaptavate, 2020) and also it is a local product unlike the wood boards.

10.3. Comparison

Finally, when comparing the advantages and drawbacks of both systems, the breathable wall upgrade with rockwool insulation is more beneficial for this retrofit. This is because it involves less damp risk at the time the wall system EC emissions are lower and its lifecycle longer whilst the only advantage of the phenolic insulation system is its thickness. However, in this case even if it is tight the rockwool insulation option still leaves an acceptable 75 sqm area for a 3 people dwelling.

SYSTEM	EC (KG CO2) "CRADLE TO GRAVE"	LIFECYCLE[1] (Years)	AREA REDUCTION (sqm) Current Total area = 80
Non-Breathable. Kingspan	2400	60	77.4
Breathable. Rockwool	1800	75	75.35

Table 11

5. Conclusions. OC[2] vs EC[3]

This paper has developed with success a feasible and cost-effective retrofit plan for a pre-1919 house that achieves the 95% reduction of CE claimed by the Wales government for 2050. Therefore, it is verified that the goal is achievable through a holistic "First fabric" approach rather than by the introduction of individual. Furthermore, the coordination of all strategies within the plan is essential for its success together with a minimisation of risks

On the other hand, it has been explored the impact on the EC footprint of the building caused by the upgrade strategy, as if it is true that it brings a massive reduction of the building OC emissions, the new elements have inherent CE which diminishes the carbon savings. Then, the study of the wall upgrade has quantified that impact in the retrofit, which it is subjected to be diminished by future studies of the material utilized within the system in order to decrease the overall EC.

All in all, it is considered successful the results obtained along this research as OC has been reduced from 3256 to 400 Kg CO_2 a year through "The "8" retrofit and "The Rockwool Breathable Wall System" only adds 2400 Kg CO_2 while is

[1] Data from Insulation Manufacturer. It is assumed as the whole wall system lifecycle for the purpose of this document.
[2] Operational Carbon
[3] Embodied Carbon

responsible for 11% of the OC reduction. That is, it is saving 784 Kg CO_2 per year, which is 58800 Kg CO_2 along its 75-year lifecycle, with a payback period of 3'06 years, only the 4% percent of the system lifecycle.

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7. Appendix A – Floor Plans.

