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1 Introduction

This report provides:

1. Embodied carbon calculations for Type 1 (9x4m) wall panels constructed with a) traditional wind posts and traditional concrete lintel and b) Wi Columns and Wi Trough lintel.
2. Embodied carbon calculations for Type 2 (4x5m) wall panels constructed with a) traditional wind posts and traditional concrete lintel and b) Wi Beam.
3. Analysis and discussion of the results.

2 Methodology

Carbon calculations follow the methodology presented in *How to calculate embodied carbon* 2nd Edition (IStructE, 2022). The calculation here covers the minimum scope required by that guide, lifecycle Modules A1-A5 (Figure 1), and is based on Eq.(1).

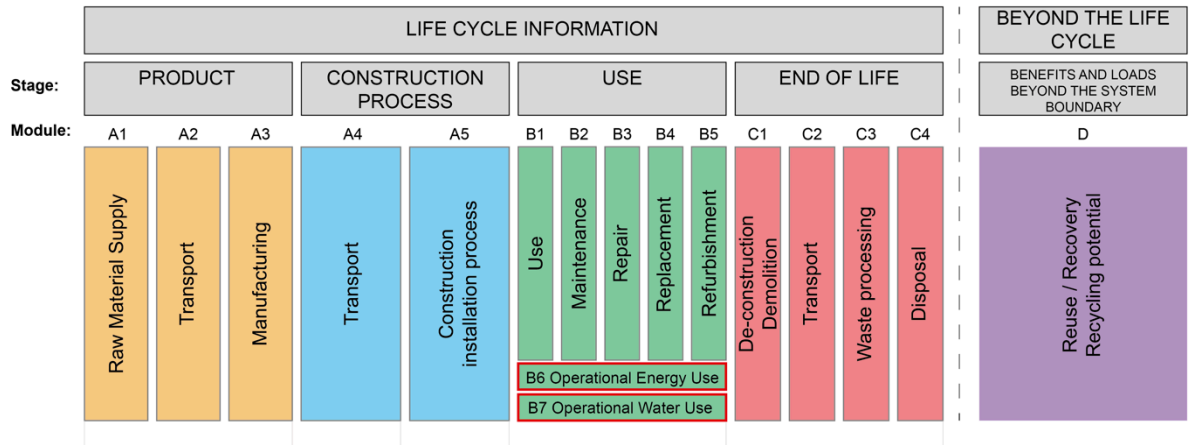

Figure 1: Life cycle modules and stages, following BS EN 15978 (BSI, 2011). Figure © John Orr.

$$EC_{A15} = \sum_{i=1}^{n} \left[Q_i \left(ECF_{A13,i} + ECF_{A4,i} + ECF_{A5w,i} \right) \right] + EC_{A5a} \qquad (1)$$

EC_{A15} = total embodied carbon for life cycle Modules A1–A5 ($kgCO_2e$)
Q_i = design quantity of i^{th} material (kg)
ECF_{A13} = embodied carbon factor for life cycle Modules A1–A3 ($kgCO_2e/kg$)
$ECF_{A4,i}$ = transportation to site (Module A4) embodied carbon for the i^{th} material ($kgCO_2e/kg$)
$ECF_{A5w,i}$ = on-site construction waste (Module A5) embodied carbon factor for i^{th} material ($kgCO_2e/kg$)
EC_{A5a} = construction activities emissions (Module A5) ($kgCO_2e$)

3 Embodied carbon calculation: Type 1

3.1 Inputs

3.1.1 Material quantities

3.1.1.1 Type 1 blockwork wall panel (9x4m) with TWPs, concrete lintel, and standard blocks.

Material quantities are taken from a bill of quantities provided by Wembley Innovation Ltd and are given in Table 1. One unit is one 9x4m panel, as shown in Figure 2.

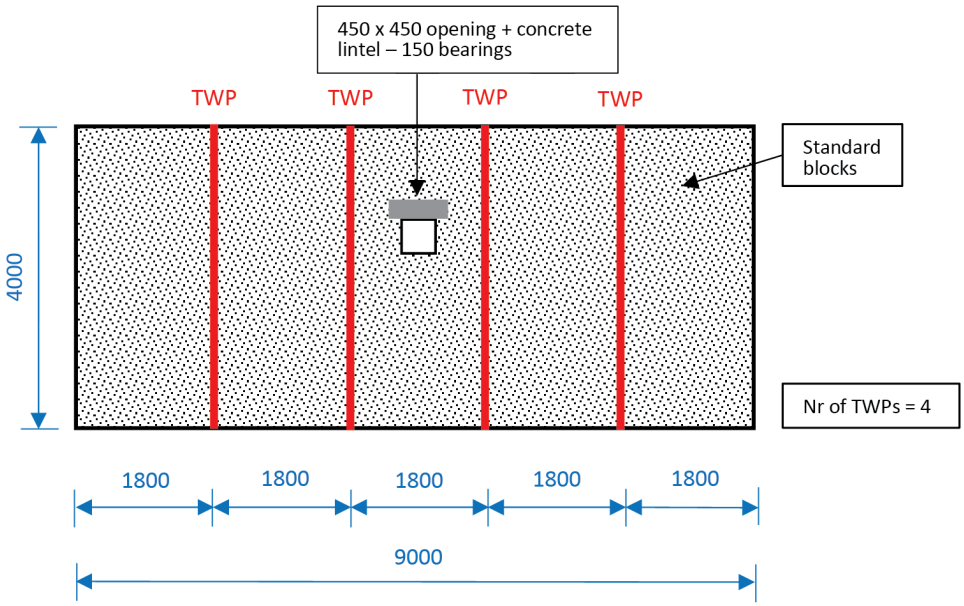

Figure 2: Type 1 wall panel designed with TWPs and standard blocks and concrete lintel. Source: Wembley Innovation.

Table 1: Material quantities for Type 1 panel TWPs with standard blocks.

	A	B	C	D	E
	Material	Type	Quantity	Description	**(kg/unit)**
1.	130x70x6mm stainless steel	Stainless steel	4nr	16m (4m per TWP)	**154**
2.	Bottom cleat (150x150x6mm)	Stainless steel	4nr	1nr cleat per WP	**4.32**
3.	Top Cleat (220x70x6mm)	Stainless steel	4nr	1nr cleat per WP	**2.96**
4.	Fireboard (100x15mm)	Plasterboard	16m	Fireboard to exposed TWP	**31.20**
5.	Standard 140mm 7.3N medium dense solid block	Medium dense solid block	358nr	19kg/block	**6802.00**
6.	Standard mortar 1:1:6	Mortar 1:1:6	0.313m^3	10mm thick mortar, 2200kg/m^3	**688.60**
7.	200x20x2.5 frame cramp ties @450c/c spacing	Stainless steel	88nr	Both sides of TWP and at end abutments	**7.04**
8.	Stone mineral wool	Stone mineral wool	40m	Filler materials either side of each TWP and at end abutments	**44.00**
9.	310ml intumescent acoustic sealant	Sealant	32nr tubes	Mastic either side of TWP (3no) and at end abutments, both sides of walls	**15.67**
10.	Precast concrete lintel	Precast Concrete Lintel	1nr	140mm x 215mm x 750mm length, 2500kg/m^3	**56.44**

3.1.1.2 Type 1 blockwork wall panel (9x4m) with Wi Columns, Wi Trough Lintel, and HBP blocks.

Material quantities are taken from a bill of quantities provided by Wembley Innovation Ltd and are given in Table 2. One unit is one 9x4m panel, as shown in Figure 3.

