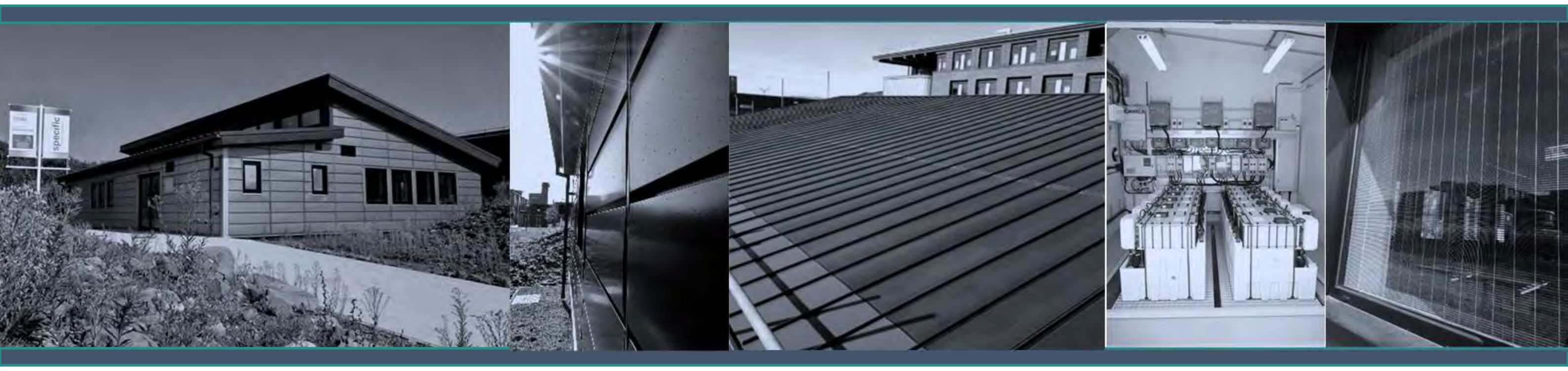
Active Classroom Case Study

Version 2.0, October 2020



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Editorial Note

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Introduction

SPECIFIC is a national Innovation and Knowledge Centre (IKC), led by Swansea University, with three main Industrial partners - Tata Steel, NSG and Akzo Nobel - established in 2011 to investigate the concept of turning buildings into power stations using solar energy to functionalise building envelopes. There are a number of different research groups within SPECIFIC, investigating functional coatings and storage solutions, such as the next generation of printable photovoltaics; a conductive coating to form a resistive heating system; and novel thermal storage solutions. Whilst these technologies are in their development stage, another group is concerned with how renewable energy technologies can be integrated into buildings. To aid this investigation, they have constructed several demonstrator buildings using a mix of pre-commercial and commercially available technologies, to achieve the energy positive philosophy. These are known as **'Active Buildings'**, defined as environmentally responsive buildings which ***"support the energy network by intelligently integrating renewable energy technologies for heat, power and transport."***

The Active Classroom, shown in Figure 1 below, was constructed in 2016 to demonstrate this concept at the British Science Festival which Swansea University hosted that year. The main purposes of the building were to:

1. Demonstrate novel technologies and products either developed at SPECIFIC or by industrial partners;
2. Be energy positive, generating more energy than it needs over an annual cycle;
3. Be designed with net zero considerations, such as use of low embodied carbon, recycled or recyclable materials wherever possible, use of local supply chains, inclusion of biodiversity elements;
4. Act as a tool for teaching the Active Building concept to others (companies, students, government bodies and construction industry stakeholders);
5. Be used for its intended purpose, i.e. for teaching;
6. Be used as a test-bed for new technologies as they developed, which could be retrofitted to the building, as well as enabling the team at SPECIFIC to develop building control systems for Active Buildings.
7. Generate and analyse data on energy use.

Figure 1: The Active Classroom, 2016

NOTE: It is important to note that the purpose of this building was to demonstrate a concept, rather than promoting individual technologies. The technologies demonstrated in this building were innovative and current at the time of designing and constructing the building (2016), but technology is rapidly evolving. Therefore, at the time of reading this document, it is possible that some of the technologies will be out-of-date. It is also likely that there are now better ways of connecting the technologies and generating data. This case study represents a snapshot in time.

Site Location

The Active Classroom is located on Swansea University's 65-acre Science and Innovation Campus, on the eastern approach into Swansea, approximately 200m from an accessible beach within Swansea Bay, as shown in Figure 2 below. The former BP transit site is located within an exposed, coastal area, experiencing, sometimes strong, south westerly winds, which carry salt water from the nearby sea. The site is adjacent to a Site of Special Scientific Interest (SSSI), known as Crymlyn Burrows, which sits to the East of the building. To the North and South are large engineering buildings and to the West, a landscaped area.

Figure 2: Aerial View of Swansea University's Bay Campus

Crymlyn Burrows is of national importance for its wildlife and as such has been designated a Site of Special Scientific Interest (SSSI). It is owned by Swansea University, who are responsible for ensuring its protection into the future. The university employs a Biodiversity Officer to look after the SSSI, and to ensure that everyone plays their part in looking after it. During the design of the Active classroom, the Biodiversity Officer was consulted to ensure that the building had no adverse effect on the site, respecting the landscaping strategy adopted on the campus, which was developed to protect the SSSI.

In designing the building, it was also important to take into consideration the fact that the building would occupy an area of landscape that had originally formed part of the scheme for the adjacent Energy Safety Research Institute (ESRI), for which the surrounding landscape contributed to their Building Research Establishment Environmental Assessment Method (BREEAM) Outstanding rating. We therefore worked closely with the Architects of that building and Swansea University's Estates department to develop a scheme which wouldn't detract from this rating. This was also important for the planning application.

Introduction

Design and Delivery of the Building Project

This document outlines the key decisions that were made at each of the RIBA Plan of Work stages, which most building projects follow in terms of the approximate order work is carried out in and when key decisions should be made. For this project, some of the work stages were undertaken in a slightly different order, due to the experimental nature of the building, as highlighted in Table 1 below. For example, the off-site panel system selected for use as the main superstructure of the building had to be ordered 4 months into the project, during Stage 3, prior to receiving planning consent. This is a risk that most clients would not be willing to take on a project and construction contracts would not normally be procured until the end of Stage 4. Also, the decision was made to build a demonstration building prior to identifying a suitable site for the demonstrator.

Table 1 below lists the key activities for this project and when they took place, alongside the RIBA work stages, highlighting that projects cannot always follow a linear path. The table also shows that applications for funding were being made throughout the process, as not all the funding sources had been identified prior to commencing the project, which again is not typical.

2016	Key Activities	RIBA Stage
January	Made decision to build a classroom to showcase during the British Science Festival which Swansea University was hosting in September 2016	0
	First engagement with Acermetric and Matrix Structures	3-4
February	Commenced discussions with BIPVCo	3-4
	Identified a suitable location for the building	0
	Commenced discussions with Local Planning Authority	0-1
	Commenced engagement with AECOM for Mechanical, Electrical & Plumbing (MEP) design	2-3
March	Commenced discussions with Landscape Architect	3
	Commenced engagement with Moixa, re: inclusion of their innovative Maslow battery	4
	Applied for an Impact Acceleration Award (IAA) to enable engagement with Moixa	3-4
	Commenced discussions with a Structural Engineer on use of screw piles	3-4
April	Contacted Solarplants re: potential battery solutions	3-4
	Commenced discussions with Tata, re: Cladding solutions	3-4
	Submitted Planning Application	3
	Applied for an IAA to work with Matrix to integrate heated floor	3-4
	Placed order for superstructure with Matrix Structures	4-5
May	Engaged with a Cost Consultant	2
	Placed order for windows with Vellacine	5
	Placed order with IPS Roofing for cladding and BIPV installation	5
	Arranged first meeting with Main Contractor, Kier	4-5
	Planning consent granted	3-4
	Submitted Building Control Application	4
June	Arranged first design co-ordination meeting with all contractors	4-5
	Construction commenced	5
July	Construction Period	5
August	Classroom superstructure was deconstructed and re-assembled	5
September	British Science Festival, including school visit, media coverage, and presentations	6
	Classroom construction completed	6
September 2016 - present	Ongoing Building Performance Evaluation (BPE) through monitoring of sensors, thermography and air-tightness testing	7

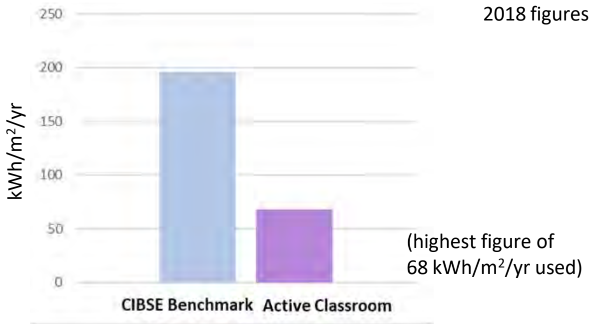
Table 1: Key Activities related to dates and RIBA Stages

Active Classroom Summary

The following illustrates the Case Study for the Active Classroom in the style of the case studies used in the *'Buildings Mission 2030'* Report, produced by the Construction Leadership Council (CLC) and the Green Construction Board (GCB) in April 2019, containing the same information for comparison. The energy benchmark for primary schools used, taken from CIBSE Guide F 'typical practice', was 196 kWh/m^2/yr and they collected data on schools using ≤ 98 kWh/m^2/yr .