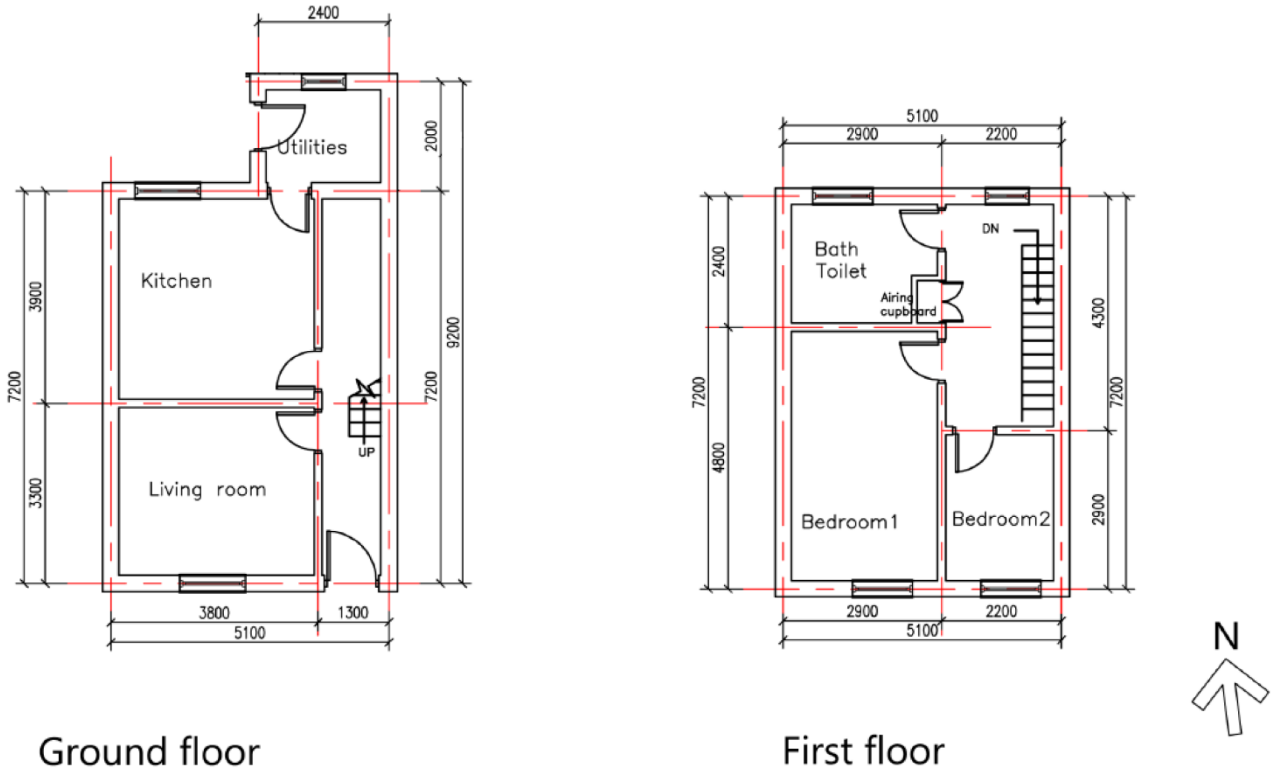


Figure 1. Floor plans provided by Lannon, S (2020) in "SAP Workshop"