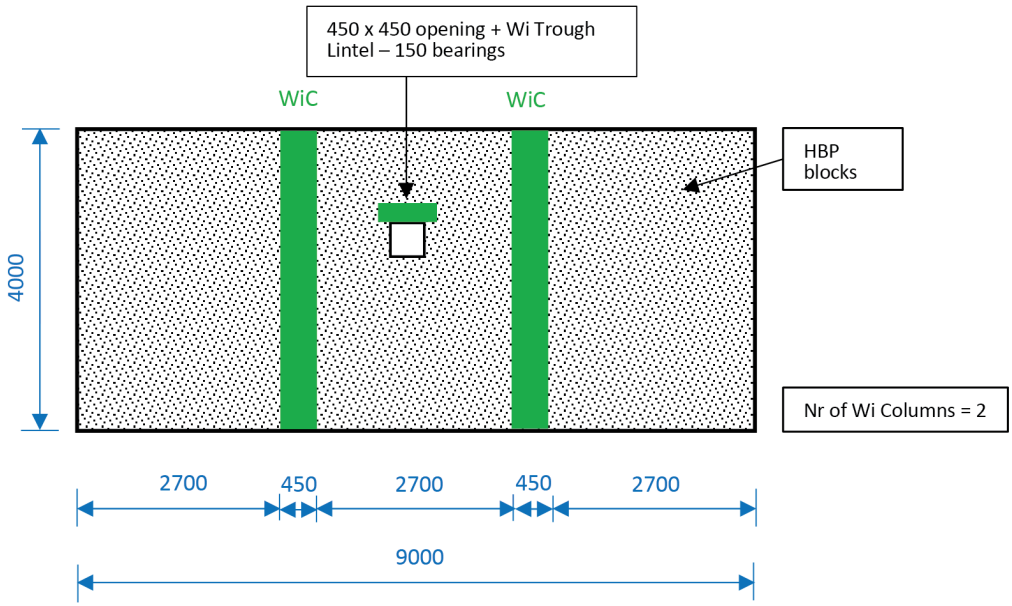

Figure 3: Type 1 wall panel designed with Wi Columns and HBP blocks and Wi Trough Lintel. Source: Wembley Innovation.

Table 2: Material quantities for Type 1 panel Wi System with HBP blocks.

	A	B	C		G
	Material	Type	Quantity	Description	**(kg/unit)**
1.	140mm Wi Column Blocks	Wi System Blocks	36nr	11.4kg/block	**410.40**
2.	Head cleat (430x60x8mm)	Mild Steel	2nr	Top of both WiCs	**3.22**
3.	H16 rebar with socket	Rebar	16m	4nr @ 4m length, 1.58kg/m; One socket per bar at 0.24kg each.	**26.24**
4.	C40 Wi mortar	C40 Wi mortar	480kg	8m x 60kg/m	**480**
5.	HBP 140mm 7.3N medium dense slot block	HBP 140mm 7.3N medium dense slot block	322nr	HBP slot block weight 17.8kg/block	**5731.60**
6.	Standard mortar (1:1:6)	Mortar 1:1:6	0.264m^3	10mm thick mortar, 2200kg/m^3	**580.80**
7.	200x20x2.5 Frame Cramp ties @ 450c/c spacing	Stainless steel	18 nr	At end abutments	**1.20**
8.	225x19x3 masonry ties @ 450c/c spacing	Stainless steel	36 nr	Both sides of WiCs	**3.69**
9.	Stone mineral wool	Stone mineral wool	12m	Filler material one side of WiC (1 no) and at end abutments	**13.20**
10.	310ml intumescent acoustic sealant	Sealant	12nr tubes	Mastic to end abutments and one side of 1nr WiC for MJ, both sides of panel.	**5.88**

	A	B	C		G
	Material	Type	Quantity	Description	**(kg/unit)**
11.	140mm Wi Lintel U blocks	Wi System Blocks	1.5nr	750mm length, 12.4kg/block	**18.60**
12.	H16 rebar without socket	Rebar	1.5m	2nr @ 750mm length, 1.58kg/m	**2.37**
13.	Short transfer rod	Mild steel	1nr	350g	**0.350**
14.	C40 Wi Mortar	C40 Wi Mortar	17.25kg	750mm x 23kg/m	**17.25**

3.1.2 Carbon factors

3.1.2.1 Modules A1-A3

3.1.2.1.1 Type 1 blockwork wall panel (9x4m) with TWPs, concrete lintel, and standard blocks

Table 3: ECF_{A13} for Type 1 TWP

Material	**ECF_{A13} ($kgCO_2e/kg$)**	**Source**	**Comment**
Stainless steel	**4.407** (Range 3.61 – 6.29)	ICE V3	Inventory of Carbon and Energy (ICE) database (Jones, 2019). Average value for stainless steel.
Fireboard	**0.390**	ICE V3	Plasterboard
7.3N Medium Block	**0.093**	ICE V3	Medium density block (generic)
Standard mortar 1:1:6	**0.152**	ICE V3	Mortar (1:1:6 Cement:Lime:Sand mix)
Stone mineral wool	**1.280**	ICE V3	Mineral Wool
Sealant	**2.366**	HTCEC	This value is general use for intumescent paint coatings of concrete from HTCEC (IStructE, 2022).
Precast Concrete Lintel	**0.194**	ICE V3	Precast concrete beams and columns, assume 100kg steel per m^3 concrete, European EAF recycled stock. For reference and context of this value, an EPD for a UK produced prestressed precast lintel was found by Naylor Concrete (2023) which has an A1-A3 carbon factor of 0.168 $kgCO_2e/kg$. The value adopted here can be updated if a specific product EPD is known to be used.

3.1.2.1.2 Type 1 blockwork wall panel (9x4m) with Wi Columns, Wi Trough Lintel, and HBP blocks

Table 4: ECF_{A13} for Type 1 Wi System

Material	**ECF_{A13} ($kgCO_2e/kg$)**	**Source**	**Comment**
Wi System Blocks (140mm Wi Column Block, 140mm Wi U Blocks)	**0.0917**		Provided by Wembley Innovation.
Stainless steel	**4.407** (Range 3.61 – 6.29)	ICE V3	Inventory of Carbon and Energy (ICE) database Average value for stainless steel.
Mild steel	**2.450**	HTCEC	This value is for general UK plate, and is recommended here unless the source of the plate is known.

Material	ECF_{A13} ($kgCO_2e/kg$)	Source	Comment
Reinforcing bar	**0.760**	HTCEC	UK sector average.
C40 Wi mortar	**0.178**		Provided by Wembley Innovation.
HBP 140mm 7.3N medium dense slot block[1]	**0.093**	ICE V3	Medium density block (generic)
Standard mortar (1:1:6)	**0.152**	ICE V3	Mortar (1:1:6 Cement:Lime:Sand mix)
Stone mineral wool	**1.280**	ICE V3	Mineral Wool
310ml intumescent acoustic sealant	**2.366**	HTCEC	This value is general use for intumescent paint coatings of concrete from HTCEC.

3.1.2.2 Module A4

Module A4 carbon has been calculated using real data from a project in London. Material quantities for a wall area of 8,928m^2 were provided by the client quantity surveyor, along with the number of deliveries required. This is then converted into a carbon factor per m^2 of wall for use on both TWP and Wi System wall panels.

Module A4 is calculated using Eq.(2):

$$EC_{A4} = \sum_{i=1}^{n} (n_i \times TD_{mode,i} \times TEF_{mode,i}) \quad (2)$$

Where EC_{A4} = embodied carbon for transport to site ($kgCO_2e$)
n_i = number of deliveries for i^{th} group of materials
$TD_{mode,i}$ = transport distance for i^{th} group of materials (km)
$TEF_{mode,i}$ = transport emission factor for i^{th} group of materials ($kgCO_2e/km$)

In Table 5 and Table 6, materials listed in column A are grouped in column B by delivery. The number of deliveries is given in column C, and the type of transport in column D. Transport distances are provided in column E. Transport emissions factors from UK Government Greenhouse gas reporting conversion factors (Department for Energy Security and Net Zero, 2023), are provided in column F. Equation (2) is used to provide the results in Column G.