Location:	**Swansea**
Year of completion	**2016**
Floor area	**186m^2**
Approximate occupancy (for 40 people)	**4.65m^2/person**
Client occupier?	**Yes**
Contractual performance target	**Yes**
Design prediction of energy performance	**Yes**

Energy consumption	**68 kWh/m²/yr**
Energy generation	**25 kWh/m²/yr**
Net energy consumption	**43 kWh/m²/yr**
Annual carbon emissions	**21 (design stage)**



Approximate form factor	**3.35**	External envelope area/floor area (if ground bearing slab = 2.32)
Quality assurance during construction?	**No**	New construction system used
After care and post occupancy monitoring?	**Yes**	Enabled via extensive metering of circuits
Envelope performance	Walls: 0.15W/m^{2}K Roof: 0.15W/m^{2}K Floor: 0.15W/m^{2}K	Design figures
Heating system description	**Electric**	Solar thermal with ASHP + MVHR, dissipated through AHUs + electric underfloor heating
Hot water generation description	**Electric**	Solar thermal, ASHP and immersion heater
Main ventilation type	**Natural**	Openable windows
Other information	The aim of the building was to generate more energy than it consumes over an annual period. Extensive metering is in place to monitor performance, identify issues and enable optimisation of systems	

Active Classroom Overview

The Active Classroom was designed to satisfy the criteria for an Active Building, combining the Active Building principles in one building, as illustrated in Figure 3 below.

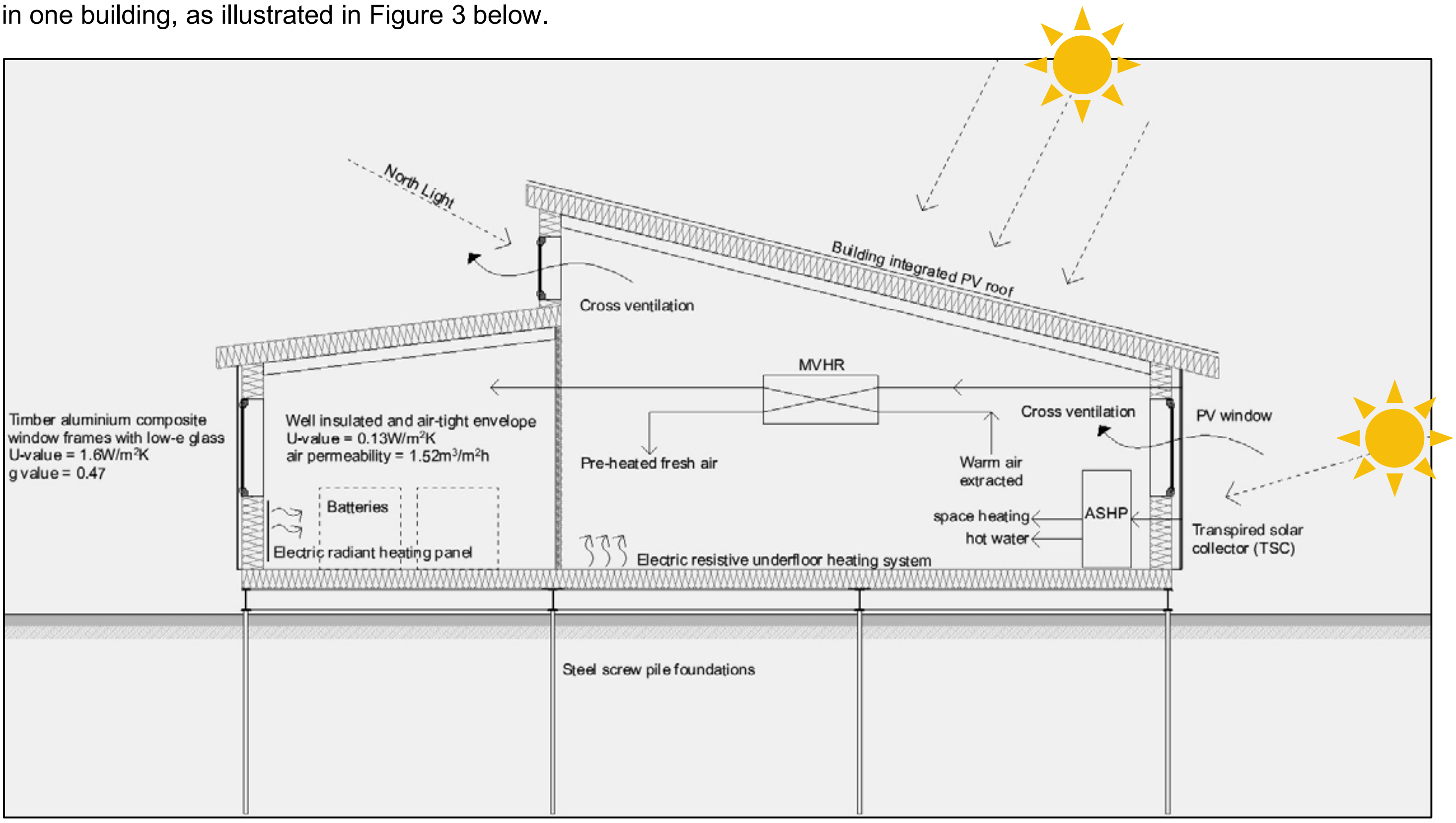


Figure 3: Section showing Active Classroom Overview

Key components:

- Lightweight construction on steel screw piles – suitable for a temporary building and for fast erection
- Offsite panel construction – for speed, less waste, greater precision of build, better quality construction
- Designed for deconstruction – screw piles can be removed and re-used, the panels can be taken apart and re-used
- Thermally efficient building envelope
- South facing aspect – enabling solar energy generation on roof and south elevation, using PV to generate electricity and a solar air collector for space heating and hot water
- Energy storage included to enable control of import and export of energy to and from the building
- Electric heating system (no gas connection)

January 2016

0 Strategic Definition

Active Building Objectives:

- Define Active Building requirements, including key principles
- Set clear objectives for Project Delivery Team (PDT)
- Identify key stakeholders, e.g. building owners, occupiers, facilities management team (FMT)
- Review data and lessons learnt from previous Active Building projects to inform PDT
- Ensure inclusion of Active Building elements and robust data collection are included in contractual documents

Project Definition

Client: College of Engineering, Swansea University.

Core Objective: To design and construct a demonstration building to showcase innovative technologies being developed by SPECIFIC and their industry partners.