Dimensions shown have been taken as inner referential dimensions

8. Appendix B – Retrofit "8" - SAP Model

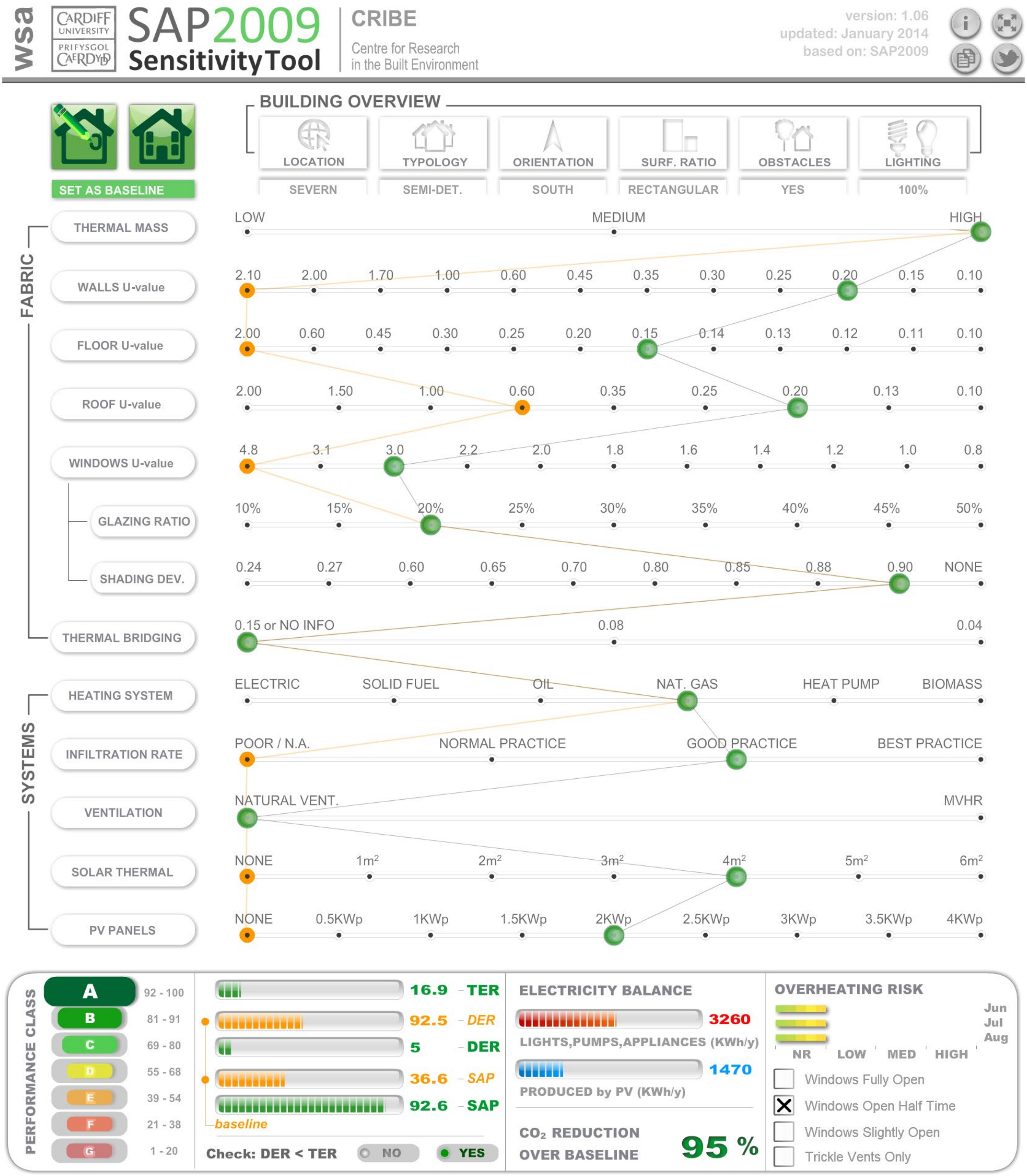


Figure 2. SAP MODEL Results. (CRIBE, 2014)

9. Appendix C– PV-Panels Details from Manufacture.

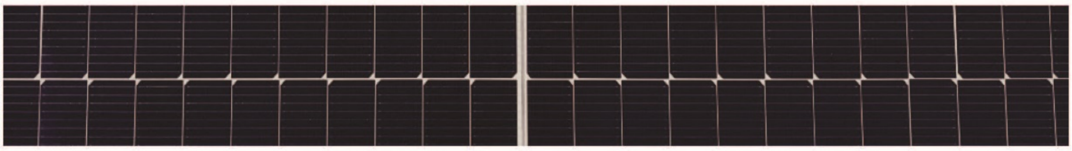
UKSOL Ltd, Building 1, Chalfont Park, Gerrards Cross, SL9 0BG

UKSOL | 30 YEAR BRITISH WARRANTY

A BRITISH BRAND OF HIGH QUALITY SOLAR MODULES

UKSOL solar PV modules are always produced with the latest high quality grade A solar cells to deliver the maximum return on your investment. Every UKSOL solar module comes with a British 12 year product warranty and a 30 year performance warranty. Technical and warranty support is provided by our dedicated customer care team based near London.

MODEL UKSOL 380-400W MONO HALF CELL MODULE



ADVANCED PERFORMANCE & PROVEN ADVANTAGES

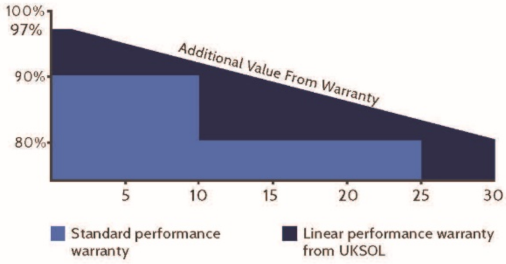
- Half cut cell technology can reduce the internal power loss and improve component overall power. Excellent heat dissipation avoids hot spot production.
- Designed for high voltage systems of up to 1500 VDC, increasing the string length of solar systems and saving on BoS costs.
- Microcrack resistant Double glass structure enhance reliability, triple EL tested of high quality control.
- MBB The optimized number and width of main gate lines, Maximize the light receiving area of components and reduce component power consumption.
- All the modules are sorted and packaged by amperage, reducing mismatch losses and maximizing system output.
- Entire module certified to with stand extreme wind (2400 Pa) and snow loads (5400 Pa)

QUALITY CERTIFICATES

- IEC61215: 2016.IEC61730: 2016 Latest Standard IS09001, IS014001 and OHSAS18001, meeting the highest international standards of strict quality control.
- Comprehensive and first-rate certification system.

BRITISH WARRANTIES

- 10 year product warranty.
- 25 year warranty on power output.



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ELECTRICAL CHARACTERISTICS AT STC

Nominal Power (Pmax)	380W	385W	390W	395W	400W
Open Circuit Voltage (Voc)	48.6V	48.8V	49V	49.2V	49.3V
Short Circuit Current (Isc)	10.26A	10.35A	10.44A	10.53A	10.65A
Voltage at Nominal Power (Vmp)	40.4V	40.6V	40.8V	41V	41.2V
Current at Nominal Power (Imp)	9.42A	9.5A	9.57A	9.64A	9.72A
Module Efficiency (%)	19.28	19.53	19.79	20.04	20.29
Operating Temperature	-40°C to +85°C				
Maximum System Voltage	1000V / 1500V DC(IEC)				
Maximum Series Fuse Rating	15A				

*STC:Irradiance 1000W/m², module temperature 25, AM=1.5
Optional black frame or white frame module according to customer requirements