3.1.2.2.1 Traditional Wall Panel (blocks, steel windposts, concrete lintels and fireboarding)

Table 5: EC_{A4} for TWP

A	B	C	D	E	F	G
Material	**Group**	**n**	**Type**	**TD_{mode} (km)**	**TEF_{mode} ($kgCO_2e/km$)**	**$EC_{A4,I}$ ($kgCO_2e$)**
130x70x6mm stainless steel	**2**	3	Rigid (>3.5 - 7.5 tonnes)	270	0.52991	429
Bottom cleat(150x150x6mm)	2 (With windpost)					
Top Cleat (220x70x6mm)	2 (with windpost)					
200x20x2.5 frame cramp ties @450c/c spacing	**5 (sundry)**	1	Rigid (>3.5 - 7.5 tonnes)	80	0.52991	42
Fireboard (100x15mm)	**3**	2	Rigid (>3.5 - 7.5 tonnes)	80	0.52991	85

A	B	C	D	E	F	G
Material	**Group**	**n**	**Type**	**TD_{mode} (km)**	**TEF_{mode} ($kgCO_2e/km$)**	**$EC_{A4,I}$ ($kgCO_2e$)**
Standard 140mm 7.3N medium dense solid block	**1**	75	Articulated (>3.5 - 33t)	167	0.91733	11490
Standard mortar 1:1:6	**6**	1	Rigid (>17 tonnes)	80	1.06991	86
Stone mineral wool	5 (sundry)					
310ml intumescent acoustic sealant	5 (sundry)					
Precast concrete lintel	**4**	20	Rigid (>3.5 - 7.5 tonnes)	223	0.52991	2363
Sum ($kgCO_2e$) per 8,928m^2						**14,495**
$kgCO_2e/m^2$						**1.62**

3.1.2.2.2 Type 1 blockwork wall panel (9x4m) with TWPs, concrete lintel, and standard blocks

The Type 1 blockwork panel with TWPs, concrete lintel, and standard blocks has an area of 36m^2, and using a carbon factor of 1.62$kgCO_2e/m^2$ from Table 5 this gives a total EC_{A4} of 58.4 $kgCO_2e$.

3.1.2.2.3 Wi System Wall Panel (Blocks & Wi System)

Table 6: EC_{A4} for Wi System

A	B	C	D	E	F	G
Material	**Group**	**n**	**Type**	**TD_{mode} (km)**	**TEF_{mode} ($kgCO_2e/km$)**	**$EC_{A4,I}$ ($kgCO_2e$)**
140mm Wi Column Blocks	**1**	75	Articulated (>3.5 - 33t)	161	0.91733	11077
Head cleat (430x60x8mm)	2 (with Wi System)					
200x20x2.5 Frame Cramp ties @ 450c/c spacing	**3 (sundry)**	1	Rigid (>3.5 - 7.5 tonnes)	80	0.52991	42
225x19x3 masonry ties @ 450c/c spacing	3 (sundry)					
H16 rebar with socket	2 (with Wi System)					
C40 Wi mortar	**2**	4	Articulated (>3.5 - 33t)	80	0.91733	294
HBP 140mm 7.3N medium dense slot block	1 (with Wi blocks)					
Standard mortar (1:1:6)	**4**	1	Rigid (>17 tonnes)	80	1.06991	86
Stone mineral wool	3 (sundry)					
310ml intumescent acoustic sealant	3 (sundry)					
140mm Wi U blocks	1 (with Wi blocks)					

A	B	C	D	E	F	G
Material	**Group**	**n**	**Type**	**TD_{mode} (km)**	**TEF_{mode} ($kgCO_2e/km$)**	**$EC_{A4,I}$ ($kgCO_2e$)**
H16 rebar without socket	2 (with Wi System)					
Short transfer rod	2 (with Wi System)					
C40 Wi Mortar	2 (with Wi System)					
Sum ($kgCO_2e$) per 8,928m^2						**11,498**
$kgCO_2e/m^2$ wall						**1.29**

3.1.2.2.4 Type 1 blockwork wall panel (9x4m) with Wi Columns, Wi Trough Lintel, and HBP blocks

The Type 1 blockwork panel with Wi Columns, Wi Trough Lintel, and HBP blocks has an area of 36m^2, and using a carbon factor of 1.29$kgCO_2e/m^2$ from Table 6 this gives a total EC_{A4} of 46.4 $kgCO_2e$.

3.1.2.3 Module A5w carbon factors

A5 carbon factors are divided into A5a (activities on site) and A5w (material wastage). Module A5w is calculated using Eq.(3):

$$ECF_{A5w,i} = WF_i \times (ECF_{A13,i} + ECF_{A4,i} + ECF_{C2,i} + ECF_{C34,i}) \quad (3)$$

$ECF_{A5w,i}$ = construction waste embodied carbon factor for i^{th} material
WF_i = waste factor for i^{th} material
$ECF_{A13,i}$ = embodied carbon factor for A1–A3 for i^{th} material
$ECF_{A4,i}$ = embodied carbon factor for transport to site for i^{th} delivery
$ECF_{C2,i}$ = transportation away from site carbon factor calculated in the same way as $ECF_{A4,I}$ but transport distance is assumed to be 50km by road if taken for reuse or recycling elsewhere (default assumption from RICS guidance)
$ECF_{C34,i}$ = waste processing and disposal embodied carbon factor

To calculate Module A5w, Modules C2, C3, and C4 are also required:

- For Module A4, delivery emissions (EC_{A4}) are distributed pro-rata by weight between the items in each delivery group and divided by the item weight to give $kgCO_2e/kg$.
- For Module C2, transport distances are assumed at 50km (local) by road, and carbon factors are calculated as described in §3.1.2.3.1.
- Modules C3 and C4 are combined in a standard value of $ECF_{C34,I}$ = 0.013 $kgCO_2e/kg$ waste (as taken from the HTCEC guide).

3.1.2.3.1 Module C2 carbon factors

For Module C2, transport emissions away from site are calculated using Equation (4).

$$ECF_{C2,i} = \sum_{mode} (TD_{mode} \times TEF_{mode}) \quad (4)$$

Where $ECF_{C2,i}$ = embodied carbon factor for transportation away from site at the end of life for i^{th} material ($kgCO_2e/kg$)
TD_{mode} = transport distance (km)
TEF_{mode} = transport emission factor ($kgCO_2e/kg/km$)

TD_{mode} is taken as 50 km (based on industry guidance (IStructE, 2022)), and TEF_{mode} is 0.00009696 $kgCO_2e/kg$ (all HGVs, average laden, from 2023 conversion factors).

3.1.2.3.2 Type 1 blockwork wall panel (9x4m) with TWPs, concrete lintel and standard blocks

Waste rates for each material are required. The waste rate (WR) is defined as a percentage of the quantity of materials brought to the site that are wasted. The values below are taken from baseline values provided in the WRAP Net Waste Tool (WRAP, 2008), HTCEC, or from discussions with Wembley Innovation:

Table 7: WF for Type 1 TWP

Material	WR	WF	Reference
Stainless steel	1.00%	0.010	HTCEC
Fireboard (100x15mm)	22.50%	0.290	HTCEC
Standard 140mm 7.3N medium dense solid block (1)	5.00%	0.053	WI
Standard mortar 1:1:6	5.00%	0.053	HTCEC
Stone mineral wool (1)	5.00%	0.053	WI
310ml intumescent acoustic sealant (1)	3.00%	0.031	WI
Precast concrete lintel (2)	0.00%	0.000	WI
Note 1: WR value based on site experience and discussion with Wembley Innovation. Note 2: Precast concrete large elements would have a WR of 1% in HTCEC, 0% is taken here for these small elements.			

