Delivering net-zero carbon schools fit for future generations

VALE of GLAMORGAN
BRO MORGANNWG

Ysgolion yr 21ain Ganrif
21st Century Schools
Trawsnewid Addysg ar draws Bro Morgannwg
Transforming Education Across the Vale of Glamorgan

Introduction

The 21st Century Schools Programme is a long-term strategic investment in educational estate throughout Wales.

It is a unique collaboration between Welsh Government, the Welsh Local Government Association (WLGA), local authorities, colleges and diocesan authorities. Further details of the 21st Century School Programme can be found through the 21st Century Schools and Welsh Government websites.

The programme was launched with Band A which ran from April 2014 to March 2019. Band B was then launched in April 2019 and is due to run until March 2024. The Council submitted an ambitious programme for both Band A and Band B of the programme. £31m was invested in education buildings during Band A and a further £135m is due to be invested as part of Band B. Throughout the 21st Century Schools programme, the Council has explored innovative solutions to ensure our school buildings are fit for future generations.


arfan
School

As part of Band A, the Council adopted a standardised approach to the delivery of new primary school buildings. The Council appointed ISG Construction and Architects Stride Treglown to deliver three primary schools, utilising the Agilis model. Ysgol Gymraeg Nant Talwg (now Ysgol Gymraeg Bro Morgannwg) was the first Agilis school building delivered in Wales, representing the first practical application of a model school in the country. Ysgol Nant Talwg was a pioneering and innovative project which optimised natural ventilation, lean construction design and adaptable teaching environments fit for the future. Two further primary school projects, Oak Field Primary School and Ysgol Gymraeg Dewi Sant, were also delivered using this model. These primary schools have continued to perform well from both an environmental and teaching and learning perspective.

On 29 July 2019, the Vale of Glamorgan Council declared a ‘climate emergency’ and committed to reducing its carbon emissions to net-zero before by 2030, supporting the implementation of the Welsh Government’s new Low Carbon Delivery Plan. This also supports Welsh Government’s commitment to the target of achieving a net-zero carbon public sector in Wales by 2030.

The net-zero target recognises that there will be some emissions but that these need to be fully offset, predominantly through natural carbon sinks such as oceans and forests. When the amount of carbon emissions produced are cancelled out by the amount removed, the UK will be a net-zero emitter.

In response to the climate emergency, the 21st Century Schools Team launched a project to explore how construction practices could be adapted to support the net-zero target as part of Band B of the 21st Century Schools Programme. ISG Ltd had been appointed to deliver three primary schools building on the principles developed in the Agilis model, across the Vale of Glamorgan, St David’s CIW Primary School, and Llancarfan Primary School.

St David’s CIW Primary School was designed to be low (in-use) carbon through improved building fabric, maximising solar gain and installing PV panels and it’s only energy source is electric. Careful consideration has been taken to select materials that maximise the fabric first approach and be easy to construct and maintain. The internal environment is being developed to maximise natural day lighting and fresh air provision.

This model was further developed to deliver net-zero (in-use) carbon school buildings for Llancarfan Primary School. To achieve this, the all-electric model was revised with additional renewables, battery storage and the installation of air-source heat pumps. Llancarfan Primary School will be the first net-zero carbon primary school buildings in Wales.

Although careful consideration has been taken to select materials that maximise the fabric first approach (whereby thermally efficient walls, roof, windows and doors reduce energy loss and minimise the energy needed to heat the building) and be easy to construct and maintain, the Council wanted to take the project further to address embodied carbon. The Council is currently working with representatives from the construction industry to develop an adaptable and scalable school design that is net-zero carbon (operation) and low embodied carbon. Hereby looking at the materials and the embodied carbon these contain and elements such as transport to site.

This project highlights the Vale of Glamorgan Council’s commitment to pushing the boundaries of school design to support the target of net-zero carbon by 2030, ensuring that our new school buildings are fit for the future.

Evolution vs revolution

Building on the team's experience delivering an optimised primary school model rather than starting again with full Passivhaus.

The model primary schools delivered to date score highly in post occupancy evaluation with end users.

The existing design works well for teachers and pupils.

Optimising what we already know works to achieve net-zero carbon.

Finding the 'sweet spot' for delivering zero carbon that's still practical, buildable and affordable.

Defining net-zero carbon

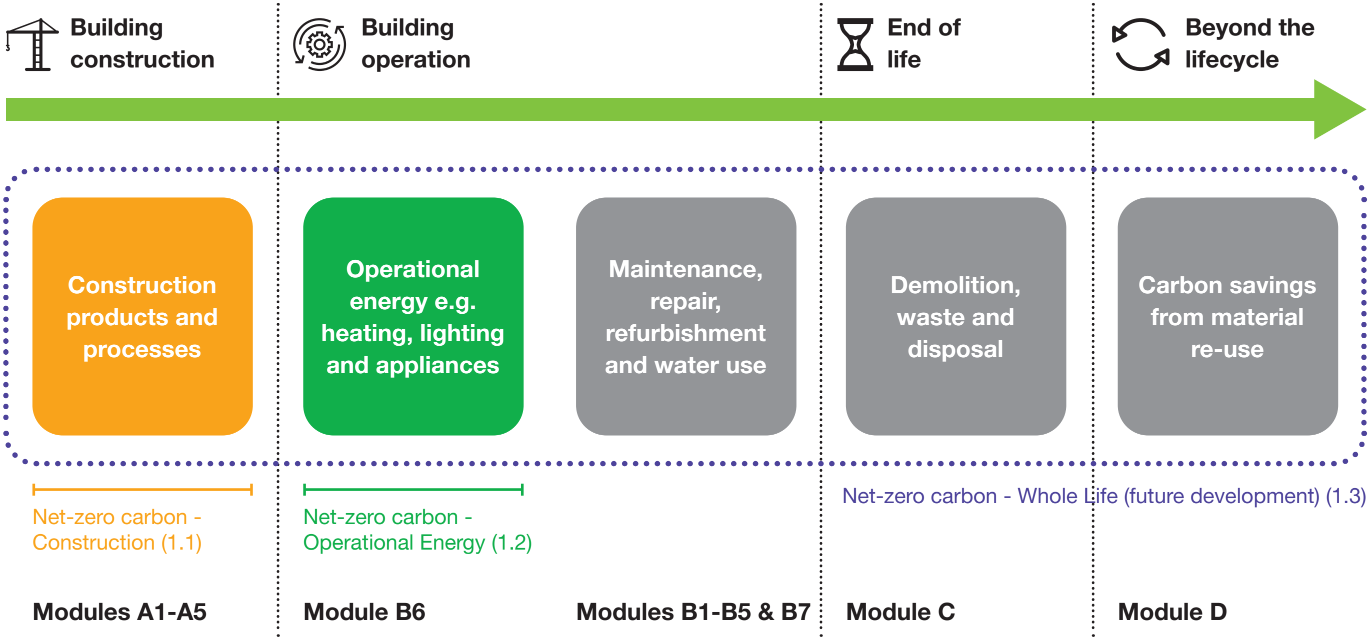
In April 2019, UK Green Building Council published 'Net-zero Carbon Buildings: A Framework Definition' which provides the property and construction sector with clarity on the outcomes required for a net-zero carbon building.

Net-zero carbon – construction (1.1): "When the amount of carbon emissions associated with a building's product and construction stages up to practical completion is zero or negative, through the use of offsets or the net export of on-site renewable energy."

Net-zero carbon – operational energy (1.2): "When the amount of carbon emissions associated with the building's operational energy on an annual basis is zero or negative. A net-zero carbon building is highly energy efficient and powered from on-site and/or off-site renewable energy sources, with any remaining carbon balance offset."