ELECTRICAL CHARACTERISTICS AT NOCT

Nominal Power (Pmax)	281W	285W	289W	293W	296W
Open Circuit Voltage (Voc)	45.9V	46.1V	46.3V	46.5V	46.6V
Short Circuit Current (Isc)	8.28A	8.36A	8.43A	8.5A	8.6A
Voltage at Nominal Power (Vmp)	38.2V	38.4V	38.6V	38.7V	38.9V
Current at Nominal Power (Imp)	7.36A	7.42A	7.49A	7.57A	7.61A

*NOCT：Irradiance 800W/m², ambient temperature 20℃, wind speed 1 m/s

MECHANICAL CHARACTERISTICS

Cell Type	Monocrystalline 156.75 × 78.375mm
Number of Cells	144 (6 × 24)
Module Dimensions	1987mm×992mm×40mm
Weight	23.0kg
Front Cover	High transmission tempered glass
Frame	Anodized aluminium alloy
Junction Box	IP67
Cable	4mm² (IEC)
Connector	MC4 / MC4 Compatible

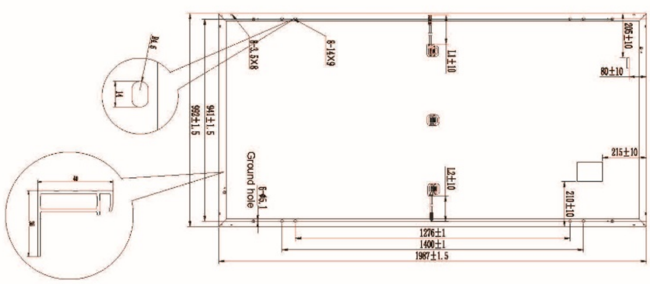
TEMPERATURE CHARACTERISTICS

Nominal Operating Cell Temperature (NOCT)	45°C + 2°C
Temperature Coefficient Of Pmax	-0.39%/K
Temperature Coefficient Of Voc	-0.29%/K
Temperature Coefficient Of Isc	0.049%/K

PACKAGING

Standard Packaging	26 pcs / Pallet
Module Quantity per 40' Container	572pcs

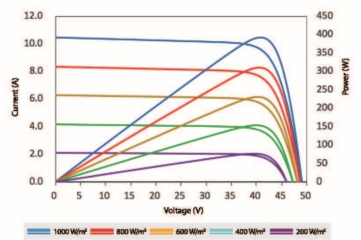
ENGINEERING DRAWINGS



Specifications in this datasheet are subject to change without prior notice.

Also available in all-black.

IV CURVES



Current-Voltage & Power-Voltage Curves At Different Irradiances

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10. Appendix D– Carbon Calculator calculations and reports

10.1. Option 1. NON-BREATHABLE. Kingspan.

Title of project:	Retrofit 8. Walls Upgrade - NON - BREATHABLE. Phelonic Insulation.
Project stage:	Planning
Construction Cost:	0
Total Carbon Footprint:	2 tonnes fossil CO_2e

Conversion (miles to km)	Miles	Kilometres
	32.00	51.5

Environment Agency

Material quantities should be entered in tonnes (except where noted)

The conversion column will help users to calculate tonnage, but it is up to users to make the calculation and enter the tonnage themselves.