Key Priorities/goals: The building must:

- Generate more energy than it consumes over an annual cycle
- Use innovative products and technologies
- Be completed by September 2016 to showcase during the British Science Festival (BSF)

Building Type and Purpose:

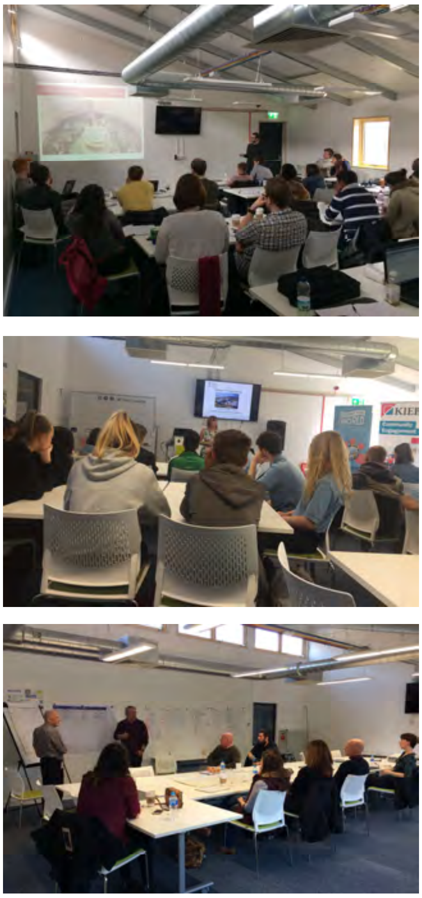


Figure 4: Active Classroom in use

The initial idea for the BSF showcase was to build a house. However, the decision was made to build a classroom for two main reasons:

1. A house would not be lived in, so any data collected would be meaningless.
2. The building would be located somewhere on the university campus, which was lacking in small teaching spaces. A self-contained classroom building would ensure the demonstration building was used for its intended purpose and would solve a problem the university had. It would be used by the following groups within Swansea University:

SPECIFIC

- To test and evaluate different technologies
- To demonstrate the Active Building concept to stakeholder groups – construction industry, developers, government departments, educational establishments
- To host innovation visits, showing visitors technologies working in practice
- To host events with partners
- As a meeting space

Materials and Manufacturing Academy (M2A)

- For teaching Engineering Doctorate students

Materials and Manufacturing Education Training and Learning (Metal) Project

- For teaching work-based learning courses
- For holding taster sessions for courses

Swansea University Sustainability Team

- For meetings

0 Strategic Definition

Process: In order to design and deliver the building in such a short space of time, a suitable construction method was established at this early stage in the design process – a system that could be designed, procured and delivered in 9 months. An obvious solution was to use a system manufactured off-site in a factory.

One of SPECIFIC's main industrial partners is Tata Steel, who have an Open Innovation Portal, established to enable them *"to collaborate with innovative people and organisations to help develop solutions to their current challenges and create new opportunities for the future."* To do this their aim is to explore new ways of working with others and identify the best ideas and technologies. The portal invites individuals or companies with ideas to submit them through their portal. Through this portal, they identified a small company, Acermetric, who had developed a steel-framed composite panel with a unique 3-D locking system that allows rapid construction (and de-construction) of the basic building frame. This was submitted around the time that we were developing ideas for the Active Classroom, so one of our contacts at Tata introduced us to the company, with the aim to evaluate the new panel in practice.

The high-risk decision to utilise this system (which had never been used on a building of this size before) was made by the SPECIFIC team and facilitated through Tata Steel – the aim being to assist the small company in establishing themselves in the construction industry and identifying ways to evolve their product to suit construction of projects of this nature.

Budget: Initially, we were allocated a small budget from the College of Engineering of £200,000. However, once the design started to take shape, it soon became apparent that this amount would need to be increased if the building was to meet the required criteria:

- a room big enough to teach 30 students
- ancillary spaces needed to support that number of students, i.e. toilets and refreshment area
- plant rooms to house battery storage and other mechanical and electrical equipment
- a foyer large enough to host groups of visitors
- use of innovative technologies

Fortunately, we were able to raise further funding from other sources:

- a demonstration fund (from WEFO as part of SPECIFIC's core funding), which funded:
  - The novel battery storage system
  - The resistive heating system
- a few EPSRC Impact Acceleration Awards, which funded:
  - A new battery from a UK company called Moixa
  - A Building Services Consultancy, AECOM
  - A project to combine SPECIFIC's resistive heating system with the construction panels
- some additional funding from the College of Engineering.

In addition, some of the materials were supplied at a discounted rate due to their experimental nature. These included:

- Steel cladding from Tata supplied at cost price
- The batteries
- Steel for the innovative construction system – supplied by Tata
- Expanded polystyrene (EPS) insulation for the panels from AkzoNobel
- Glass for the windows – free issue from NSG

NOTE: It was anticipated that this building would cost more than a standard classroom building of the same size, due to the innovative technologies and products, the timescales, and the additional metering needed for capturing data. These initial additional capital costs should be offset during the lifetime of the building through reductions in running costs. This will be investigated through undertaking Life Cycle Cost (LCC) comparisons.

1 Preparation and Briefing

Active Building Objectives:

- Develop feasibility study on proposed site(s) incorporating constraints – financial, site, other
- Develop high level data monitoring and performance specifications
- Arrange early stakeholder engagement sessions
- Identify options for renewable energy generation
- Identify potential energy storage solutions for heat and electricity

The developing brief

At this stage, we had decided to construct a classroom building to showcase new technologies developed by SPECIFIC and their Industry partners. We needed to progress swiftly to meet the ambitious programme. Immediate priorities were:

1. Construction system – we started liaising with Acermetric and Matrix Structures (the manufacturers of the novel panels)

2. Liaise with Swansea University Estates – to find a suitable site within the campus

3. Liaise with Local Authority Planning Department – to establish the possibility of constructing a demonstrator building on a site that already had a pre-developed masterplan. In addition, the site identified by Estates was a site that formed part of a landscaping plan for a building adjacent to the site (the Engineering Safety Research Institute (ESRI)), contributing to its Building Research Establishment Environmental Assessment Method (BREEAM) Outstanding status.

4. Landscaping – to ensure this building was not detrimental to the existing landscape scheme we liaised with the following people:
    - Landscape Architect for the adjacent ESRI building
    - Swansea University's Biodiversity Officer (also Warden of adjacent SSSI)
    - Local Authority Planning Officer

5. To determine who will use the building and how it will be used, Stakeholder meetings with M2A and the Metal Project were arranged to determine their needs.

6. To determine the purpose from SPECIFIC's point of view and establish what data SPECIFIC wanted to capture

7. To determine what innovative technologies should be specified for the building, starting with existing contacts:
    - BIPVCo (a spin-out company from Swansea University and Tata) roof
    - A novel battery system to be supplied through a local PV installer
    - SPECIFIC technologies – resistive heating system, thermochemical store?

8. Liaise with SPECIFIC Industry partners, to ensure they were involved and had an opportunity to trial their products:
    - Tata:
        - New coating just developed for their steel cladding (pre-commercial) – Colorcoat Prisma®
        - Transpired Solar Collector (TSC) – Colorcoat Renew SC®
        - Coretinium® wall cladding – magnetic, white board properties, ideal for classroom environments
    - NSG:
        - High performance glazing – Energikare™ Advantage
    - AkzoNobel:
        - EPS insulation (already specified in Matrix panels)
        - Special coatings

2 Concept Design

February – March 2016

Active Building Objectives:

- Develop simple massing and initial energy model on early design scheme(s)
- Report on early design recommendations to enable inclusion of Active Building elements
- Provide information to support early Life Cycle Costing (LCC) assessment
- Collate information on Active Building technologies to support Design and Access Statement (DAS) for planning
- Undertake initial Life Cycle Assessment (LCA) – carbon
- From site analysis, identify optimum site position for building in relation to site features and energy generation
- Use outputs from energy model to determine optimum size of energy storage systems
- Determine electricity network connection locations and positioning of data hub

Site considerations

Building Position on site:

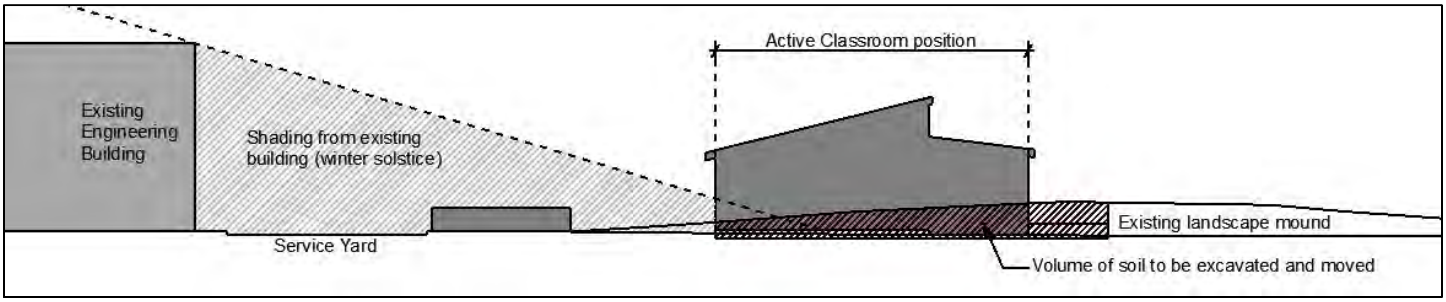


Figure 5: Cross section through site

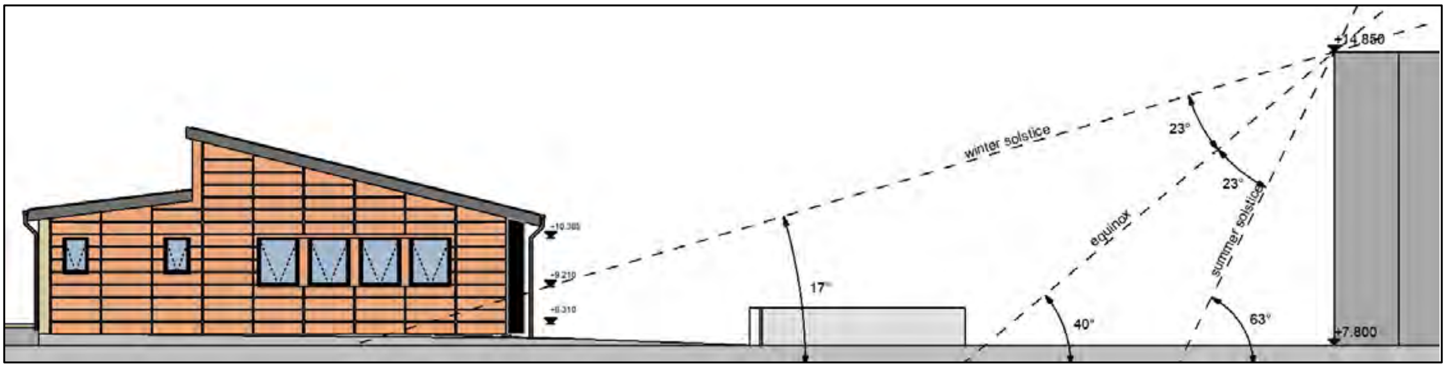


Figure 6: Section exploring potential façade shading

These sketches show the balancing exercise undertaken to position the building at the optimum distance from other buildings to minimise shading of the south elevation and to minimise the amount of excavated material to be taken off site. Excavating and removing soil from construction sites is expensive and generates carbon emissions, so should be minimised where possible.

Site Constraints Checklist

Constraint	Yes	No	Comments
South Facing Orientation possible	✓		
Shading:			
Partial	✓		Shading to lower part of S elevation during winter months
Full			
None			
Shading type:			
Other building(s)	✓		
Deciduous vegetation			
Evergreen vegetation			
Space for electric vehicle (EV) parking	✓		
Space for E-bike shelter		✓	

2 Concept Design

Site Analysis

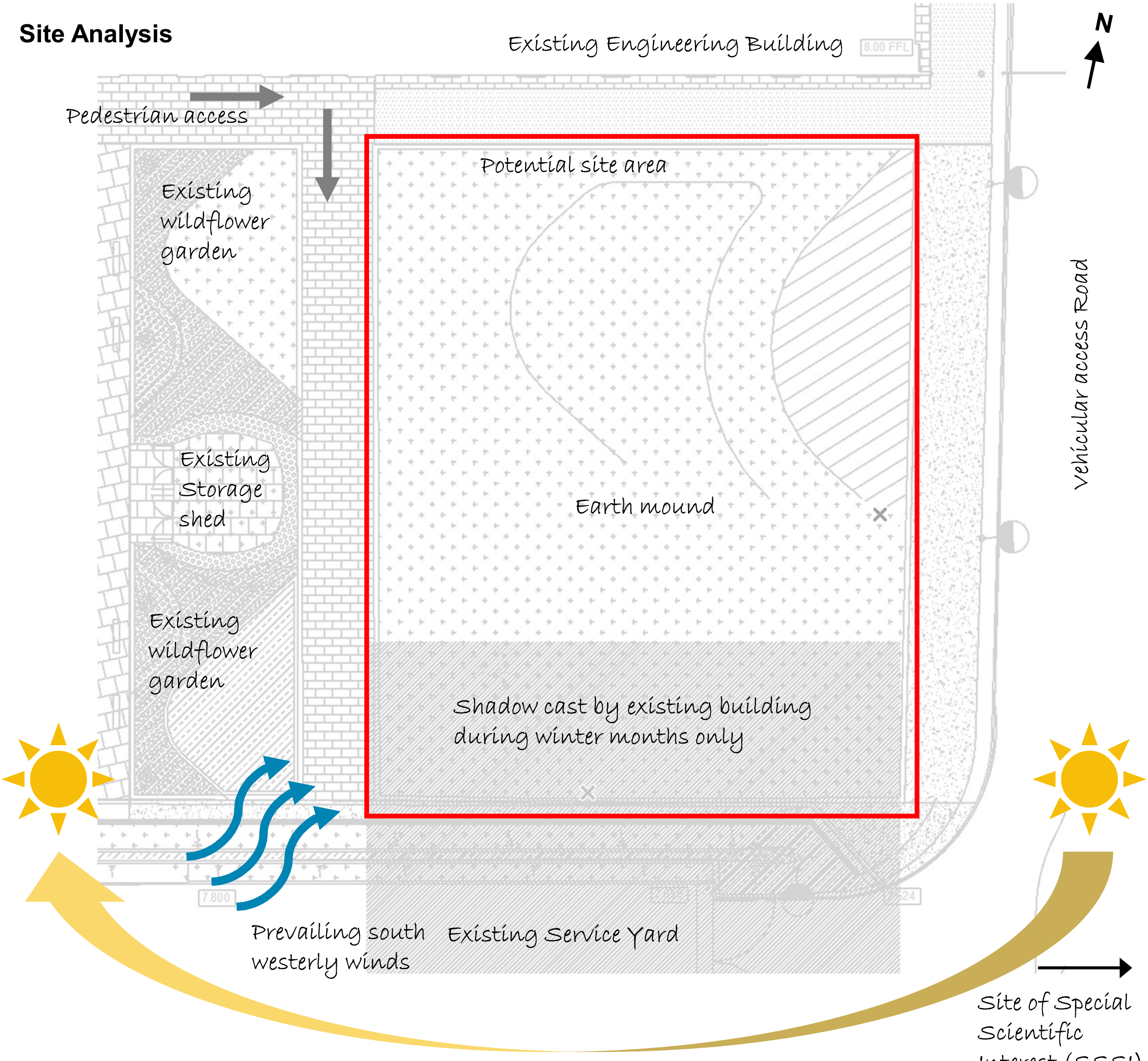


Figure 7: Site Analysis for the Active Classroom

Figure 8: Photos of the existing site

Early design considerations

Offsite Panel System

As the programme for this project was so ambitious and in line with our goals to demonstrate emerging products and technologies, we decided to use the offsite panel system manufactured by Matrix as the main construction method. This enabled us to design the building to the panel dimensions from the outset, avoiding any redesign work later on in the programme.

The main design parameters had been set at this stage, i.e. the need to provide a classroom for up to 30 students, with ancillary accommodation including toilets and a small kitchen space. We also knew that there would need to be a large enough plant room to house the battery system. The plan below shows the layout designed to the panel dimensions.