A third approach for net-zero carbon – whole life (1.3) is also proposed at a high level, but further work will be needed to define the scope and requirements for this approach.

Breakdown of three net-zero carbon scopes



All modules referred to are from EN15978 Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method

The LETI Climate Emergency Design Guide has an alternative but similar definition worth noting:

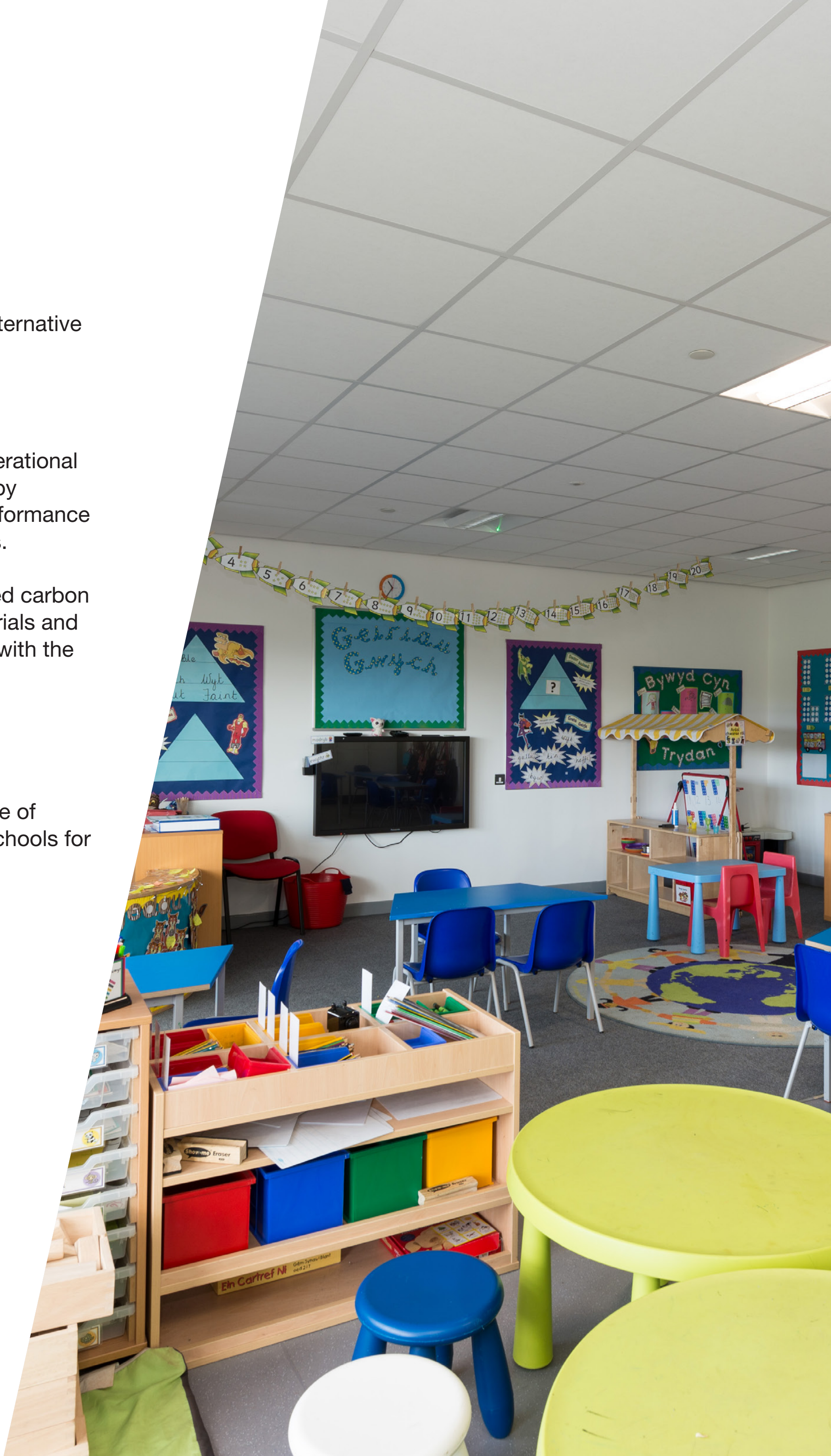
Whole life carbon is formed of two key components:

Operational Carbon: a new building with net-zero operational carbon does not burn fossil fuels, is 100% powered by renewable energy, and achieves a level of energy performance in-use in line with our national climate change targets.

Embodied Carbon: Best Practice targets for embodied carbon are met, and the building is made from re-used materials and can be disassembled at its end of life in accordance with the circular economy principles.

Our journey

The following projects outline the journey that the Vale of Glamorgan council is on to deliver net-zero carbon schools for future generations.



Example projects

The “Agilis” primary model

Ysgol Gymraeg Nant Talwg, Barry

The “Agilis” model was jointly developed by ISG construction and architects Stride Treglown. The purpose was to design a primary model which could be delivered with a greater efficiency in terms of cost and time than previous bespoke options.

The model was used to design several primaries within Band B of the 21st Century schools programme; Ysgol Gymraeg Nant Talwg (now known as the primary phase of Ysgol Gymraeg Bro Morgannwg), Oak Field Primary and Ysgol Gymraeg Dewi Sant. Both Nant Talwg and Dewi have a pupil capacity of 210 with 48 part-time nursery places, Oak Field has a pupil capacity of 420 with 96 part-time nursery places.

Project details

Value: £2.774 million – 2014 *(Q3 2020 £3.87m)*

Project size: $1400m^2$

Cost per m^2: £1,981.52 *(£2,762.24)*

Energy efficiency measures: Photovoltaics, maximise natural daylight, simple extract ventilation, underfloor heating (operates at a lower temperature than traditional heating

Contractor: ISG

M&E Consultant: Hoare Lea

Architect: Stride Treglown

Average annual energy cost

Average annual energy consumption, cost and CO2e (per m^2)	Annual Energy Consumption		Indicative Cost		Carbon Emissions		Total CO2
	kWh	kWh/m2	£	£/m2	kgCO2	kgCO2/m2	kgCO2
Electric	54824	39.16	8223.6	5.87	12782	9.1	
Gas	149482	107.03	3438.08	2.45	27485	19.7	40267

Positive points to note

This model features an efficiency of design, a lean building process, speedy construction and cost effectiveness compared to a more traditional bespoke option. It offers flexibility through removable internal walls and the ability for the client to customise the external appearance as well as the internal positioning of certain elements such as toilet blocks.

The development of a template design based on lessons learnt over a time from other projects enabled continuous improvements to be made upon a standardised product. Refining the design and build process over several projects also helped to reduce construction waste and build time. For example, one of the design revisions was the simplification of the roof profile which made construction more straightforward and streamlined the building's appearance.

How it changed from the previous model

- Simple design and robust construction
- Extensive lessons learnt and feedback giving benchmark data
- High performing envelope (40% improvement on building control minimum u-values)
- Community benefits were made a contractual requirement. The contractors and client developed a robust community benefits and Targeted Recruitment & Training (TR&T) plan to deliver upon these targets

Example projects

Low carbon (operational) model

St David’s CIW Primary

Alongside the project to investigate and develop a net-zero carbon school to be delivered in future, the 21st Century Schools team have considered and implemented measures to create low and net-zero carbon in-use schools within our current Band B projects.

The first project looked at creating a low-carbon option where net-zero may not be achievable. To achieve this, an all-electric model was developed for St David’s CIW Primary school (SDP). The new building will have capacity for 210 pupils with 48 part-time nursery places.