Category	Construction material	Unit Conversion or Density	Embodied tCO_2e per tonne of material	Quantity (tonnes)	Distance between source of supply and site (km)	Mode of transport	Footprint (tonnes fossil CO_2e) Embodied	Transport	Sum
Quarried Material	Quarried aggregate	2.0 tonnes/m3	0.005						
	Recycled aggregate	2.0 tonnes/m3	0.005						
	Marine aggregate	2.0 tonnes/m3	0.008						
	Asphalt, 4% (bitumen) binder content (by mass)	1.7 tonnes/m3	0.066						
	Asphalt, 5% (bitumen) binder content	1.7 tonnes/m3	0.071						
	Asphalt, 6% (bitumen) binder content	1.7 tonnes/m3	0.076						
	Asphalt, 7% (bitumen) binder content	1.7 tonnes/m3	0.081						
	Asphalt, 8% (bitumen) binder content	1.7 tonnes/m3	0.086						
	Bitumen	2.4 tonnes/m3	0.490						
	Bricks	1.9 tonnes/m3	0.240						
	Clay: general (simple baked products)	1.9 tonnes/m3	0.240						
	Clay tile	2.4 tonnes/m3	0.480						
	Vitrified clay pipe DN 100 & DN 150	2.4 tonnes/m3	0.460						
	Vitrified clay pipe DN 200 & DN 300	2.4 tonnes/m3	0.500						
	Vitrified clay pipe DN 500	2.4 tonnes/m3	0.550						
	Ceramics: general	1.9 tonnes/m3	0.700						
	Ceramics: Tiles and Cladding Panels	2.2 tonnes/m3	0.780						
	Sand	1.2 tonnes/m3	0.005						
	Soil - general / rammed soil	1.7 tonnes/m3	0.024						
	Stone: general	2.0 tonnes/m3	0.079						
	Granite	2.9 tonnes/m3	0.700						
	Limestone	2.2 tonnes/m3	0.090						
	Sandstone	2.2 tonnes/m3	0.060						
	Shale	2.7 tonnes/m3	0.002						
	Slate	1.6 tonnes/m3	0.035						
	Sub-total			0			0.0	0.0	0.0
Timber	Timber: general	0.5 tonnes/m3	0.310	**0**	**38**	**Road**	0.029	0.000	0.029
	Glue laminated timber	0.5 tonnes/m3	0.420						
	Hardboard	26.0 kg/m2*20mm	0.580						
	MDF	14 kg/m2*20mm	0.390						
	Oriented Strand Board (OSB)	1 tonnes/m3	0.450						
	Particle Board	6 kg/m2*20mm	0.540						
	Plywood	11 kg/m2*20mm	0.450						
	Reclaimed timber	1 tonnes/m3	0.031						
	Sawn Hardwood	0.6 tonnes/m3	0.240						
	Sawn Softwood	0.5 tonnes/m3	0.200						
	Sub-total			0			0.0	0.0	0.0

Category	Construction material	Unit Conversion or Density	tCO_2e/t or unit	Tonnage or unit	Distance	Mode	Embodied	Transport	Sum
Metals	Copper: EU Tube & Sheet	8.9 tonnes/m3	2.71						
	Copper: Reused copper	8.9 tonnes/m3	0.27						
	Iron	7.87 tonnes/m3	2.03						
	Lead	11.34 tonnes/m3	1.67						
	Steel: General - UK (EU) Average Recycled Content	7.8 tonnes/m3	1.46	**0**	**661**	**Road**	0.069	0.003	0.072
	Steel: Bar & rod - UK (EU) Average Recycled Content	7.8 tonnes/m3	1.40						
	Steel: Coil (Sheet), Galvanised - UK (EU) Average Recycled Content	7.8 tonnes/m3	1.54						
	Steel: Engineering steel - Recycled	7.8 tonnes/m3	0.72						
	Steel: Pipe- UK (EU) Average Recycled Content	7.8 tonnes/m3	1.45						
	Steel: Plate- UK (EU) Average Recycled Content	7.8 tonnes/m3	1.66						
	Steel: Sections - UK (EU) Average Recycled Content	7.8 tonnes/m3	1.53						
	Steel: Wire - Virgin	7.8 tonnes/m3	3.02						
	Steel: Stainless	8 tonnes/m3	6.52						
	Steel: Reused steel	7.8 tonnes/m3	0.15						
	Aluminium: General	2.7 tonnes/m3	9.16						
	Aluminium: Extruded	2.7 tonnes/m3	9.08						
	Aluminium: Rolled	2.7 tonnes/m3	9.18						
	Handrail: galvanised with fittings	0.0115 tonnes/m	0.02						
	Handrail: stainless steel with fittings	0.0115 tonnes/m	0.09						
	Handrail: stainless steel welded	0.0105 tonnes/m	0.08						
	Sheet piling: light use	0.1 tonnes/m2	0.12						
	Sheet piling: medium use	0.13 tonnes/m2	0.15						
	Sheet piling: heavy use	0.19 tonnes/m2	0.20						
	Flap valves: DN 100 & DN 150	0.008 tonnes/1	0.01						
	Flap valves: DN 200 & DN 300	0.02 tonnes/1	0.02						
	Flap valves: DN 500	0.06 tonnes/1	0.06						
	Sub-total			0			0.1	0.0	0.1
Plastics	Plastics: general	1.38 tonnes/m3	3.31						
	Polyethylene: general	0.92 tonnes/m3	2.54						
	High Density Polyethylene (HDPE) Resin	0.96 tonnes/m3	1.93						
	HDPE Pipe	1.05 tonnes/m3	2.52						
	Expanded Polystyrene	1.05 tonnes/m3	3.29						
	General Purpose Polystyrene	1.05 tonnes/m3	3.43						
	High Impact Polystyrene	1.05 tonnes/m3	3.42						