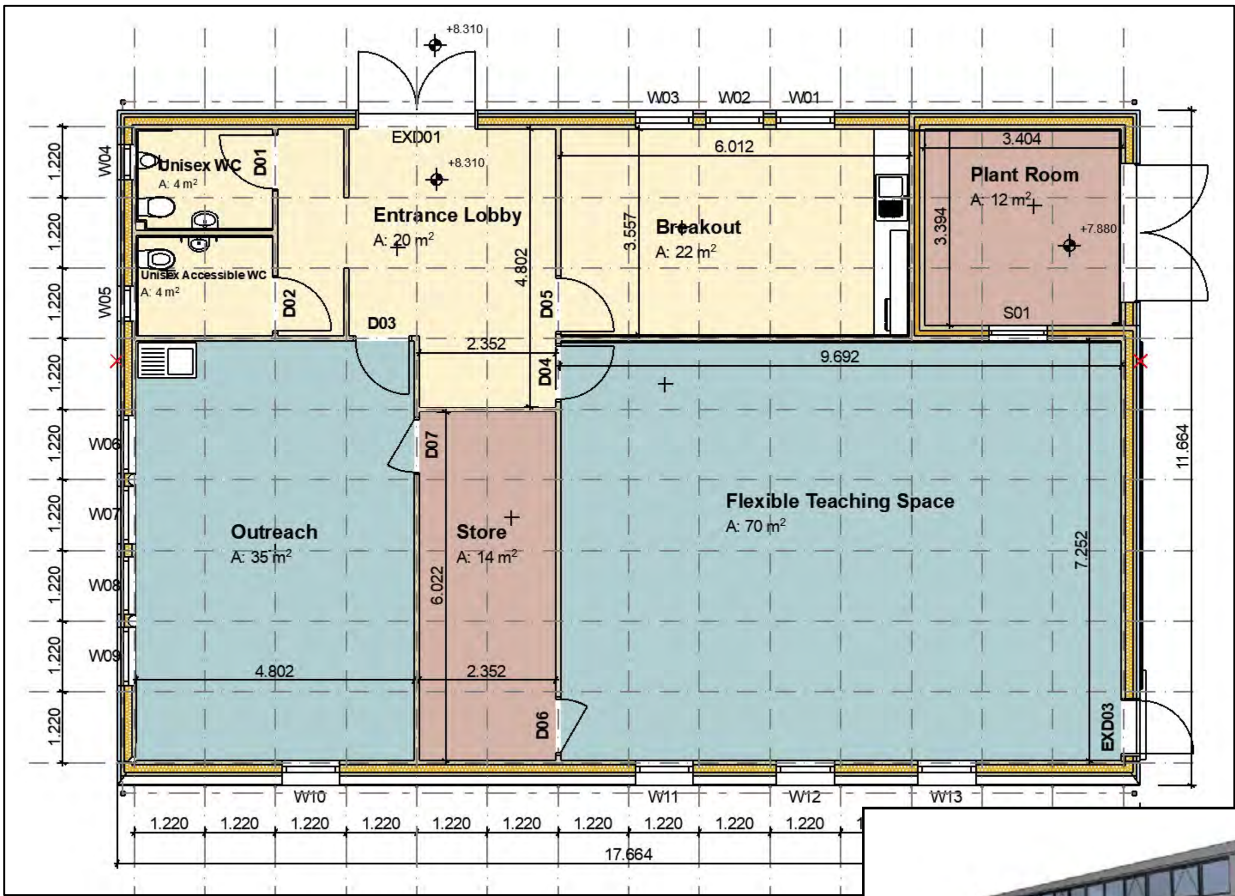


Figure 11: Plan of the Active Classroom

Questions for Matrix/Acermetric

- Is this achievable within the timescale?
  - Yes.
- Is it possible to design their system to a U-value of 0.15W/m^{2}K?
  - Yes, using a cavity wall construction for the external walls consisting of two panels with insulation between.
- Can they build to the initial design?
  - Yes.
- Can the system accommodate continuous strip windows?
  - Originally yes – see Figure 12.

The initial design utilised continuous strip windows, which the supplier thought would be possible. However, it was later determined that this was not possible within the system, so the windows were redesigned so that each window fitted into one panel.

Figure 12: Window design development

2 Concept Design

Other considerations during this stage included:

- Should we incorporate rainwater harvesting?
    - Taking advice from the drainage engineer – no. It would be too expensive and energy intensive to make it worthwhile for a building of this size. Rainwater harvesting systems incorporate pumps and treatment of water before water captured can be used within the building. This can be cost prohibitive, particularly when the site is adjacent to a mains water supply and has minimal anticipated water usage.
    - A simple rainwater butt would be installed to capture rainwater for landscape irrigation and external window cleaning.

- Stakeholder meetings:
    - Main building users:
        - M2A
        - Project Metal
        - SPECIFIC
    - Swansea University Estates:
        - Project Officer
        - Facilities Management Team
        - Sustainability Team

- Planning constraints:
    - The site selected was intended for another building in the original campus masterplan.
    - Timescale – the planning process would need to be accelerated.
    - The site was currently landscaped to satisfy the BREEAM requirements of an adjacent building, ESRI.

- Design for deconstruction:
    - Foundation type – we specified steel screw piles, which the structural engineer, once appointed, designed.
    - The panel system itself could be dismantled.
    - Minimise materials, e.g. no suspended ceilings.

- Which items have a long lead-in time (i.e. need to be ordered early)?
    - Windows – need to choose a window type that minimise thermal bridging and maintain thermally efficient envelope, ideally provided by a Welsh supplier. A hybrid timber-aluminium composite window system was selected.
    - BIPV roof, as it would need to be manufactured bespoke for this building and was the first roof to be manufactured by BIPVCo.
    - The Acermetric/Matrix panel system.

- What other low carbon or sustainable design features could we incorporate into the project?
    - Recycled plastic product for use as kitchen worktop, possibly as wall cladding in the toilets.
    - Biodiversity element – green roof, living wall?
    - Re-use of materials from other decommissioned Swansea University buildings, e.g. carpet tiles

Active Building Objectives:

- Use evidence from concept model to determine renewable energy generation options
- Identify predicted energy loads versus generation capacity
- Develop an energy strategy
- Develop performance specifications
- Design for adaptability – both spatially and in terms of building services
- Establish energy storage capacity required, including spatial requirements for storage and associated systems
- Start developing software to enable communication between the BMS and the grid
- Ensure tendering contractors understand the Active Building concept and how to apply the concept

During this stage, we submitted a Planning Application, following pre-application discussions with the Planning Officer and his recommendations on the most appropriate route: temporary planning consent for up to 5-years, due to the nature of the existing planning consent for the campus and to expedite the planning process.

Some of the systems being used had to be procured earlier than usual for a construction project, due to the compressed timescales. This included: the building system (Acermetric/Matrix Structures), the windows (Vellacine) and the cladding, including the BIPVCo roof (IPS Roofing).

Building Fabric

General

The superstructure is constructed using novel, lightweight, factory-made panels, designed by a company called Acermetric; manufactured and installed by a company called Matrix Structures. These panels consist of a lightweight frame manufactured using 1.5mm gauge galvanised steel and packed with 68mm of expanded polystyrene (EPS) insulation, with one layer of 9mm magnesium oxide (MgO) board either side of the frame, forming the panel surface, combined into 86mm thick sandwich panels. The panels interlock and are locked together with one tool, forming a rigid structure for the building. Once the structure has been erected and locked together, all frame junctions are sealed with insulating tape and strips of MgO board fitted to cover each joint. This ensures air permeability levels are achieved and provides the required level of fire integrity. The building was designed to achieve a minimum U-value of $0.15W/m^2K$ for the whole building envelope (although an in-situ thermographic survey carried out indicates this was not achieved in practice - refer to Stage 7: In Use).

The building was designed to an air permeability of $3.09m^3/m^2h$ at 50Pa, but an in-situ air test confirmed that the actual air permeability is $1.52m^3/m^2h$, which can be attributed to the sealing between panels.

The panelised system is flat-pack offering the many advantages of offsite construction (quality control, less disruption by weather, reduced environmental impact on-site), while avoiding the disadvantages of other modular construction technologies that fabricate entire modules or buildings offsite which are then transported to site on a lorry, transporting a lot of air also. The flat-pack technology results in efficient transport to site, as well as opening up export opportunities that are not available with other modular systems. This is significant when considering the Whole Life Carbon (WLC) and Life Cycle Assessment (LCA) of a building, which include site operations and transport.

External Walls

The external walls consist of two skins of the Acermetric composite panels with a 94mm cavity between, fully filled with mineral wool insulation, giving a total thickness of 266mm. Externally the panels are clad using Tata Trisobuild® WP40 Colorcoat Prisma® coated steel cladding planks, fixed to galvanised steel top hat sections secured to the panels. These top hat sections are 100mm deep on the south elevation (to provide enough cavity depth for the transpired solar collectors (TSCs)) and 30mm deep on all other elevations. Internally, the panels are simply painted, leaving the joints between visible. For a more 'finished' appearance these could be plastered as is common practice in buildings, although plastering adds more materials (hence more carbon) and more site operations.