In-use low (to net-zero) carbon will be achieved through improved building fabric, maximising solar gain and installing PV panels. Careful consideration has been taken to select materials that are healthy, have lower embodied energy and are easy to construct and maintain. The internal environment is being developed to maximise natural day lighting and fresh air provision.

Project details

Value: £4.435 million - 2020

Project size: 1,466m^2

Cost per m²: £3,025.24

Energy efficiency measures: Photovoltaics (increased from Agilis), plant room with space for future batteries, maximise natural daylight, simple extract ventilation, underfloor heating, high performing building envelope

Contractor: ISG

M&E Consultant: McCann & Partners

Architect: Stride Treglown

Average annual energy cost

Average annual energy consumption, cost and CO2e (per m²)	Annual Energy Consumption		Indicative Cost		Carbon Emissions		Total CO2
	kWh	kWh/m2	£	£/m2	kgCO2	kgCO2/m2	kgCO2
Electric	74246	48.75	£ 11,129.35	7.31	17310	11	17310


St. David's CIW
Primary School

Positive points to note

This model features a more efficient design based on lessons learnt from the Agilis model. The design maximises roof mounted PV with space to potentially install batteries in the plant room in future.

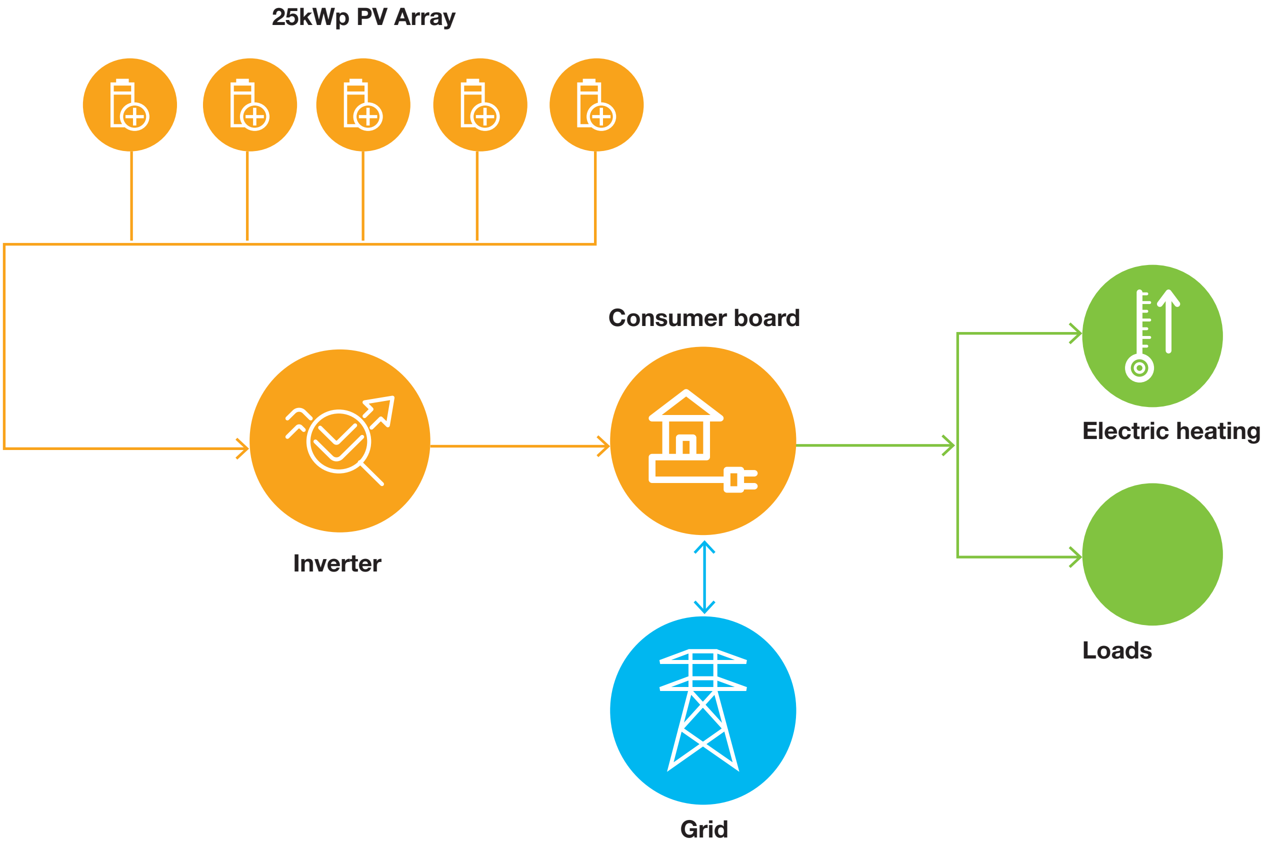
It was decided an all-electric solution is preferable to installing efficient gas boilers as it is easier to decarbonise electricity sources than gas. Mains gas CO2 emissions has fallen sharply during the transition from coal to natural gas, but as the grid continues to transition towards more electricity being generated from solar and wind power, it is likely the CO2 emissions from electricity will be lower overall. An all-electric solution also enables more of the energy consumed by the school to come directly from on-site renewables.

SDP currently operates without mains gas, it does use LPG but consumption at the school is generally lower than similar sized primaries and so it is hoped this will help the transition to an all-electric model.

How it changed from the previous model

- Increased PV and capacity for future energy efficiency technology
- Extensive lessons learnt and feedback giving benchmark data
- Increased fabric performance

ASHP PV Battery Line Diagram



Example projects

Net-zero carbon (operational) model

Llancarfan Primary

Building upon the low carbon, all-electric solution, the team developed a net-zero carbon in-use model. To achieve this, the all-electric model was revised with additional renewables for the Llancarfan Primary School (LPS). The new buildings will have capacity for 210 pupils with 48 part-time nursery places.

In-use net-zero carbon will be achieved through improved building fabric, maximising solar gain, installing PV panels and an air source heat pump. As with the low carbon model, careful consideration has been taken to select materials that are healthy, have lower embodied energy and be easy to construct and maintain. The internal environment is being developed to maximise natural day lighting and fresh air provision.

Project details

Value: £5.04 million 2020

Project size: 1,466m^2

Cost per m²: £3,437.93

Energy efficiency measures: Photovoltaics, plant room with batteries, air source heat pump, maximise natural daylight, simple extract ventilation, underfloor heating, high performing building envelope

Contractor: ISG

M&E Consultant: McCann & Partners

Architect: Stride Treglown

Average annual energy cost

Average annual energy consumption, cost and CO2e (per m²)	Annual Energy Consumption		Indicative Cost		Carbon Emissions		Total CO2
	kWh	kWh/m2	£	£/m2	kgCO2	kgCO2/m2	kgCO2
Electric	-10052	-6.6	4660	3.06	-2344	-1.5	-2344