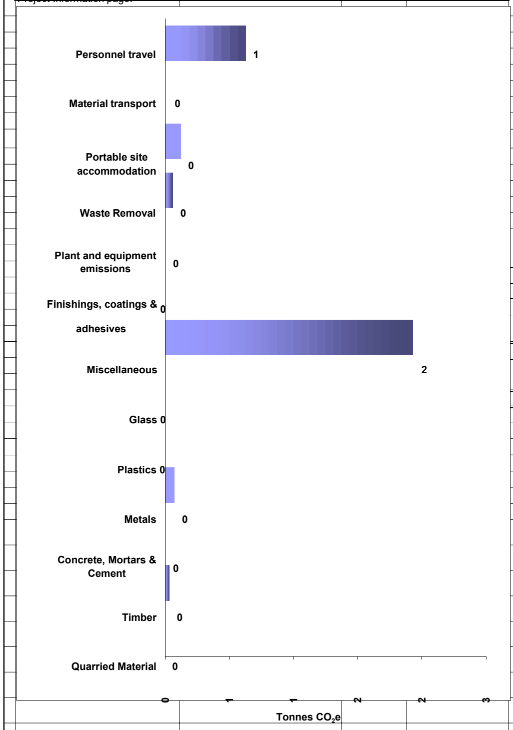
Title of project:		
Construction cost:		
Total Carbon Footprint:	2.2	tonnes fossil CO_2e

We would like to hear from you:

We would like to build a database of case studies on the EA website to share knowledge, emission reduction ideas and lessons learnt.

Please send your completed examples to ccc@environment-agency.gov.uk Do not forget to include a short description of the actions / measures you have identified for the reduction of the total carbon footprint in the Project Information page.

Environment Agency



Sub-totals	tonnes CO_2e	%
Quarried Material	0.0	0%
Timber	0.0	1%
Concrete, Mortars & Cement	0.0	0%
Metals	0.1	2%
Plastics	0.0	0%
Glass	0.0	0%
Miscellaneous	1.9	67%
Finishings, coatings & adhesives	0.0	1%
Plant and equipment emissions	0.0	0%
Waste Removal	0.1	2%
Portable site accommodation	0.1	4%
Material transport	0.0	0%
Personnel travel	0.6	22%

Significant materials (figures include transport to site)

Site accommodation - Grid electricity	**0.119**	**tonnes CO2e**
K118- Koltherm insulation	**1.415**	**tonnes CO2e**
Poliurethane. Flexible Foam	0.004	tonnes CO2e
Waterborne paint	0.020	tonnes CO2e
Damp Proof Course/Membrane	**0.521**	**tonnes CO2e**

The accuracy of individual values is unlikely to be better than +/-5%. As a consequence of using default factors and estimated tonnages, carbon footprints obtained from this calculator might be expected to be within +/-25% of the true value. Given the range of values associated with certain materials (cements for example), default values may give results that are out by 100% or more. Local data should be used where available.

Plaster: general (Gypsum)

10.2. Option 2. BREATHABLE. Rockwool.

Title of project:	Retrofit 8. Walls Upgrade -BREATHABLE. Rockwall Insulation.
Project stage:	Planning
Construction Cost:	0
Total Carbon Footprint:	2 tonnes fossil CO_2e

Conversion (miles to km)	Miles	Kilometres
	0.00	0.0

Environment Agency

Material quantities should be entered in tonnes (except where noted)

The conversion column will help users to calculate tonnage, but it is up to users to make the calculation and enter the tonnage themselves.