3 Spatial Coordination

Living Wall

A large proportion of the east elevation is clad with a living wall system, to help promote biodiversity in the built environment. This utilises a system designed and developed by a company called Treebox – 'Easiwall-Pro'. Features include:

- Manufactured in the UK from 80% recycled materials
- 100% recyclable
- Modular design with vertical planting troughs attached to a solid back panel. This provides the necessary rigidity and waterproofing enabling it to be used as cladding on buildings in place of other façades.

The panels were supplied as 1.0 x 2.0m units and incorporate an automated irrigation system, controlled via the Building Management System (BMS). The planting troughs are filled with a green roof derived substrate mixture, which is ideal for the mix of native coastal plants used.

As discussed in the introduction, the site is adjacent to a SSSI of which Swansea University's Biodiversity Officer is the Warden. We worked closely with the Biodiversity Officer to establish a list of suitable plants to grow in the wall and then grew the plants from seed. All the plants are native species, present in the adjacent SSSI and the coastal areas of Wales. During the build, we also arranged for groups of local school children to collect seeds from the verges around the campus to scatter in the living wall. Since completion, some of the plants have been transplanted around the campus to boost the decreasing number of certain species in the area, such as Sea Stock.

The wall provides a visual feature elevation and has helped engage people with the building, highlighting the connection between the built and natural environment. It has been particularly successful in helping to engage young people in the built environment and the work being undertaken at SPECIFIC - BBC Newsround featured a secondary school that visited the *"Classroom of the Future"* and helped plant the living wall, during the British Science Festival.

Figure 13: Photos showing living wall progress from seed planting to a flourishing wall and transplant of rare species

Internal Walls

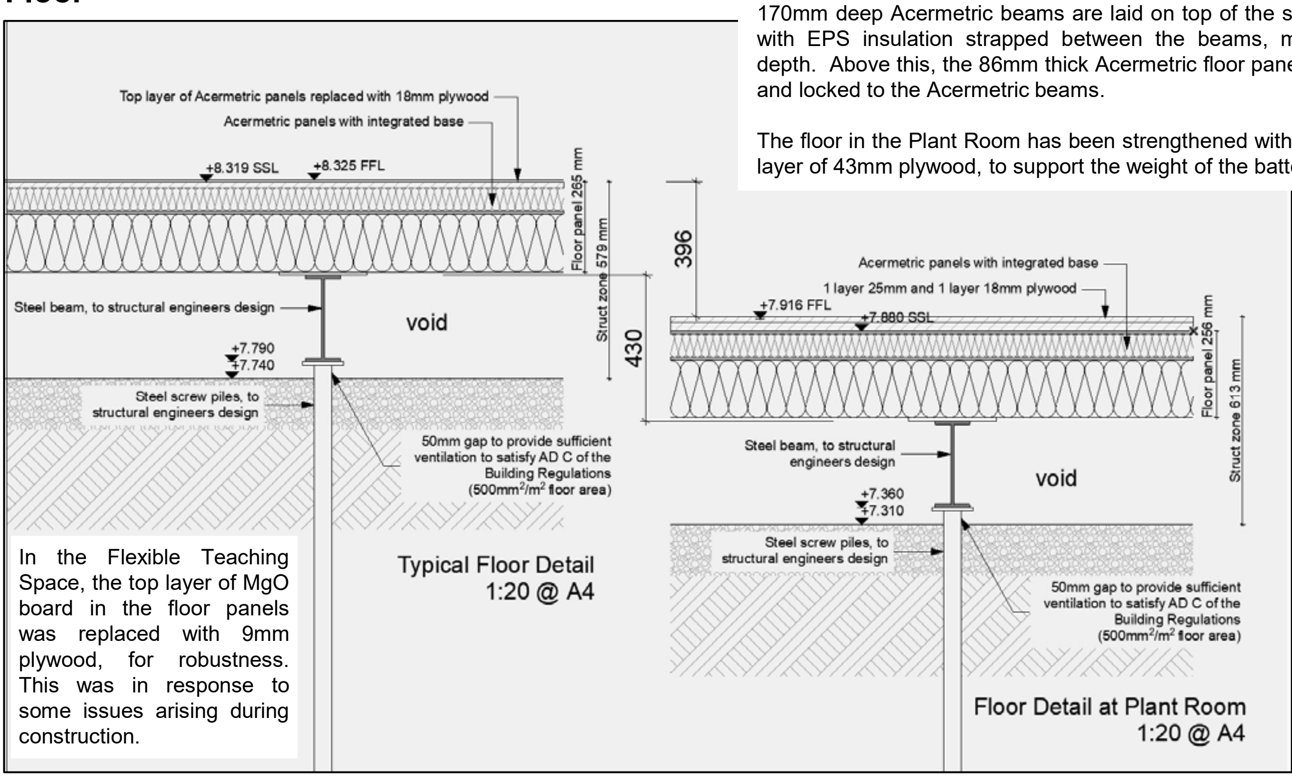
The internal walls are formed using a single skin of the composite panels. While most of the partitions are simply painted, exposing the joints between panels, both sides of the wall dividing the main classroom from the kitchen have been clad in a new product called Tata Coretinium®. This provides a clean, smooth, ferromagnetic surface which can be used to display posters and notices, or for use as a whiteboard. The installation enabled Tata to trial two different installation techniques – the first involved screwing one panel directly into the wall substrate and overlapping the top sheet of the next panel to provide a secret fixing detail; the second used an aluminium framing system, developed by a company called Reform, who were introduced to SPECIFIC by Matrix Structures. The second technique was found to be the most successful and Reform are now the main installer of Coretinium® wall cladding for Tata.

Figure 14: The Coretinium® wall

Floor

170mm deep Acermetric beams are laid on top of the steelwork grid, with EPS insulation strapped between the beams, matching their depth. Above this, the 86mm thick Acermetric floor panels are placed and locked to the Acermetric beams.

The floor in the Plant Room has been strengthened with an additional layer of 43mm plywood, to support the weight of the batteries.



In the Flexible Teaching Space, the top layer of MgO board in the floor panels was replaced with 9mm plywood, for robustness. This was in response to some issues arising during construction.

Figure 15: Cross section through floors of Flexible Teaching Space and Plant Room

Substructure

We carried out some research into suitable foundations for a temporary, lightweight building that would have minimal impact on the ground and identified steel helical screw piles as the most appropriate. We then procured a Structural Engineer, CB3 Consult Ltd to design the foundations to suit the building system. Screw piles are a good solution for lightweight buildings, even if they are permanent.

The foundation design included a grid of steel beams fixed to the top of the pile caps, providing a base for the superstructure, which simply sits on top of this grid. Screw piles make excellent temporary foundations as they are quick and easy to install and remove, saving both time and money. The removal of screw piles causes minimal ground disturbance and piles can often be used again. This was particularly attractive to me when considering foundation choice, as this building was designed to be semi-permanent, with planning consent granted for a maximum of 5 years. In addition, the use of screw piles minimised the amount of excavated material that needed to be removed from the site and avoided the use of concrete for the substructure, beneficial for both environmental and time reasons. The only concrete used on this project was the concrete pads needed for the balustrading supports to the external fire escape stair.

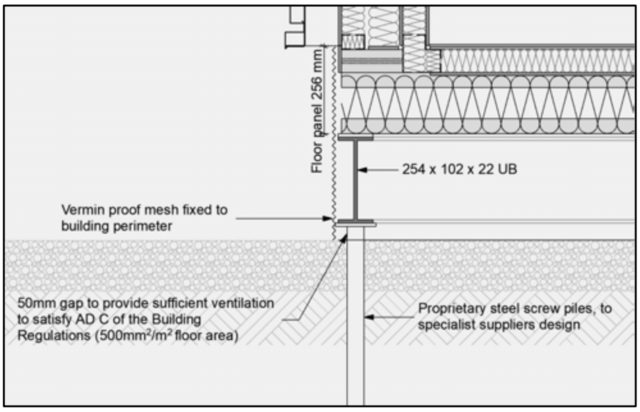


Figure 16: Cross section through floor and foundations

Figure 17: The steel screw pile foundations and the steel grid to support the building. The lower square in the foreground is the plant room, which is lower to enable flat access from the existing pavement.