Llancarfan
Primary School

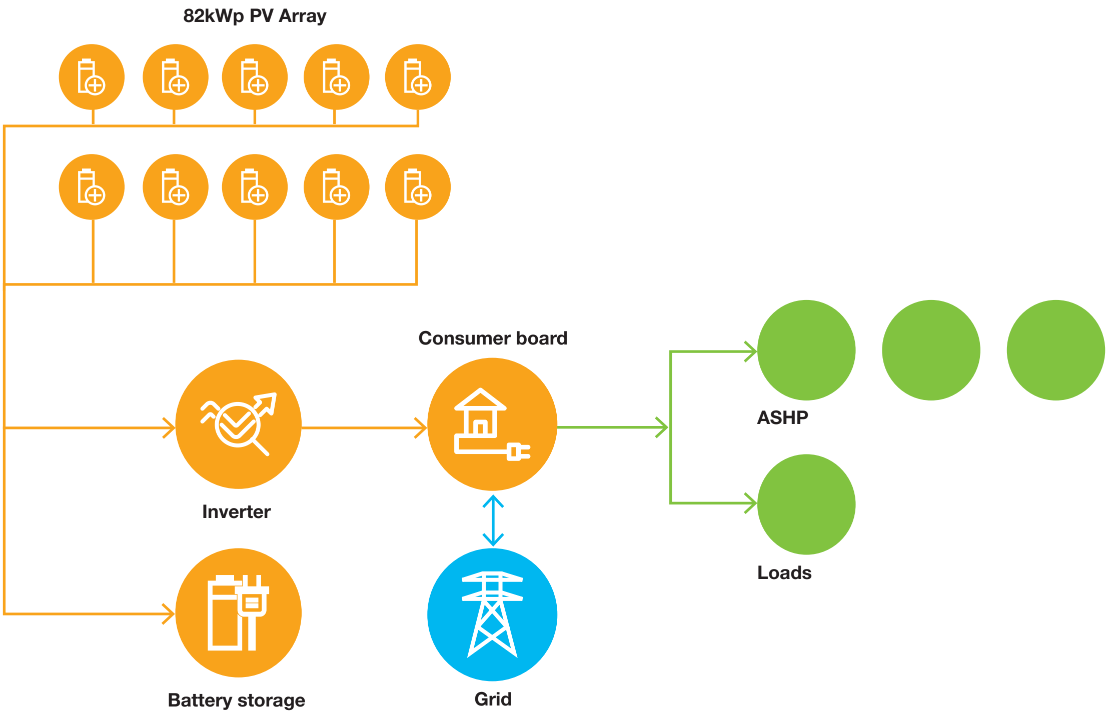
Positive points to note

The design maximises roof mounted PV with space to potentially install batteries in the plant room in future. The addition of an air source heat pump is an efficient method to meet hot water and heating requirements.

How it changed from the previous model

- Increased renewables and energy efficiency technology (battery storage)

ASHP PV Battery Line Diagram



Our approach to net-zero operational carbon

The scheme was developed around the current industry best practice guidance for achieving net-zero carbon operational energy including UK Green Building Council and LETI.

The Key Performance Indictors detailed by LETI were used as a key metric of the energy strategy. The key performance indicators cover all items which contribute towards low energy and net-zero carbon buildings such as building fabric, efficiency measures, heating and hot water and renewables. The key performance indicators were used to determine what measures should be adopted in the design of the development to achieve low or net-zero carbon and whether future adaptability should be included in the design to allow the building to achieve net-zero carbon.

Operational energy

Implement the following indicative design measures:

Fabric U-values (W/m^2.K)

Walls	0.13 - 0.15
Floor	0.09 - 0.12
Windows	0.10 - 0.12
Roof	1.0 (triple glazing)
Doors	1.2

Fabric efficiency levels

Air tightness	<1 (m^3/h. m^2@50Pa)
Thermal bridging	0.04 (y-value)
G-value of glass	0.5 - 0.4

Power efficiency levels

Lighting power density	4.5 (W/m^2 peak NIA)
Lighting out of hours	0.5 (W/m^2 peak NIA)
Small power out of hours	2 (W/m^2 peak NIA)

System efficiency levels

MVHR	90% (efficiency)
Heat pump SCoP	>2.8
Central AHU SFP	1.5 - 1.2 W/l.s

Maximise renewables so that 70% of the roof is covered

Window areas guide (% of wall area)

North	15-25%
East	15-25%
South	15-25%
West	15-25%

Balance daylight and overheating

Include external shading

Include openable windows and cross ventilation

Form factor of 1 - 3

Reduce energy consumption to:

65 kWh/m^2 .yr

Energy use intensity (EUI) in GIA, excluding renewable energy contribution

Reduce space heating demand to:

15 kWh/m^2 .yr

Approach to net-zero (operational) carbon

Steps to achieving a net-zero carbon building (operational)

The approach to achieving a net-zero carbon – operational building was based on the framework outlined in the UKGBC document – Net-zero Carbon Buildings: A Framework Definition. The steps of the framework and how we approached these on Llancarfan Primary are detailed below.

01 Reduce operational energy use

Reductions in energy demand and consumption should be prioritised over all measures

02 Increase renewable energy source

On site renewable energy source should be prioritised

03 Zero carbon balance

Any remaining carbon should be offset via the purchase of off site renewable energy

04 Measurement & verification

Annual energy use and renewable energy generation on site must be reported and independently verified in use each year for first five years

Approach to Llancarfan Primary

- [x] Improve building fabric
- [x] Improve catering equipment
- [x] Improve plugged in equipment
- [x] Low carbon heating

- [x] Maximise PV on roof

- [x] VoG aspiration for building to achieve NZC OE on site with no off site renewables such as PPA agreements

- [x] Operational energy performance evaluated to verify NZC and determine energy breakdown for future evaluation

From the exercise a number of options were determined with different configurations to achieve net-zero carbon in operation. These included the use of different low carbon heating options in combination with other improvements such as a further enhanced building fabric, wind turbines, increased amount of PV and a remote PV arrays such as on canopies over play areas or car parking spaces.

These options were analysed from a cost perspective and it was decided that the most effective approach was to use a combination of ASHPs and maximising the PV on the roof.

NZC OE Options put forward for evaluation

	Low carbon options							Building fabric				
	ASHP	GSHP	PV	PV - Roof integrated or building mounted	Remove PV array (PPA)	Battery storage	Wind turbine	Walls	Floor	Roof	Windows	Air permeability
Option 1 - ASHP and roof integrated PV	Y	N	88kWp	RI	N	88kWp	N	0.14	0.14	0.12	1.0 pane 1.6 frame	3
Option 2 - ASHP and 6kW wind turbine	Y	N	68kWp	BM	N	68kWp	6kW	0.14	0.14	0.12	1.0 pane 1.6 frame	3
Option 4 - GSHP and roof integrated PV	N	Y	88kWp	RI	N	88kWp	N	0.14	0.14	0.12	1.0 pane 1.6 frame	3
Option 5 - GSHP and 6kW wind turbine	N	Y	68kWp	BM	N	68kWp	6kW	0.14	0.14	0.12	1.0 pane 1.6 frame	3
Option 6 - GSHP and Passivhaus fabric	N	Y	68kWp	BM	N	68kWp	N	0.13	0.064	0.1	0.5 pane 0.8 frame	0.3 ach
Option 7 - Remote PV array	N	N	68kWp	BM	Y	68kWp	N	0.14	0.14	0.12	1.0 pane 1.6 frame	3

Approach to net-zero (operational) carbon

The chosen u-values and air tightness for Llancarfan Primary are detailed below in comparison with the L2A 2014 Wales Notional Building, the building against which compliance with Building Regulations is currently assessed against, and the LETI KPI design measure figures on achieving NZC. Improvements to the building fabric were targeted based on cost effectiveness with the improvements to the walls, floor and roof maximised to be similar to the LETI KPIs. It was determined that the use of triple glazing and an enhanced air tightness were not currently cost effective measures to implement.