Table 8: ECF_{C2} for Type 1 TWP

TD_{mode}	TEF_{mode}	Mode	ECF_{C2}
50 (1)	0.00009696	Road	0.004848
Note 1: ECF_{C2} is the transportation away from site carbon factor. This is calculated as described in §3.1.2.3.1 with transport distance is assumed to be 50km by road if taken for reuse or recycling elsewhere (default assumption from RICS guidance).			

Table 9: A5w for Type 1 TWP system

Material	ECF_{A13}	ECF_{A4}	ECF_{C2}	ECF_{C34}	WF	ECF_{A5w}
Stainless steel	4.407	0.0107	0.004848	0.013	0.010	0.045
Fireboard	0.390	0.0110	0.004848	0.013	0.290	0.122
Standard 140mm 7.3N medium dense solid block	0.093	0.0068	0.004848	0.013	0.053	0.006
Standard mortar 1:1:6	0.152	0.0005	0.004848	0.013	0.053	0.009
Stone mineral wool	1.280	0.0026	0.004848	0.013	0.053	0.068
310ml intumescent acoustic sealant	2.366	0.0026	0.004848	0.013	0.031	0.074
Precast concrete lintel	0.194	0.1689	0.004848	0.013	0.00	0.000

3.1.2.3.3 Type 1 blockwork wall panel (9x4m) with Wi Columns, Wi Trough Lintel, and HBP blocks

Waste rates for each material are required. The waste rate (WR) is defined as a percentage of the quantity of materials brought to the site that are wasted.

The construction process for the Wi Trough Lintel system requires temporary works. These would normally be included in Module A5, but in this case we can be certain that the temporary works will be reused in future projects (and have already been reused many times) and therefore are not included in the calculations.

Table 10: WF for Type 1 panel with Wi Columns, Wi Trough Lintel and HBP blocks

Material	**WR_{Wi}**	**WF_{Wi}**	**Reference**
Wi System Blocks (Wi Columns, Wi Lintel U Blocks)	5.00%	0.053	WI
Stainless steel	1.00%	0.010	HTCEC
Mild Steel	1.00%	0.010	HTCEC
Rebar	1.00%	0.010	WI
C40 Wi mortar	5.00%	0.053	HTCEC
HBP 140mm 7.3N medium dense slot block	5.00%	0.053	WI
Standard mortar (1:1:6)	5.00%	0.053	HTCEC
Stone mineral wool	5.00%	0.053	Wrap
310ml intumescent acoustic sealant	3.00%	0.031	WI

Table 11: ECF_{C2} for Type 1 panel with Wi Columns, Wi Trough Lintel and HBP blocks

TD_{mode}	**TEF_{mode}**	**Mode**	**ECF_{C2}**
50 (1)	0.00009696	Road	0.004848
Note 1: ECF_{C2} is the transportation away from site carbon factor. This is calculated as described in §3.1.2.3.1 with transport distance is assumed to be 50km by road if taken for reuse or recycling elsewhere (default assumption from RICS guidance).			

Table 12: A5w for Type 1 panel with Wi Columns, Wi Trough Lintel and HBP blocks, with WF_{Wi} from Table 10

Material	**ECF_{A13}**	**ECF_{A4}**	**ECF_{C2}**	**ECF_{C34}**	**WF_{WI}**	**ECF_{A5w}**
Wi System Blocks (Wi Columns, Wi Lintel U Blocks)	0.0917	0.0073	0.0048	0.013	0.053	0.0058
Stainless steel	4.407	0.0071	0.0048	0.013	0.010	0.0448
Mild Steel	2.450	0.0022	0.0048	0.013	0.010	0.0250
H16 rebar	0.760	0.0022	0.0048	0.013	0.010	0.0079
C40 Wi mortar	0.178	0.0022	0.0048	0.013	0.053	0.0104
HBP 140mm 7.3N medium dense slot block	0.093	0.0073	0.0048	0.013	0.053	0.0062
Standard mortar (1:1:6)	0.152	0.0006	0.0048	0.013	0.053	0.0090
Stone mineral wool	1.280	0.0071	0.0048	0.013	0.053	0.0687
310ml intumescent acoustic sealant	2.366	0.0071	0.0048	0.013	0.031	0.0739

3.1.3 Module A5a carbon emissions

Module A5a carbon emissions, activities on site, are normally calculated based on the project cost. Whilst this is appropriate for a building analysis, it would be less useful here. In the following, electricity use required for site activities is taken from data provided by Wembley Innovation and given in Table 13.

The carbon emissions factor for this report have been taken from the UK Government Greenhouse gas reporting: conversion factors 2023. The values for electricity generation (Scope 2) and transmission and distribution (Scope 3) are added together to provide a 'electricity consumption' carbon factor, in line with the guidance provided with the conversion factors. This gives an emission factor of 0.207074 (for electricity generation) *plus* 0.01792 (for transmission and distribution) = 0.225 $kgCO_2e/kWh$.

Table 13: A5a emissions for Type 1 with a) TWPs and concrete lintel and b) Wi Columns, Wi Trough Lintel and HBP blocks, per 9x4m unit

	Grid electricity	**Carbon emission factor ($kgCO_2e/kWh$)[1]**	**Embodied carbon ($kgCO_2e$)**
(a) TWPs, concrete lintel and standard blocks	10 kWh	0.225	**2.250**
(b) Wi Columns, Wi Trough Lintel and HBP blocks	5 kWh	0.225	**1.125**
Note 1: Data point from https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2023			

3.2 Calculation

The Module A1-A5 embodied carbon is calculated based on Eq.(1).

3.3 Results

The total embodied carbon results for Type 1 panels are given in Table 14. One unit is one 9x4m panel, inclusive of the materials given in Table 1 for TWPs and Table 2 for the Wi System. The top two contributors to EC_{A15} for each are also shown in Figure 4.

Table 14: EC_{A15} for Type 1 panel with a) TWPs, concrete lintel and standard blocks and b) Wi Columns, Wi Trough Lintel and HBP blocks.

	EC_{A15}	-
(a) TWPs, concrete lintel and standard blocks	**1720 kgCO_2e per unit** *Range: 1584 – 2041 kgCO_2e per unit*	*Range based on upper and lower values for ECF_{A13} for stainless steel.*
(b) Wi Columns, Wi Trough Lintel and HBP blocks	**930 kgCO_2e per unit** *Range: 926 – 939 kgCO_2e per unit*	46% reduction compared to TWP *Range based on upper and lower values for ECF_{A13} for stainless steel.*