3 Spatial Coordination

Roof

The roof is also formed using the Acermetric panels. 150mm deep Acermetric beams fixed to the inner skin of Acermetric wall panels, form the first level of structure. These remain exposed within the building. Above these, a layer of 86mm Acermetric panels are fitted and fixed into the beams, on top of which are fixed a further layer of 170mm deep Acermetric beams, with EPS insulation boards fitted between. This is covered with a layer of 18mm oriented strand board (OSB), to take the final roof sheeting layers.

On the south facing roof, 25mm x 50mm tantalised timber battens are fixed above this board layer to provide a zone for the electric cables for the photovoltaic roof covering. The building integrated photovoltaic (BIPV) roof covering is fixed to a layer of 18mm plywood, on top of the battens, providing the final layer. A damp-proof membrane is fixed to the plywood, prior to fixing the roof cladding. The total roof depth is 450mm. The BIPV is bonded to Tata Colorcoat® Urban standing seam roof sheeting in a factory environment and brought to site with all the connections in place, enabling a simple and efficient installation process.

The north facing roof covering is Tata Colorcoat® Urban, without the BIPV product. This is fixed directly onto the membrane covered OSB, without the need for the extra plywood and batten layers, providing a total roof thickness of approximately 400mm.

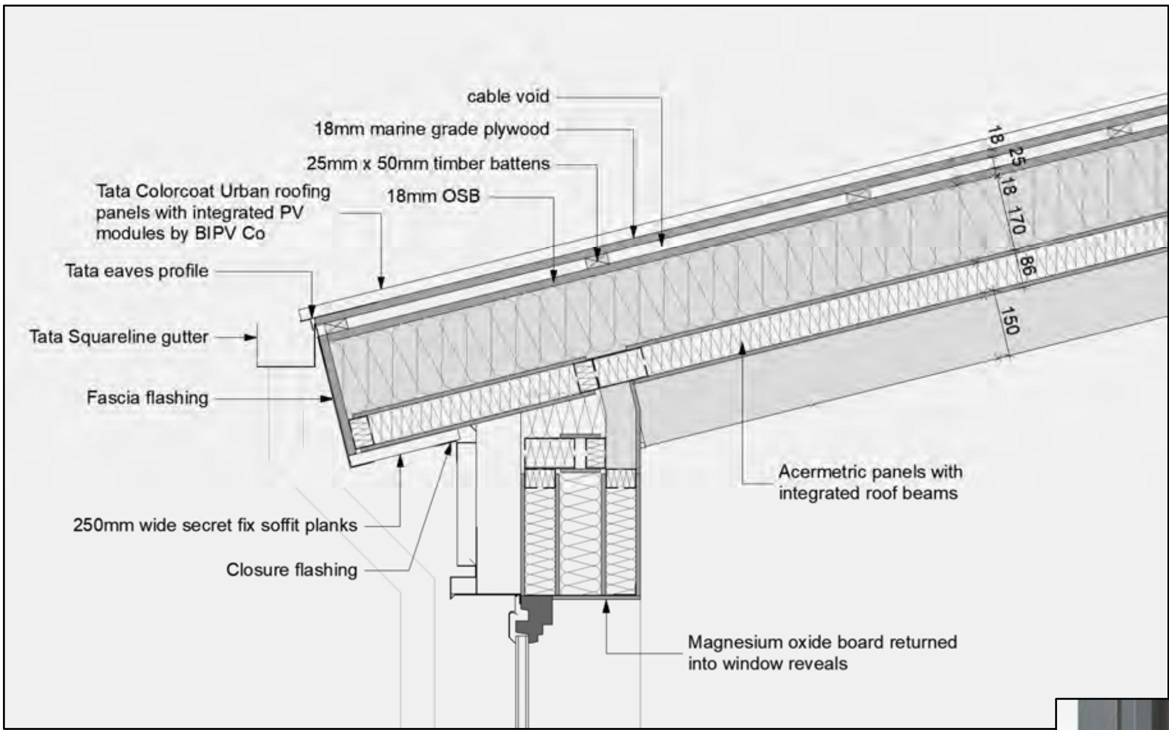


Figure 18: Cross section through BIPV roof

Windows

Timber-aluminium hybrid frames were used for the windows, combining the benefits of the thermal efficiency, quality and aesthetics of engineered timber internally, with a long life, low-maintenance outer cladding of polyester powder coated (PPC) aluminium. The glass is Pilkington energikare^{TM} Advantage, which offers excellent thermal efficiency, with a Ug-value of 0.9 W/m^2 K, equivalent to triple glazing but in a double-glazed unit.

Figure 19: Cross section through a timber-aluminium hybrid window

4 Technical Design

Active Building Objectives:

- Develop detailed building physics/dynamic thermal model
- Review design information and Mechanical, Electrical and Plumbing (MEP) strategy
- Review technical specifications developed to ensure Active Building technologies included
- Consider most appropriate types of energy storage – thermal and electrical
- Develop data monitoring specifications
- Specify control systems to enable controlled interaction of energy with local and national grid networks

This process really started during the Developed Design Stage (Stage 3) for this project, due to the accelerated programme.

During this stage, we engaged with the Swansea University Estates Team , who assigned a Project Officer to help project manage the construction phase. A Main Contractor, Kier, was appointed to manage the site. Their responsibilities included:

- Act as Principal Contractor*
- Undertake groundworks
- Substructure installation
- Mechanical installations
- Electrical installations (excluding PV and battery system)
- Plumbing/sanitaryware installations
- Joinery
- Flooring
- Painting and Decoration
- Fixed fittings and furniture
- External landscaping

Normally, the Main Contractor would be responsible for all other Contractors on site. However, due to the innovative nature of this project and the tight timescales, some of the key Contractors had already been appointed separately prior to Kier's engagement.

The first co-ordination meeting with all the separate contractors took place during this stage. These included:

- Kier – Main Contractor
- Matrix structure – Superstructure manufacturers
- Acermetric – Superstructure designers
- IPS – cladding and roofing, including PV installation
- Solar Plants – solar installers, including battery system
- SPECIFIC – Architect/Project Manager and Smart Systems Engineers
- Vellacine – windows and external doors

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* *The Construction (Design & Management) Regulations (CDM 2015) are the main set of regulations for managing the health, safety and welfare of construction projects. They set out what people involved in construction work need to do to protect themselves and anyone the work affects from harm. Under these regulations, a **Principal Contractor** is appointed to manage health and safety on the construction site. This includes planning, managing, monitoring and co-ordinating the construction phase so that health and safety risks are controlled.*