U Values

Element	L2A 2014 Wales Notional	Llancarfan Primary School (NZC OE)	LETI KPI NZC
Walls (W/m2K)	0.26	0.14	0.13-0.15
Floor (W/m2K)	0.22	0.14	0.09-0.12
Roof (W/m2K)	0.18	0.12	0.10-0.12
Exposed ceilings/floors (W/m2K)	0.22	-	0.09-0.12
Windows (W/m2K)	1.60	1.33	1.00 (triple glazing)
Doors (W/m2K)	1.5-2.2	1.5	1.2

Air permeability

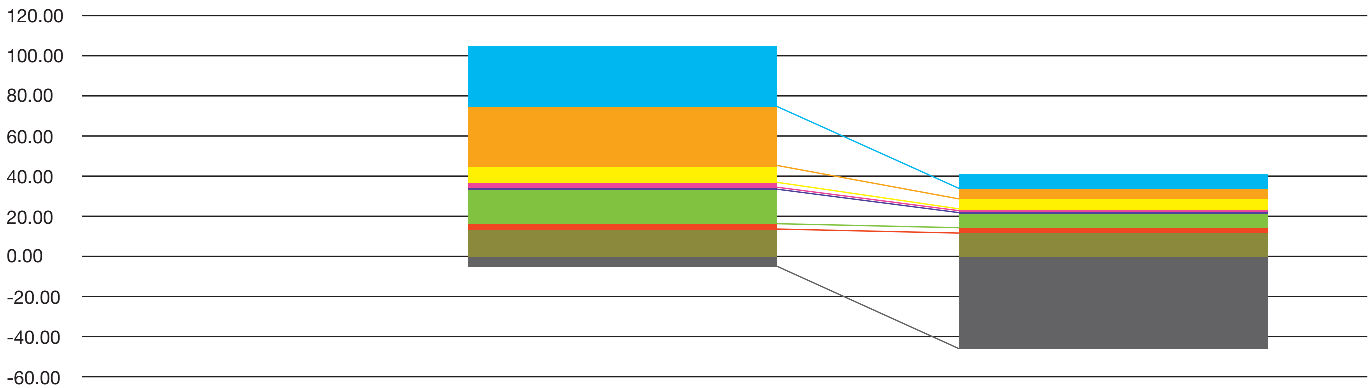
Element	L2A 2014 Wales Notional	Llancarfan Primary School (NZC OE)	LETI KPI NZC
Air tightness (m3/h. m2@50Pa)	3	3	<1


Llancarfan
Primary School

Operational energy assessment

The proposed building was modelled under CIBSE TM54 methodology to determine the operation energy use and demonstrate net-zero carbon for operational energy. A breakdown of the annual energy consumption of the proposed Llancarfan Primary compared to a previous ‘L2A 2014 compliant’ project is shown in the graphs below.

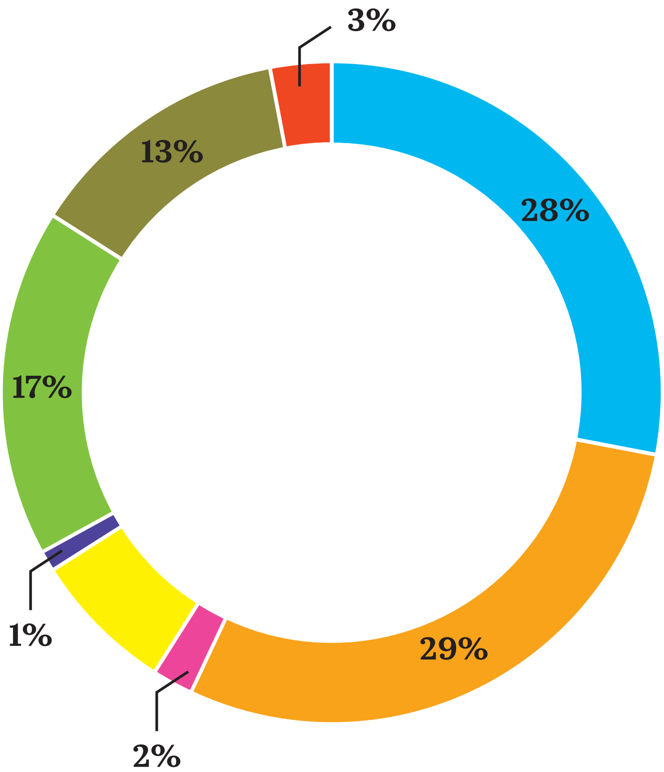
Annual consumption kWh/m²



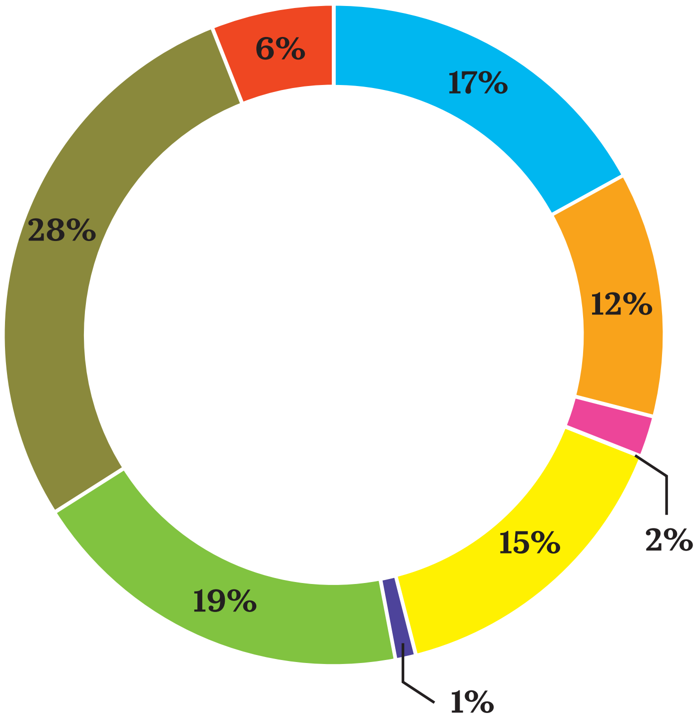
	L2A Wales 2014 Primary	Llancarfan Primary
Heating	30.3	7.1
Hot water (Elec)	30.5	5.0
Lighting (Internal)	8.1	6.08
Auxallaries	2.3	0.8
Lighting (External)	0.8	0.4
Equipment	17.8	7.7
Server	2.90	2.3
Catering	14.0	11.2
Photovolatic	-5.20	-47.2
Total	**101.5 kWh/m²**	**-6.6 kWh/m²**

With the use of ASHPs and an improved building fabric the annual consumption due to heating and hot water usage has reduced significantly. This has resulted in the energy consumption of the school being more influenced by other uses such as equipment and catering. The in-use energy use of the school will be closely monitored to ensure any areas with higher than calculated energy use are investigated to ensure they are operating correctly.

L2A Wales 2014 Primary



Llancarfan Primary



The calculated operational energy performance was compared against the LETI KPIs for space heating and energy consumption. The space heating demand was found to be higher due to the differences in improvement to building fabric compared to LETI KPIs where it was found triple glazing and enhanced levels of air tightness were deemed to not yet be cost effective.

However the overall energy consumption was found to be lower due to the use of low carbon heating and hot water via heat pumps with an average SCOP of 3.5, giving 3.5 units of heat for every unit of electricity, and general improvements elsewhere such as lighting, energy efficient plugged in appliances and improved catering equipment

It should be noted the LETI KPI applies to all school types. It will be a lot harder to meet these figures on a comprehensive school which has more plugged in equipment and server equipment. A primary school has simpler provision leading to lower equipment energy consumption to offset.