Category	Construction material	Unit Conversion or Density	Embodied tCO_2e per tonne of material	Quantity (tonnes)	Distance between source of supply and site (km)	Mode of transport	Footprint (tonnes fossil CO_2e) Embodied	Transport	Sum
Quarried Material	Quarried aggregate	2.0 tonnes/m3	0.005						
	Recycled aggregate	2.0 tonnes/m3	0.005						
	Marine aggregate	2.0 tonnes/m3	0.008						
	Asphalt, 4% (bitumen) binder content (by mass)	1.7 tonnes/m3	0.066						
	Asphalt, 5% (bitumen) binder content	1.7 tonnes/m3	0.071						
	Asphalt, 6% (bitumen) binder content	1.7 tonnes/m3	0.076						
	Asphalt, 7% (bitumen) binder content	1.7 tonnes/m3	0.081						
	Asphalt, 8% (bitumen) binder content	1.7 tonnes/m3	0.086						
	Bitumen	2.4 tonnes/m3	0.490						
	Bricks	1.9 tonnes/m3	0.240						
	Clay: general (simple baked products)	1.9 tonnes/m3	0.240						
	Clay tile	2.4 tonnes/m3	0.480						
	Vitrified clay pipe DN 100 & DN 150	2.4 tonnes/m3	0.460						
	Vitrified clay pipe DN 200 & DN 300	2.4 tonnes/m3	0.500						
	Vitrified clay pipe DN 500	2.4 tonnes/m3	0.550						
	Ceramics: general	1.9 tonnes/m3	0.700						
	Ceramics: Tiles and Cladding Panels	2.2 tonnes/m3	0.780						
	Sand	1.2 tonnes/m3	0.005						
	Soil - general / rammed soil	1.7 tonnes/m3	0.024						
	Stone: general	2.0 tonnes/m3	0.079						
	Granite	2.9 tonnes/m3	0.700						
	Limestone	2.2 tonnes/m3	0.090						
	Sandstone	2.2 tonnes/m3	0.060						
	Shale	2.7 tonnes/m3	0.002						
	Slate	1.6 tonnes/m3	0.035						
	Sub-total			0			**0.2**	**0.0**	**0.2**
Timber	Timber: general	0.5 tonnes/m3	0.310	**0**	**38**	**Road**	0.118	0.002	0.120
	Glue laminated timber	0.5 tonnes/m3	0.420						
	Hardboard	26.0 kg/m2*20mm	0.580						
	MDF	14 kg/m2*20mm	0.390						
	Oriented Strand Board (OSB)	1 tonnes/m3	0.450						
	Particle Board	6 kg/m2*20mm	0.540						
	Plywood	11 kg/m2*20mm	0.450	**0**	**38**	**Road**	0.156	0.001	0.157
	Reclaimed timber	1 tonnes/m3	0.031						
	Sawn Hardwood	0.6 tonnes/m3	0.240						
	Sawn Softwood	0.5 tonnes/m3	0.200						
	Sub-total			1			**1.0**	**0.0**	**1.0**
		Unit Conversion or Density	**tCO_2e/t or unit**	**Tonnage or unit**	**Distance**	**Mode**			
Metals	Copper: EU Tube & Sheet	8.9 tonnes/m3	2.71						
	Copper: Reused copper	8.9 tonnes/m3	0.27						
	Iron	7.87 tonnes/m3	2.03						
	Lead	11.34 tonnes/m3	1.67						
	Steel: General - UK (EU) Average Recycled Content	7.8 tonnes/m3	1.46	**0**	**661**	**Road**	0.039	0.002	0.041
	Steel: Bar & rod - UK (EU) Average Recycled Content	7.8 tonnes/m3	1.40						
	Steel: Coil (Sheet), Galvanised - UK (EU) Average Recycled Content	7.8 tonnes/m3	1.54						
	Steel: Engineering steel - Recycled	7.8 tonnes/m3	0.72						
	Steel: Pipe- UK (EU) Average Recycled Content	7.8 tonnes/m3	1.45						
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	Steel: Sections - UK (EU) Average Recycled Content	7.8 tonnes/m3	1.53						
	Steel: Wire - Virgin	7.8 tonnes/m3	3.02						
	Steel: Stainless	8 tonnes/m3	6.52						
	Steel: Reused steel	7.8 tonnes/m3	0.15						
	Aluminium: General	2.7 tonnes/m3	9.16						
	Aluminium: Extruded	2.7 tonnes/m3	9.08						
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	Handrail: galvanised with fittings	0.0115 tonnes/m	0.02						
	Handrail: stainless steel with fittings	0.0115 tonnes/m	0.09						
	Handrail: stainless steel welded	0.0105 tonnes/m	0.08						
	Sheet piling: light use	0.1 tonnes/m2	0.12						
	Sheet piling: medium use	0.13 tonnes/m2	0.15						
	Sheet piling: heavy use	0.19 tonnes/m2	0.20						
	Flap valves: DN 100 & DN 150	0.008 tonnes/1	0.01						
	Flap valves: DN 200 & DN 300	0.02 tonnes/1	0.02						
	Flap valves: DN 500	0.06 tonnes/1	0.06						
	Sub-total			0			**0.0**	**0.0**	**0.0**
Plastics	Plastics: general	1.38 tonnes/m3	3.31						
	Polyethylene: general	0.92 tonnes/m3	2.54						
	High Density Polyethylene (HDPE) Resin	0.96 tonnes/m3	1.93						
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	Expanded Polystyrene	1.05 tonnes/m3	3.29						
	General Purpose Polystyrene	1.05 tonnes/m3	3.43						
	High Impact Polystyrene	1.05 tonnes/m3	3.42						