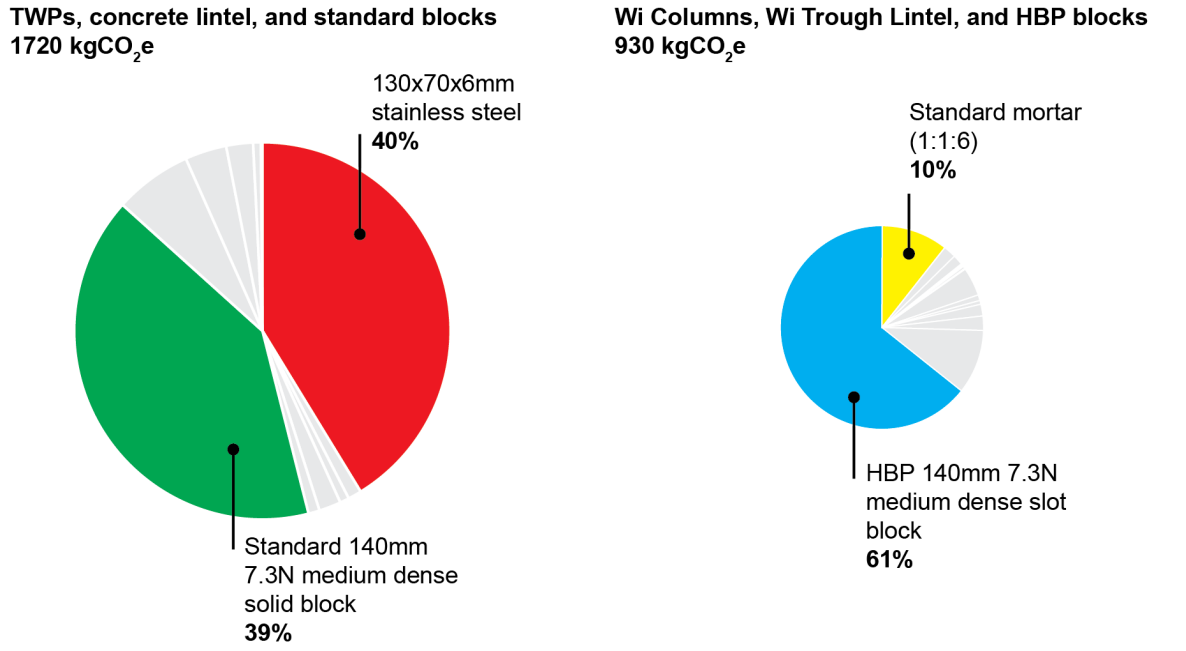

Figure 4: EC_{A15} results for a) TWPs, concrete lintel and standard blocks (left) and b) Wi Columns, Wi Trough Lintel and HBP blocks (right) showing top two contributors to EC_{A15}.

As can be seen in the results presented above, the *Wi Columns, Wi Trough Lintels and HBP block* panel achieves a 46% carbon saving compared with the *TWPs, concrete lintels and standard blocks* panel.

4 Embodied carbon calculation: Type 2

4.1 Inputs

4.1.1 Material quantities

4.1.1.1 Type 2 blockwork wall panel (4x5m) with TWPs, concrete lintel and standard blocks

Material quantities are taken from a bill of quantities provided by Wembley Innovation Ltd and are given in Table 15. One unit is one 4x5m panel, as shown in Figure 5.

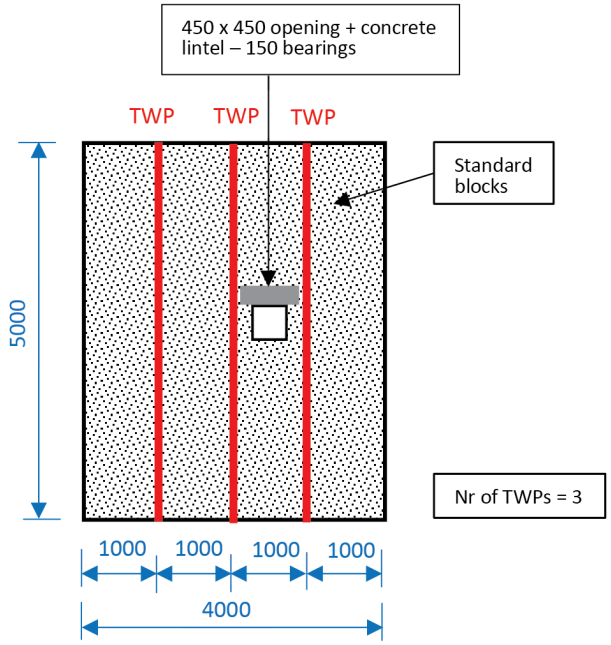

Figure 5: Type 2 wall panel designed with TWPs and standard blocks and concrete lintel. Source: Wembley Innovation.

Table 15: Material quantities for Type 2 panel with TWPs, concrete lintel and standard blocks.

	A		B	C	G
	Material	Type	Quantity	Description	**(kg/unit)**
1.	130x70x6mm stainless steel	Stainless steel	3nr	15m (5m per TWP)	**144**
2.	Bottom cleat (150x150x6mm)	Stainless steel	3nr	1nr cleat per WP	**3.24**
3.	Top Cleat (220x70x6mm)	Stainless steel	3nr	1nr cleat per WP	**2.22**
4.	Fireboard (100x15mm)	Plasterboard	15m	Fireboard to exposed TWP	**29.36**
5.	Standard 140mm 7.3N medium dense solid block	Medium dense solid block	198nr	Weight = 19kg/block	**3762**
6.	Standard mortar 1:1:6	Mortar	0.165m^3	10mm thick mortar, 2200kg/m^3	**363**
7.	200x20x2.5 frame cramp ties @450c/c spacing	Stainless steel	88nr	Both sides of TWP and at end abutments	**7.04**
8.	Stone mineral wool	Stone mineral wool	40m	Filler material either side of each TWP & abutment.	**44**
9.	310ml intumescent acoustic sealant	Sealant	32nr tubes	Mastic either side of TWP & abutments, both sides of wall panel.	**15.67**

	A		B	C	G
	Material	Type	Quantity	Description	(kg/unit)
10.	Precast concrete lintel	Precast concrete lintel	1nr	140mm x 215mm x 750mm length, 2500kg/m^3	**56.44**

4.1.1.2 Type 2 blockwork wall panel (4x5m) with Wi Beam and HBP blocks

Material quantities are taken from a bill of quantities provided by Wembley Innovation Ltd and are given in Table 16. One unit is one 4x5m panel, as shown in Figure 6.

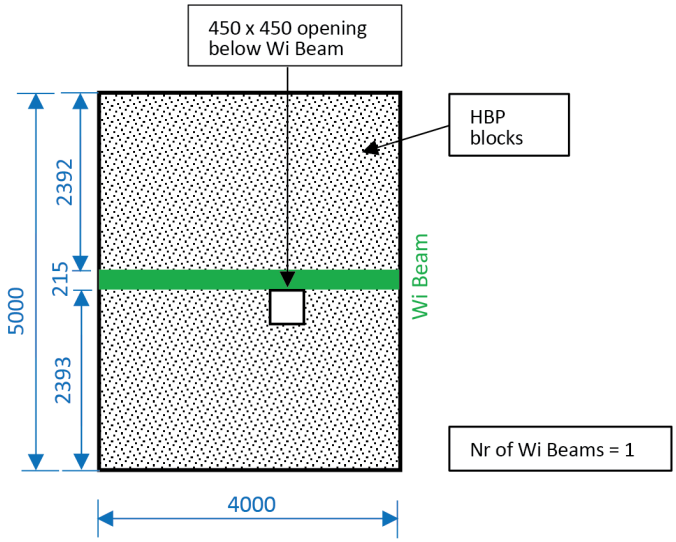

Figure 6: Type 2 wall panel designed with Wi Beam and HBP blocks. Source: Wembley Innovation.

Table 16: Material quantities for Type 2 panel with Wi Beam and HBP blocks.

	A		B	C	G
	Material	Type	Quantity	Description	(kg/unit)
1.	140mm Wi Beam Blocks	Wi System Blocks	9nr	Wi block 12.4kg/block	**111.6**
2.	End cleats (200x60x8)	Mild steel	2nr	Both ends of WiB	**1.49**
3.	200x20x2.5 Frame Cramp ties @ 450c/c spacing	Stainless steel	22nr	at end abutments	**13.2**
4.	Long transfer rod (675x34x4mm)	Mild steel	5nr	0.712kg each	**3.56**
5.	H16 rebar no socket	Rebar	8m	2nr at 4m length, 1.58kg/m	**12.64**
6.	C40 Wi mortar	Mortar	92kg	4m x 23kg/m	**92**
7.	HBP 140mm 7.3N medium dense slot block	HBP 140mm 7.3N medium dense slot block	189nr	HBP slot block weight = 17.8kg/block	**3364.2**
8.	Standard mortar (1:1:6)	Mortar	0.160 m^3	10mm thick mortar, 2200kg/m^3	**352**
9.	Stone mineral wool	Stone mineral wool	10m	At end abutments	**13.2**