The procurement of equipment and ongoing energy management by the school will play a large part in achieving the 5 year verification to be net-zero in relation to operational energy.

Comparison with LETI KPIs

Space heating demand

LETI KPI	Llancarfan Primary
15 kWh/m^2 .yr	21 kWh/m^2 .yr

Space heating demand is a measure of the buildings overall thermal performance including air tightness

Energy consumption

LETI KPI	Llancarfan Primary
65 kWh/m^2 .yr	41 kWh/m^2 .yr

Energy Use Intensity (EUI) excluding renewable energy contribution. EUI includes all energy uses in the building (regulated and unregulated) including heating, hot water, fans and pumps, plugged in equipment, lighting, server and catering energy use

Net-zero carbon (operational) and low-embodied

The project team has chosen to aim for net-zero carbon (operational) and low embodied. Further details of the approach and targets are provided in the methodology section below.

A further caveat is that the modelling of the embodied carbon does not currently include MEP and FFE but will be considered as the design progresses. The modelling was undertaken with the available project information to date. Further, more detailed modelling will be undertaken when information becomes available.

There is currently little data available on building services embodied carbon when compared to other building elements. In order to build a better understanding on projects and on the industry as a whole, the project will be requesting Environmental Product Declarations (EPDs) from suppliers and compare the (Global Warming Potential) GWP data that should be available therein. This will help to make informed choices when specifying plant.

Discussion has commenced around internal finishes of the building and the impact of maintenance and upkeep has on the overall embodied carbon figures. The embodied carbon of maintenance and upkeep can be considerable across the whole life cycle.

Finishes are also the area of the building that people have most contact with, and so considering how low embodied carbon approaches can improve the wellbeing experience of the space is important and will be discussed further as the design progresses.

Net-zero carbon (operational) and low embodied

Project details

Project size: 247m^2

Energy efficiency measures: Photovoltaics, plant room with batteries, air source heat pump, maximise natural daylight, mechanical heat recovery ventilation, underfloor heating, highest performing building envelope

Contractor: ISG

M&E Consultant: Hydrock

Architect: HLM

The main project developed a net-zero carbon (operational) and low embodied, model. A 48 part-time place nursery option was used to explore the NZC model but with flexibility to compare against previous primary models and that could be scaled to meet all educational needs.

This NZC model builds upon the NZC in-use models with additional parameters and research into embodied carbon of materials and even more stringent targets for energy performance (see below). The full scope is set out in the methodology and methods section above.

- The project has set the following parameters for building fabric (based on LETI guide):
  - a) Wall U-Value = 0.12
  - b) Roof U-Value = 0.12
  - c) Floor U-Value = 0.12
  - d) Glazing = 1.00 U-Value & 0.4 G Value.
  - e) Air Permeability = 1.0 (m3/(h.m2) @ 50Pa)
- The project set an embodied carbon target of <600kgCO2/m² (based on LETI guide).
- The estimated PV required is circa. 13.1kWp (based on initial modelling of nursery).

Positive points to note

This final model builds upon all of the good practice from previous models. The design is efficient, practical and scalable. Overall, it will be a highly sustainable environment to learn in and to learn from.

To achieve the highest level of building performance, a mechanical ventilation heat recovery (MVHR) system will be installed. This will ensure fresh air is always circulated whilst maintaining a tight building envelope. The cost of running the system is paid back through energy savings.

The Embodied Carbon (EC) will be very low compared with the standard model by mainly utilising timber products for the frame and internal elements. It should be noted that timber EC varies considerably depending upon the extraction and manufacturing methods, transport, and to a certain extent the tree species. Some EC systems include carbon sequestered during the tree's lifespan which means timber can come out as net positive carbon (i.e. it removes more carbon from the atmosphere during its lifetime than is released during processing). In addition, one of the benefits of using timber as a product in terms of EC is that the carbon sequestered by the tree over its lifespan is temporarily locked into the building instead of being released if the tree were to decompose in-situ.

How it changed from the previous model

- Increased renewables and energy efficiency technology
- Lower EC and plans to off-set any remaining EC
- Highest performing building envelope

Methodology and methods

The process

01 Set up working group and determine strategy

A working group was formed, bringing together experts from different aspects of construction; including client, architects, engineers, quantity surveyors, and sustainability. The group set parameters for the project.

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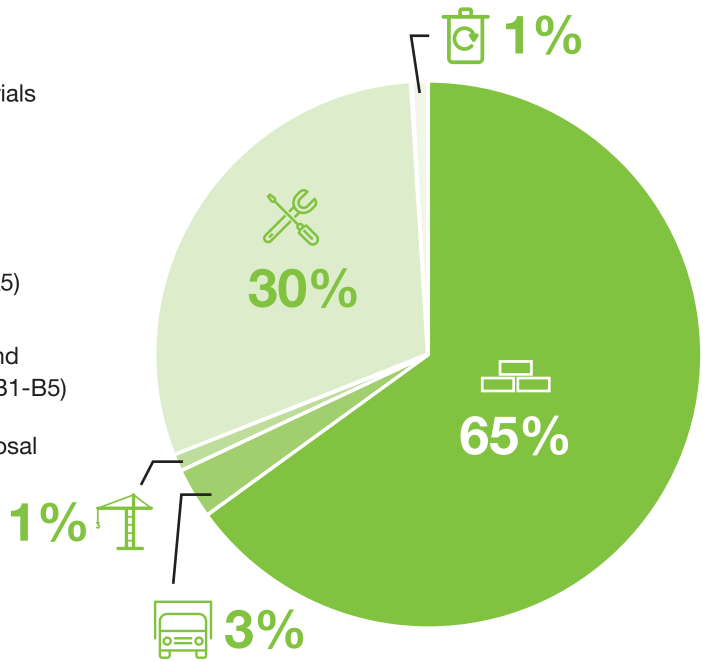
02 Create sustainability framework and set targets

Carbon isn't the only driver and sustainability representatives from ISG construction developed a "Sustainability Framework" to aid the working group. This framework included methodologies for carbon neutrality, materials, waste, health and well-being, water efficiency, ecology, social value and in-use performance. Supplementing this framework and to help set targets for energy efficiency and embodied carbon, the project also utilised the "LETI Climate Emergency Design Guide" (further details of specific targets are highlighted in the project section below).

Embodied carbon

Focus on reducing embodied carbon for the largest uses:

- Products/materials (A1-A3)
- Transport (A4)
- Construction (A5)
- Maintenance and replacements (B1-B5)
- End of life disposal (C1-C4)



Average split of embodied carbon per building element:

30%	Superstructure
21%	Internal finishes
16%	Substructure
16%	Façade
13%	MEP

Reduce embodied carbon by 40% or to:

<600 KgCo²/m²

Area in GIA

03 Examine baseline (Agilis) model

The “Agilis” primary model was used to baseline impacts and identify areas for improvement.

04 Create smart design

The “net-zero carbon” (NZC) school model was used as the operational carbon baseline. The design used Building Bulletin recommendations for classroom and facilities sizing.

05 Model in-use energy performance and plan for renewables

The potential energy performance of the net-zero carbon design against Part L compliant and BREEAM Excellent models (latter is equivalent to "Agilis" model) was developed. A target was set for the NZC model that 'it must produce net operational CO_2 emission of less than or equal to 0 kg.CO_2 per annum'. To achieve this the design team first assessed the optimum building orientation using the IES Virtual Environment 2019 software. The team utilised passive design principles to optimise the building fabric, then energy efficient technologies and options for renewable technologies were considered. The modelling proves the NZC target is achievable. (The results are displayed below.) The team also tested the building model against climate change scenarios to predict and reduce the risk of overheating in future.