Title of project:

Construction cost:

Total Carbon Footprint: 1.8 tonnes fossil CO_2e

We would like to hear from you:

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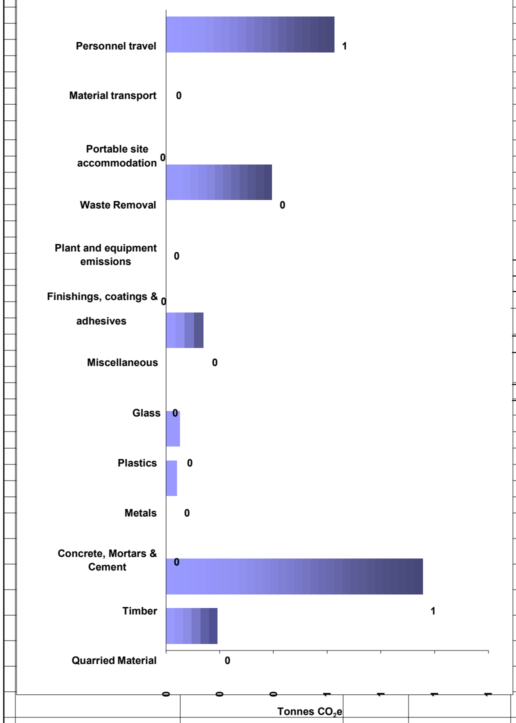
Environment Agency



Sub-totals	tonnes CO_2e	%
Quarried Material	0.2	8%
Timber	1.0	40%
Concrete, Mortars & Cement	0.0	0%
Metals	0.0	2%
Plastics	0.0	2%
Glass	0.0	0%
Miscellaneous	0.1	6%
Finishings, coatings & adhesives	0.0	0%
Plant and equipment emissions	0.0	0%
Waste Removal	0.4	16%
Portable site accommodation	0.0	0%
Material transport	0.0	0%
Personnel travel	0.6	26%

Significant materials (figures include transport to site)

Site accommodation - Grid electricity	0.012	tonnes CO2e
rockwool insulation	**0.138**	**tonnes CO2e**
Wood wool boards	**0.682**	**tonnes CO2e**
polipropylene	0.050	tonnes CO2e

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Welsh School of Architecture

Final Assignment Submission Declaration

Essay Title: Monitoring Plan: Sustainable Retrofit Plan. Pre-1919 Mid of Terrace House.

Module: Low Carbon Buildings

Before submitting your essay, please complete the following checklist, fill in the number of words in your assignment, and then sign the declaration at the bottom of the page:

Checklist:

- ✓ ☐ I have taken into account guidance provided by the assignment brief and by the module tutor.
- ✓ ☐ I have acknowledged and documented all sources from which I have borrowed ideas and information
- ✓ ☐ I have ensured that any computer software used in the preparation of this work is appropriately licensed.
- ✓ ☐ I have proofread my essay.
- ✓ ☐ I have used a font of at least Arial 11 and left a reasonable margin space around the work.
- ✓ ☐ Number of words: 2700 not including the abstract, contents list, tables, figures, reference list

Declaration:

This assignment is my own work, and does not involve either plagiarism or collusion

Plagiarism: is defined as *"using words or ideas of others without acknowledging them as such and submitting them for assessment as though they were one's own work"* (para 2.1.1, University Academic Regulations Handbook). This includes direct copying, close paraphrase, the unacknowledged use of ideas developed by others and commercial essay bank services.	**Collusion:** is said to occur when *"work has been undertaken by or with others is submitted and passed off as solely the work of one person" (*para 2.1.2, University Academic Regulations Handbook). Where this is done with the knowledge of the originator, both parties can be considered to be at fault.

The text of my assignment submission (not including title and reference list) is not more than 2750 words.

Student id: 1948781 Course: ENVIRONMENTAL DESIGN OF BUILDINGS 2DL

Date:1 03/04/2020

✓ ***I confirm by ticking this box that the information given in this form is correct.***