	A		B	C	G
	Material	Type	Quantity	Description	(kg/unit)
10.	310ml intumescent acoustic sealant	Sealant	10nr tubes	Mastic to end abutments both sides of wall panel	**4.9**
11.	Wi debonding sleeve	Plastic	4nr	2nr per end cleat	**0.116**

4.1.2 Carbon factors

4.1.2.1 Modules A1-A3

4.1.2.1.1 Type 2 blockwork wall panel with TWPs, concrete lintel and standard blocks

Table 17: ECF_{A13} for Type 2 TWP

Material	ECF_{A13} ($kgCO_2e/kg$)	Source	Comment
Stainless steel	**4.407** (Range 3.61 – 6.29)	ICE V3	Inventory of Carbon and Energy (ICE) database Average value for stainless steel.
Fireboard	**0.390**	ICE V3	Plasterboard
7.3N Medium Block	**0.093**	ICE V3	Medium density block (generic)
Standard mortar 1:1:6	**0.152**	ICE V3	Mortar (1:1:6 Cement:Lime:Sand mix)
Stone mineral wool	**1.280**	ICE V3	Mineral Wool
Sealant	**2.366**	HTCEC	This value is general use for intumescent paint coatings of concrete from HTCEC.
Precast Concrete Lintel	**0.194**	ICE V3	Precast concrete beams and columns, assume 100kg steel per m^3 concrete, European EAF recycled stock. For reference and context of this value, an EPD for a UK produced prestressed precast lintel was found by Naylor Concrete (2023) which has an A1-A3 carbon factor of 0.168 $kgCO_2e/kg$. The value adopted here can be updated if a specific product EPD is known to be used.

4.1.2.1.2 Type 2 blockwork wall panel with Wi Beam and HBP blocks

Table 18: ECF_{A13} for Type 2 Wi Beam

Material	ECF_{A13} ($kgCO_2e/kg$)	Source	Comment
140mm Wi Beam Blocks[1]	**0.0917**		Provided by Wembley Innovation.
Stainless steel	**4.407** (Range 3.61 – 6.29)	ICE V3	Inventory of Carbon and Energy (ICE) database Average value for stainless steel.
Mild steel	**2.450**	HTCEC	This value is for general UK plate, and is recommended here unless the source of the plate is known.
Reinforcing bar	**0.760**	HTCEC	UK sector average.
C40 Wi mortar	**0.178**		Provided by Wembley Innovation.

Material	ECF_{A13} ($kgCO_2e/kg$)	Source	Comment
HBP 140mm 7.3N medium dense slot block[1]	**0.093**	ICE v3	Medium density block (generic)
Standard mortar (1:1:6)	**0.152**	ICE V3	Mortar (1:1:6 Cement:Lime:Sand mix)
Stone mineral wool	**1.280**	ICE V3	Mineral Wool
310ml intumescent acoustic sealant	**2.366**	HTCEC	This value is general use for intumescent paint coatings of concrete from HTCEC.
Plastic	**3.310**	ICE V2	General plastics.

4.1.2.2 Module A4

Module A4 is calculated in the same way as described for Type 1 panels in §3.1.2.2.

4.1.2.2.1 Type 2 blockwork wall panel TWPs, concrete lintel and standard blocks

The Type 2 blockwork panel with TWPs, concrete lintel, and standard blocks has an area of $20m^2$, and using a carbon factor of $1.62kgCO_2e/m^2$ from Table 5 this gives a total EC_{A4} of $32.5\ kgCO_2e$.

4.1.2.2.2 Type 2 blockwork wall panel Wi Beam with HBP blocks

The Type 2 blockwork panel with Wi Beam with HBP blocks has an area of $20m^2$, and using a carbon factor of $1.29kgCO_2e/m^2$ from Table 5 this gives a total EC_{A4} of $25.8\ kgCO_2e$.

4.1.2.3 Module A5w carbon factors

A5 carbon factors are divided into A5a (activities on site) and A5w (material wastage). Module A5w is calculated using Eq.(5):

$$ECF_{A5w,i} = WF_i \times (ECF_{A13,i} + ECF_{A4,i} + ECF_{C2,i} + ECF_{C34,i}) \quad (5)$$

$ECF_{A5w,i}$ = construction waste embodied carbon factor for i^{th} material
WF_i = waste factor for i^{th} material
$ECF_{A13,i}$ = embodied carbon factor for A1–A3 for i^{th} material
$ECF_{A4,i}$ = embodied carbon factor for transport to site for i^{th} delivery
$ECF_{C2,i}$ = transportation away from site carbon factor calculated in the same way as $ECF_{A4,I}$ but transport distance is assumed to be 50km by road if taken for reuse or recycling elsewhere (default assumption from RICS guidance)
$ECF_{C34,i}$ = waste processing and disposal embodied carbon factor

To calculate Module A5w, Module C2, C3, and C4 are also required:

- For Module A4, delivery emissions (EC_{A4}) are distributed pro-rata by weight between the items in each delivery group and divided by the item weight to give $kgCO_2e/kg$.
- For Module C2, transport distances are assumed at 50km (local) by road and calculated in the same manner as §3.1.2.3.1.
- Modules C3 and C4 are combined in a standard value of $ECF_{C34,I} = 0.013\ kgCO_2e/kg$ waste (as taken from the HTCEC guide).

4.1.2.3.1 Type 2 blockwork wall panel with TWPs, concrete lintel and standard blocks

Waste rates for each material are required. The waste rate (WR) is defined as a percentage of the quantity of materials brought to the site that are wasted. The values below are taken from baseline values provided in the WRAP Net Waste Tool, HTCEC or from discussions with Wembley Innovation:

Table 19: WF for Type 2 with TWPs, concrete lintel and standard blocks

Material	WR	WF	Reference
Stainless steel	1.00%	0.010	HTCEC
Fireboard (100x15mm)	22.50%	0.290	HTCEC
Standard 140mm 7.3N medium dense solid block (1)	5.00%	0.053	WI
Standard mortar 1:1:6	5.00%	0.053	HTCEC
Stone mineral wool (1)	5.00%	0.053	WI
310ml intumescent acoustic sealant (1)	3.00%	0.031	WI
Precast concrete lintel (2)	0.00%	0.000	WI
Note 1: WR value based on site experience and discussion with Wembley Innovation. Note 2: Precast concrete large elements would have a WR of 1% in HTCEC, 0% is taken here for these small elements.			

Table 20: ECF_{C2} for TWP

TD_{mode}	TEF_{mode}	Mode	ECF_{C2}
50 (1)	0.00009696	Road	0.004848
Note 1: ECF_{C2} is the transportation away from site carbon factor. This is calculated as described in §3.1.2.3.1 with transport distance is assumed to be 50km by road if taken for reuse or recycling elsewhere (default assumption from RICS guidance).			

Table 21: A5w for Type 2 panel with TWPs, concrete lintel and standard blocks

Material	ECF_{A13}	ECF_{A4}	ECF_{C2}	ECF_{C34}	WF	ECF_{A5w}
Stainless steel	4.407	0.0064	0.0048	0.013	0.010	0.045
Fireboard	0.390	0.0065	0.0048	0.013	0.290	0.120
Standard 140mm 7.3N medium dense solid block	0.093	0.0068	0.0048	0.013	0.053	0.006
Standard mortar 1:1:6	0.152	0.0005	0.0048	0.013	0.053	0.009
Stone mineral wool	1.280	0.0014	0.0048	0.013	0.053	0.068
310ml intumescent acoustic sealant	2.366	0.0014	0.0048	0.013	0.031	0.074
Precast concrete lintel	0.194	0.0938	0.0048	0.013	0.000	0.000

4.1.2.3.2 Type 2 blockwork wall panel with Wi Beam and HBP blocks

Waste rates for each material are required. The waste rate (WR) is defined as a percentage of the quantity of materials brought to the site that are wasted.