Simulation type	Walls U value (W/(m2.K)	Roof U value (W/(m2.K)	Floor U value (W/(m2.K)	Glazing & doors U value (W/(m2.K)	Glazing G value	Air permeability (m^3/ ($h.m^2$)@50Pa)
Part L compliant	0.25	0.20	0.20	1.60	0.40	5.0
BREEAM Excellent compliant	0.18	0.16	0.16	1.40	0.40	4.0
Zero carbon model	0.12	0.12	0.12	1.00	0.40	1.0

The building services assumptions for the assesment are listed below

Simulation type	Space heating	Ventilation	Domestic hot water
Part L compliant	Gas mounted boilers with wall mounted raidiators	Natural ventilation provided by openable windows	Gas fired boilers with calorifiers
BREEAM Excellent compliant	Gas mounted boilers with wall mounted raidiators	Natural ventilation provided by openable windows	Gas fired boilers with calorifiers
Zero carbon model	Air source heat pumps with underfloor heating	Mechanical ventilation with heat recovery	Instantaneous electric point of use water heaters

The building services assumptions for the assesment are listed below

Simulation type	Renewable technology	Orientation	Incline from horizontal (°)	Array rating (kWp)	W per panel (1m x 1.6m)	Quantity of PV panels (m^2)*	Estimated output (kWh / annum)
Part L compliant	Photovoltaic (PV) panels	South	20°	1.9	300	10	1,716
BREEAM Excellent compliant	Photovoltaic (PV) panels	South	20°	0.9	300	5	858
Zero carbon model	Photovoltaic (PV) panels	South	20°	13.1	300	70	12,009

* Note: PV panel is estimated and is shown to allow context only. kWp array rating should be utilised.

Dynamic Simluation Model (DSM) Results

Simulation type	Total energy consumption (kWh / annum)	Total energy generated (kWh / annum)	Net operational energy (kWh / annum)	Mains electricity carbon factor UK Gov. 2019	Net CO2 (kg. CO2)
Zero carbon model	13,229.1	14,413.2	-1184.1	0.2773	-328.35

06 Investigate embodied carbon of materials

Four material scenarios were created, each of these scenarios was modelled for embodied carbon using the One Click software. Some materials did not have local options available on the software and so a best-fit approach was used. This did have an impact upon results, but wider EC data was used as a sense-check; including the ICE database (Bath University). The material scenarios were revised based upon the results and wider factors like local availability, durability and end-of-life disposability.

1. Agilis Model (Standard / Baseline)

Roof	Standing seam
Structure	Steel frame
External	Brick façade or metal cladding*
Internal	Concrete Blockwork
Insulation	Rockwool
Windows and doors	Aluminium

*cladding shown on HLM drawing for nursery (primaries have brick)

2. Welsh Focus

Roof	Slate tile
Structure	Steel frame*
External	Brick façade
Internal	Concrete Blockwork
Insulation	Sheeps wool
Windows and doors	Timber

3. Timber Focus

Roof	Clay pantile
Structure	Timber frame
External	Timber cladding*
Internal	Timber Cassette
Insulation	Cellulose
Windows and doors	Timber

4. Green (/Sequestration) Focus

Roof	Green roof
Structure	Timber frame
External	Lime render
Internal	Adobe* or hemp blocks
Insulation	Hempcrete**
Windows and doors	Timber

*strocks (cob bricks) one option for adobe
**sprayed or blocks

07 Scope costings

The different material scenarios were appraised to provide estimated costs per m² for each option, against carbon. Individual elements within the material scenarios were discussed to see where savings could be made.

08 Revise design and materials

The building design and materials were re-examined to identify any further savings to carbon or cost (repeating steps 4-7). In the initial design, a winter garden option was explored; this would be a glass-fronted area adjacent to the classrooms which could be used for play and learning all year round. After considerations of cost and reducing high carbon materials (glass), this element was removed but may be worth exploring in future projects. A simplified form was progressed.

Further changes were made to the materials which included some compromises between lowest carbon impact and cost. Overall, the model will utilise materials scenario 3 (Timber focus) with a standing seam roof. These materials have the lowest EC within cost/m² budget and have a suitable track record within the industry with proven maintenance performance.

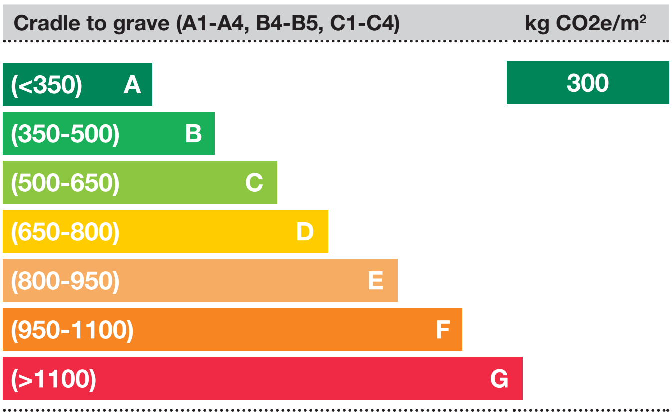
Roof	Standing Seam Roof
Structure	Timber frame
External	Timber cladding
Internal	Timber Cassette
Insulation	Cellulose
Windows and doors	Timber/ Aluminium composite

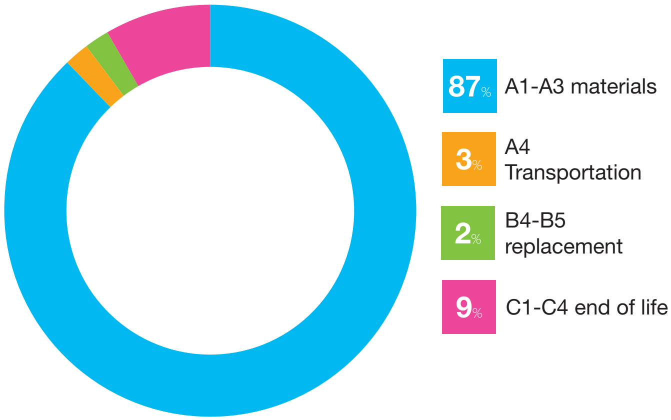
09 Scope costings

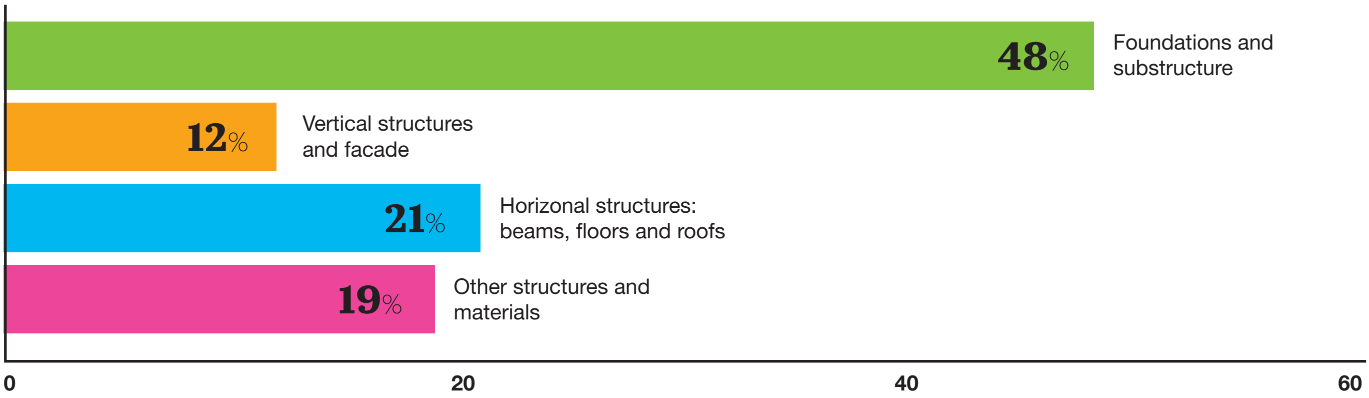
The team agreed the final design and explored procurement options; including options to procure local Welsh manufactured materials and products

The team have also used these principles and modelled them as a desk top exercise against the Llancarfan design which has given the following results.
One Click modelling – Potential to achieve a 47.46% improvement in comparison to the Leti guidance of 40% this is 271kg CO_2e/m^2

Llancarfan Net-zero operational and low embodied carbon

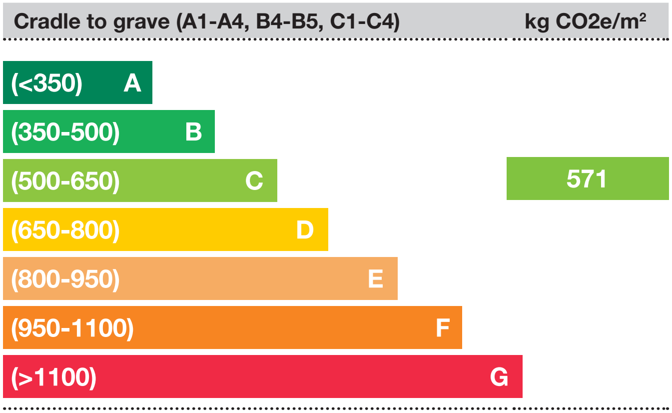


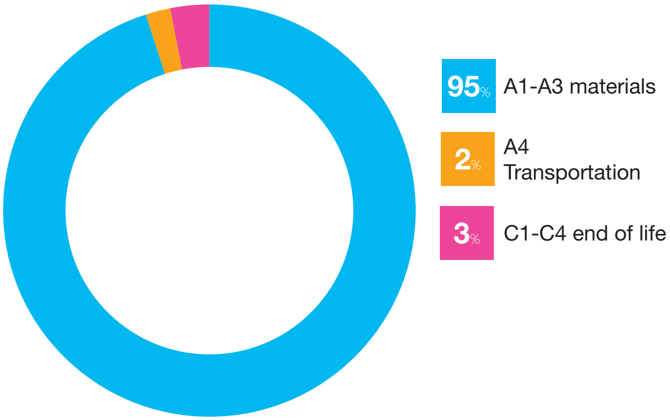


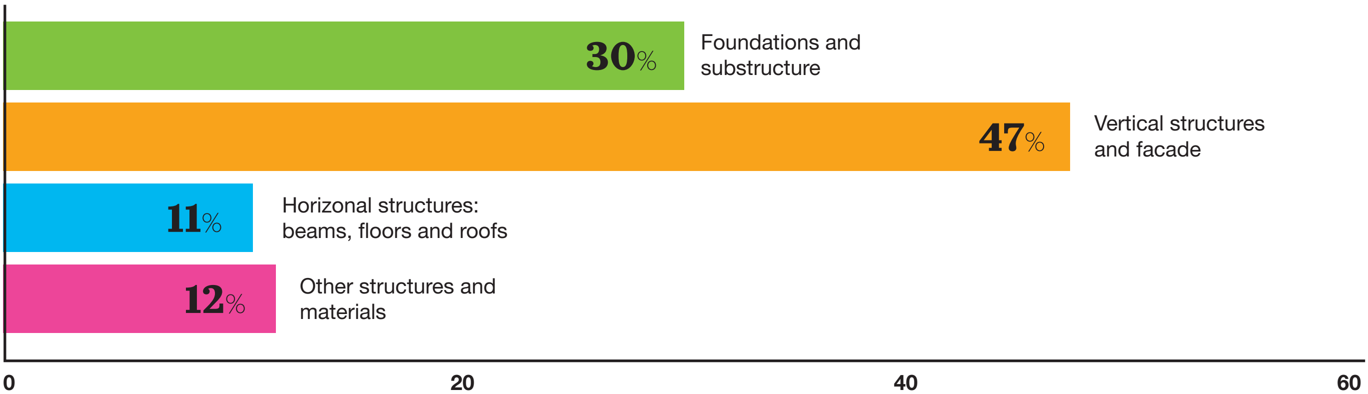


The modelling to date has predominantly focused on key building materials within the sub and super structure. As the design matures further, more detailed analysis will be undertaken including MEP, FFE and construction operations will become considerations.

Llancarfan VoG standard Design







The journey

Ysgol Nant Talwg

- Band A
- Completed in 2014
- 1st standard design
- BREEAM Excellent
- Sprinklers
- £1,981.52 m² (limited externals)
- £2,762.24 Q3 2020

St Davids

- Band B
- Commenced September 2020
- Low carbon
- BREEAM Excellent
- Sprinklers
- £3,025.24 m²

Llancarfan

- Band B
- Commenced November 2020
- Net-zero carbon in operation
- BREEAM Excellent
- Sprinklers
- £3,437.92 m² (limited externals)

Llancarfan model project

- Net-zero carbon in operation
- Low embodied carbon
- BREEAM Excellent
- Sprinklers
- £3,827.44 m² (limited externals)

Cost implications

Llancarfan

Baseline design compliant with current building regulations, gas fired boilers with limited PV renewables.

£4,562,199.60 = £3,112/ m^2 gifa

Llancarfan - net-zero (in use) carbon

This is an uplift cost of 9.48% which is invested in renewable technology and improved building fabric performance.

£5,040,000 = £3,437.92/ m^2 gifa

Llancarfan (desktop modelled solution)– net-zero (in use) carbon and low embodied carbon approach

This is a further uplift cost of 11.33%.

£5,611,032 = £3,827.44/ m^2 gifa

The project cost figures are an all-inclusive figure which includes all client costs, FF&E, ICT, externals and abnormals.

What worked well?

- Collaboration enabled a wider range of factors to be considered and cross-examined against different elements of construction.
- Setting targets early informed the whole approach and avoided costly changes to design or compromises later in the process.
- Useful to have industry standards such as LETI and UKGBC guidance to use as a framework.

What lessons can be learnt?

- As this is approach is new to the industry, not all of the material options were available to investigate on the One Click software due to lack of EPD'S. Finding a local option was sometimes difficult and so this impacted results; for example, sheeps wool insulation had a higher EC than expected as no Welsh option was available when it is known as an abundant local material. This means the EC data needs to be carefully analysed considering this caveat, but this should become less of a drawback as further data is added to the software and the design is progressed.
- Compromises continue to be challenge between design, carbon and cost.

Next steps

- The project team will continue to develop the model to maximise the positive social, environmental and economic impacts, particularly decarbonisation. Carbon emissions will be modelled and monitored throughout the construction and in-use stages.
- We must ensure end users on the same journey and that pupils are involved in the development.
- Further work on embodied carbon will need to be undertaken with the industry, universities and the supply chain.
- We must work collectively to eliminate the performance gap by constant monitoring of the project in all aspects including design, procurement and construction.
- Post Project evaluation must be comprehensively undertaken and continued for 5 years.
- The final models will be scaled for use in future projects. The team will encourage learning from these projects to be embedded in wider 21st Century Schools and public infrastructure programmes.

For further detail please contact
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Thank you to all our partners for their collaboration and contributions