Table 22: WF for Type 2 panel with Wi Beam and HBP blocks

Material	WR_{Wi}	WF_{Wi}	Reference
Wi Beam Blocks	5.00%	0.053	WI
Stainless steel	1.00%	0.010	HTCEC
Mild Steel	1.00%	0.010	HTCEC
Rebar	1.00%	0.010	WI
C40 Wi mortar	5.00%	0.053	HTCEC
HBP 140mm 7.3N medium dense slot block	5.00%	0.053	WI
Standard mortar (1:1:6)	5.00%	0.053	HTCEC
Stone mineral wool	5.00%	0.053	Wrap
310ml intumescent acoustic sealant	3.00%	0.031	WI
Plastic	1.00%	0.010	WI

Table 23: ECF_{C2} for Type 2 Wi Beam system

TD_{mode}	TEF_{mode}	Mode	ECF_{C2}
50 (1)	0.00009696	Road	0.004848
Note 1: ECF_{C2} is the transportation away from site carbon factor. This is calculated in the same way as ECF_{A4} but transport distance is assumed to be 50km by road if taken for reuse or recycling elsewhere (default assumption from RICS guidance).			

Table 24: A5w for Type 2 panel with Wi Beam and HBP blocks

Material	ECF_{A13}	ECF_{A4}	ECF_{C2}	ECF_{C34}	WF_{Wi}	ECF_{A5w}
140mm Wi Beam Blocks	0.0917	0.0071	0.0048	0.0130	0.053	0.0061
Stainless steel	4.407	0.0027	0.0048	0.013	0.010	0.0447
Mild Steel	2.450	0.0062	0.0048	0.0130	0.010	0.0250
H16 rebar with socket	0.76	0.0062	0.0048	0.0130	0.010	0.0079
C40 Wi mortar	0.178	0.0062	0.0048	0.013	0.053	0.0106
HBP 140mm 7.3N medium dense slot block	0.093	0.0071	0.0048	0.013	0.053	0.0062
Standard mortar (1:1:6)	0.152	0.0005	0.0048	0.013	0.053	0.0090
Stone mineral wool	1.280	0.0027	0.0048	0.013	0.053	0.0685
310ml intumescent acoustic sealant	2.366	0.0027	0.0048	0.013	0.031	0.0738
Plastic	3.310	0.0027	0.0048	0.013	0.010	0.0336

4.1.3 Module A5a carbon emissions

In the following, electricity use required for site activities is taken from data provided by Wembley Innovation and given in Table 25.

The carbon emissions factor for this report have been taken from the UK Government Greenhouse gas reporting: conversion factors 2023. The values for electricity generation (Scope 2) and transmission and distribution (Scope 3) are added together to provide a 'electricity consumption' carbon factor, in line with the guidance provided with the conversion factors. This gives an emission factor of 0.207074 (for electricity generation) *plus* 0.01792 (for transmission and distribution) = 0.225 $kgCO_2e/kWh$.

Table 25: A5a emissions for Type 2 panel with a) TWPs, concrete lintel and standard blocks and b) with Wi Beam and HBP blocks, per 4x5m unit.

	Grid electricity	**Carbon emission factor ($kgCO_2e/kWh$)[1]**	**Embodied carbon ($kgCO_2e$)**
(a) TWPs, concrete lintel and standard blocks	10 kWh	0.225	**2.250**
(b) Wi Beam and HBP blocks	5 kWh	0.225	**1.125**
Note 1: Data point from https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2023			

4.2 Calculation

The Module A1-A5 embodied carbon is calculated based on Eq.(1).

4.3 Results

The total embodied carbon results for Type 2 panels are given in Table 26. One unit is one 4x5m panel, inclusive of the materials given in Table 15 for TWPs and Table 16 for the Wi Beam panel. The top contributors to EC_{A15} for each are also shown in Figure 7.

Table 26: EC_{A15} for Type 2 panel with a) TWPs, concrete lintel and standard blocks and b) with Wi Beam and HBP blocks.

	EC_{A15}	-
(a) TWPs, concrete lintel and standard blocks	**1287 $kgCO_2e$ per unit** *Range: 1160 – 1584 $kgCO_2e$ per unit*	*Range based on upper and lower values for ECF_{A13} for stainless steel.*
(b) Wi Beam and HBP blocks	**557 $kgCO_2e$ per unit** *Range: 546 – 582 $kgCO_2e$ per unit*	57% reduction compared to TWP *Range based on upper and lower values for ECF_{A13} for stainless steel.*

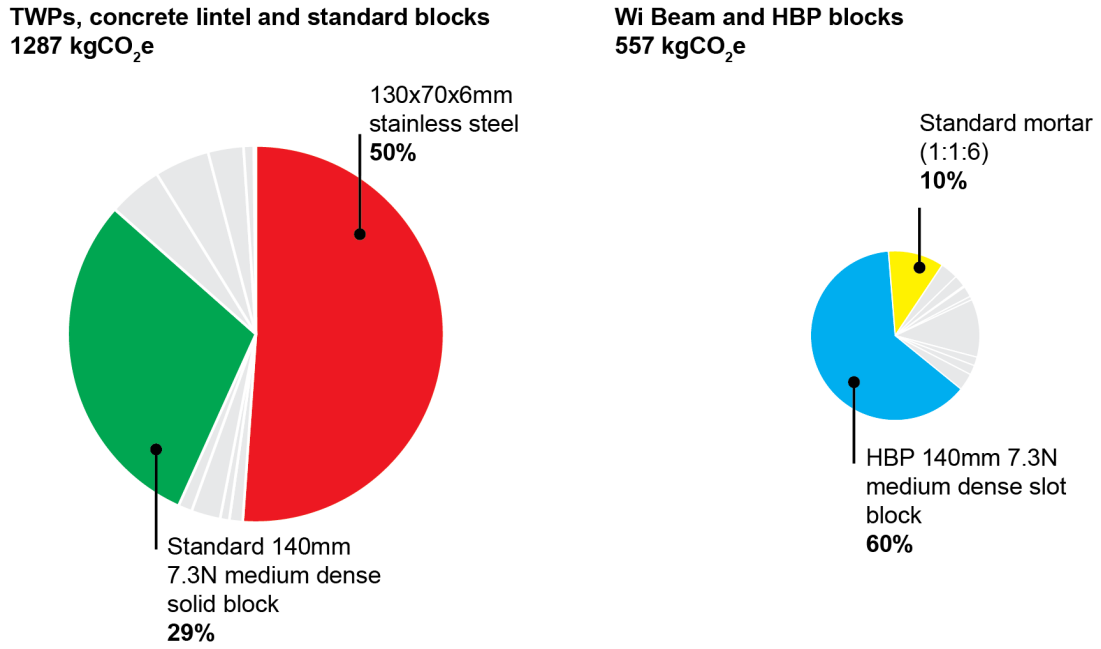

Figure 7: EC_{A15} results for Type 2 panel with a) TWPs, concrete lintel and standard blocks (left) and b) with Wi Beam and HBP blocks (right) showing top contributors to EC_{A15}.

As can be seen in the results presented above, the *Wi Beam and HBP blocks* panel achieves a 57% carbon saving compared with the *TWPs, concrete lintel and standard blocks* panel.

5 Analysis and Discussion

5.1 Electricity supply

The HBP factory has been installed with solar panels producing 328 kWp (kW peak). The provided information estimates an output of the installation over 20 years of 4,338,026 kWh. Averaging this over the 20-year period (balancing out the linear degradation in performance assumed in the solar proposal), this equates to approximately 600 kWh per day.

HBP consumed on average 208 kWh electricity per day in 2022. If this is taken as a representative year, the installed system should supply close to 400 kWh of renewable electricity to the grid every day for 20 years – about 2.9MWh in total of new renewable energy source supplied to the grid.

The carbon emissions of the electricity consumed by the HBP factory prior to installation of the solar panels can be estimated from the electricity production plus transmission and distribution (total of 0.225 $kgCO_2e/kWh$)[1], which amounts to approximately 46.8 $kgCO_2e$ emissions per day for the plant. This is an underestimate, since the grid factors include generation by renewables, where it could be argued that the installation is replacing non-renewables in the energy mix.

HBP produces between 12,000 and 14,000 blocks per day. If we assume an average of 13,000 blocks, the installation negates the need for any UK grid electricity. 46.8 $kgCO_2e$ divided equally amongst the blocks (for simplicity) amounts to 3.6 gCO_2e per block. This is small compared to the embodied carbon of the block – the Wi column and Wi beam blocks have an A1-A3 embodied carbon of 0.0917 $kgCO_2e/kg$ (and weigh 11.4 – 12.4kg each).

Overall, the solar installation is an extremely positive addition in terms of sustainability as it means the HBP factory is entirely self-sufficient in electricity supply and is also a net contributor to the grid of clean renewable electricity, for at least the next 20 years.

[1] From https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2023

5.2 Comparison between Wi System and TWP – Type 1

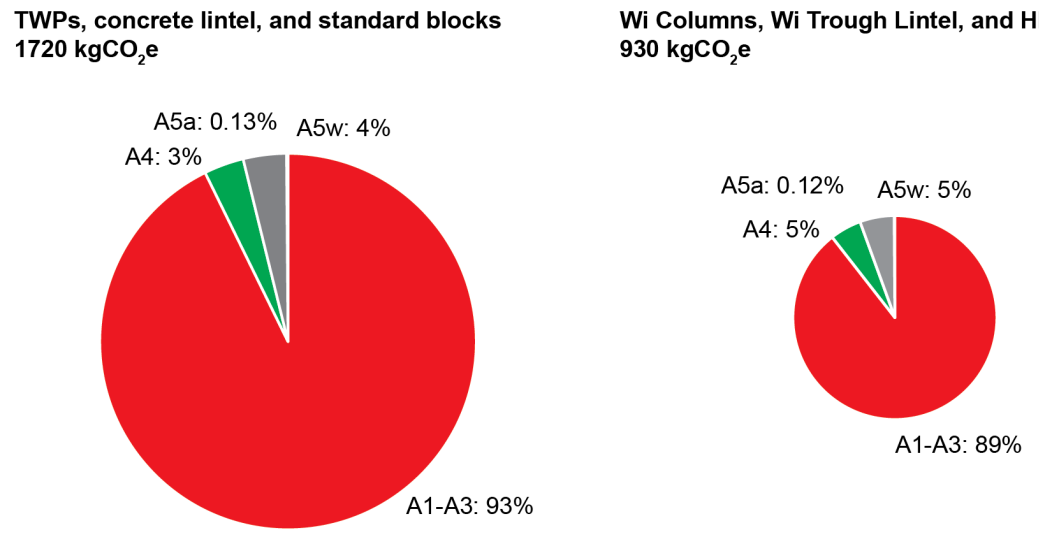

Figure 8: Split in embodied carbon by life cycle Module.

5.2.1 Raw materials

Both systems are dominated by Module A1-A3 carbon.

As can be seen in the results presented above, the *Wi Columns, Wi Trough Lintels and HBP block* panel achieves at least a 46% carbon saving compared with the *TWPs, concrete lintels and standard blocks* panel.

The Wi System uses considerably less stainless steel than the TWP (168kg, 44% of the total embodied carbon for TWP, compared to 5kg, 2% of total embodied carbon for Wi System). The Wi System uses slightly less blockwork (6161kg compared to 6802kg for the TWP). The Wi System does not require fire boarding, which saves a small amount of carbon compared to the TWP.

Future changes to the design could therefore focus on the emission reduction hierarchy shown in Figure 9, which reminds us the most important thing we can do now is to use less stuff.

Figure 9: Hierarchy of emissions reductions. Image © John Orr (Orr et al., 2021)

5.2.2 Transportation

The Wi Columns, Wi Trough Lintel, and HBP blocks have lower A4 emissions (46 $kgCO_2e$ compared to 58 $kgCO_2e$ for TWPs, concrete lintel, and standard blocks).

This report has based the transportation carbon on a real project, which allowed the analysis of actual transport logistics to be included. This is a more robust analysis than simply using the crude metric of $kgCO_2e/kg/km$. The Wi System has approximately 20% fewer deliveries required, meaning less trucks on the road which brings additional benefits, for example in lower air pollution emissions and road traffic around construction sites.

5.2.3 Waste

Module A5w contributes a small percentage of the total carbon. The waste rates have been applied equally to both systems. Further improvements in site practice could allow these to be reduced.

5.2.4 Site activities

Site activity data has been estimated in kWh by the Wembley Innovation team. The total contribution in both is very small.

5.3 Comparison between Wi System and TWP – Type 2

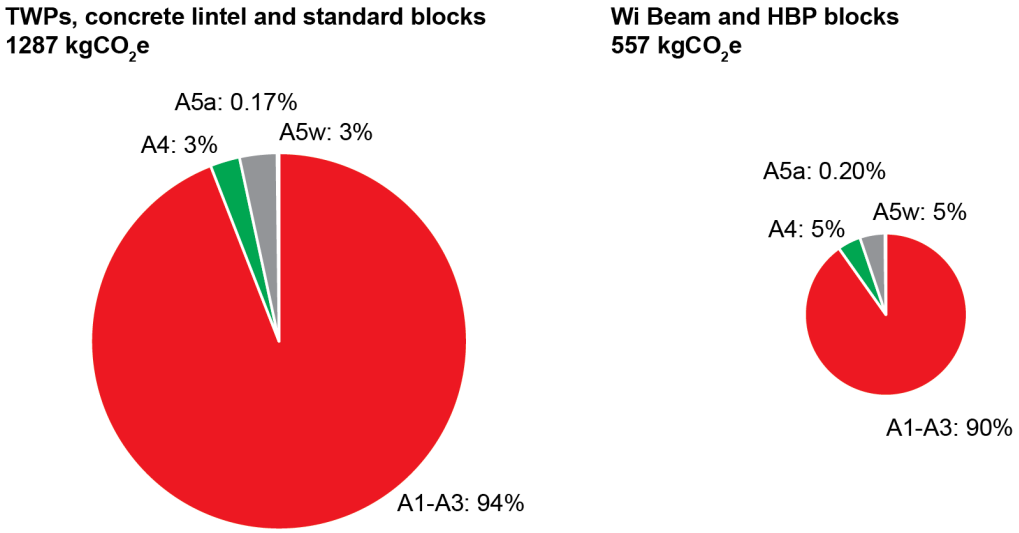

Figure 10: Split in embodied carbon by life cycle Module.

5.3.1 Raw materials

Both systems are dominated by Module A1-A3 carbon.

As can be seen in the results presented above, the *Wi Beam and HBP blocks* panel achieves at least a 57% carbon saving compared with the *TWPs, concrete lintel and standard blocks* panel.

The Wi System uses considerably less stainless steel than the TWP (157kg, 54% of the total embodied carbon for TWP, compared to 13kg, 11% of total embodied carbon for Wi System). The Wi System uses slightly less blockwork (3476kg compared to 3762kg for the TWP). The Wi System does not require fire boarding, which saves a small amount of carbon compared to the TWP.

5.3.2 Transportation

The Wi System has a lower A4 emissions (26 kgCO_2e compared to 32 kgCO_2e for TWP). Further benefits of the Wi System that result from fewer deliveries are outlined in §5.2.2 above.

5.3.3 Waste

Module A5w contributes a small percentage of the total carbon. The waste rates have been applied equally to both systems. Further improvements in site practice could allow these to be reduced.

5.3.4 Site activities

Site activity data has been estimated in kWh by the Wembley Innovation team. The total contribution in both is very small. Further analysis could be undertaken to validate the assumptions made.

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