4 Technical Design

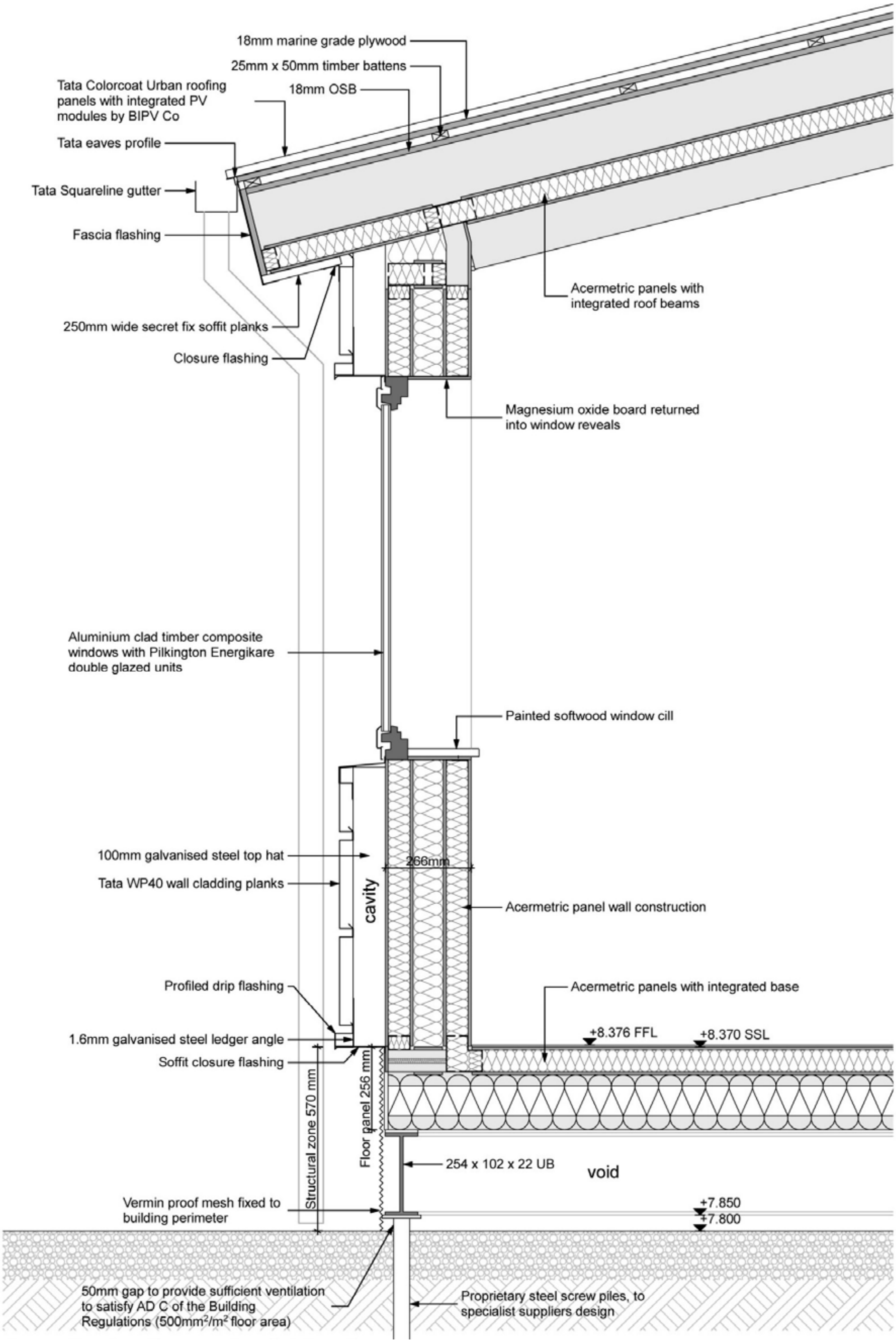


Figure 20: Cross section through South Elevation

Ventilation System

A Mechanical Ventilation and Heat Recovery (MVHR) unit is located within the central store room, supplying fresh air to the main classroom and extracting air from this space to redistribute into the kitchen. The heat recovery unit has two intake connections – one from an external louvre on the north side of the building and one from the transpired solar collector (TSC) (see page 27). The TSC provides a source of pre-heated air to use for space heating.

The toilets have an extract fan with extract grilles at high level, controlled via a Passive Infra-Red (PIR) sensor that detects movement.

The ventilation system was designed by the appointed MEP Consultant, AECOM, and includes a combination of natural ventilation through openable high and low-level windows; and forced air ventilation through an air source heat pump (ASHP) and the MVHR unit.

Mechanical ventilation is the primary method of ventilation, and this was designed to satisfy Building Bulletin (BB)101 (which provides guidance on ventilation, thermal comfort and indoor air quality in schools) requirements for average ventilation rates in teaching spaces (5 l/s per person). Initially an overheating simulation was run with the minimum ventilation rate (3 l/s per person) and although this satisfied the overheating criteria, it did not meet the Indoor Air Quality criteria. To satisfy indoor air quality requirements set out in BB101, adequate ventilation is needed to limit the concentration of carbon dioxide in all teaching and learning spaces. When measured at seated head height, during the continuous period between the start and finish of teaching on any day, the average concentration of CO_2 should not exceed 1500 parts per million (ppm). The maximum concentration of CO_2 should not exceed 5000 ppm during the teaching day. In January, where the windows are unlikely to be opened, the level of CO_2 was initially expected to be over 1500 ppm. This was overcome by boosting the mechanical ventilation rate.

Where applicable, natural ventilation supplements mechanical ventilation to ventilate the building in accordance with BB101, through external top hung windows, which are opened manually by the occupants to suit their comfort levels.

Generally, the average CO_2 level has been 700 – 900ppm, indicating that the MVHR is performing well. Several instances where the CO_2 level peaked over 1500ppm have been recorded, as predicted at design stage. This was combatted by opening the windows, or boosting the mechanical ventilation rate, until the level dropped.

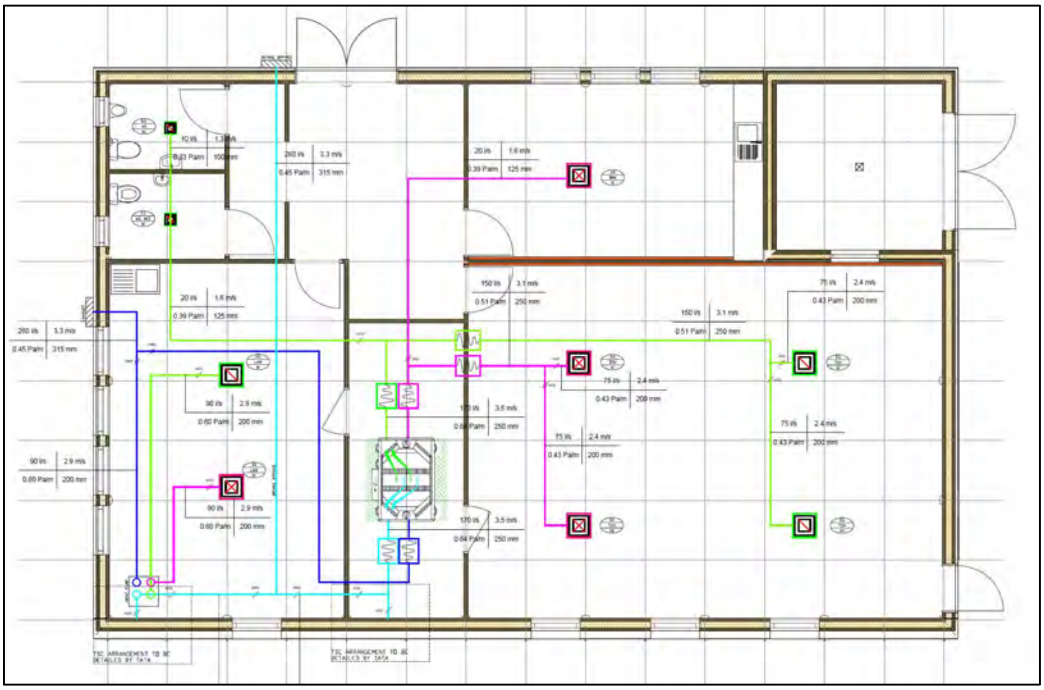


Figure 21: Ventilation Strategy Plan

4 Technical Design

Heating System

To help select and size the heating system, a heat loss assessment was carried out at design stage. Total heat losses due to infiltration and ventilation were calculated at design stage as being 10.7kW.

To determine actual heat losses from the building, it was proposed to measure heat flux loss at different points in the building, including the centre of panels, as a reference, which can then be compared with the thermogram to assess the losses from the frames between the panels. Further work also includes determining the as-built U-values, which can be assessed in Winter.

A combination of heating systems is used within the building, as described below:

Resistive Underfloor Heating System

A 10kWp resistive heating system, utilising a novel conductive coating technology developed at SPECIFIC provides underfloor heating to the main classroom space. This comprises a conductive coating applied to 1.064 x 1.142m sized Prisma® coated 0.7mm gauge steel sheets bonded to 1.2 x 2.4m plywood panels (2 sheets per panel). Channels routed in the plywood house electric braids which enable an electric current to pass through the coating providing an efficient form of resistive heating.

We maintain the floor temperature at 29°C, to provide a room temperature of 20°C, although it actually feels a few degrees warmer than this, which is likely due to the perception of occupants feeling warmer if their feet are warm.

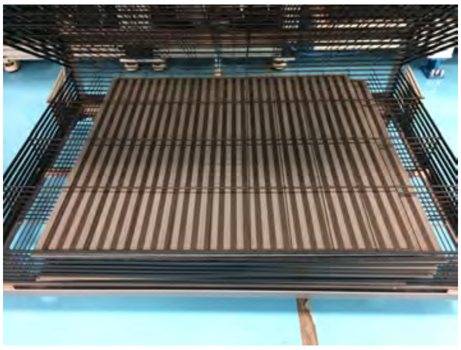


Figure 22: The heating panels

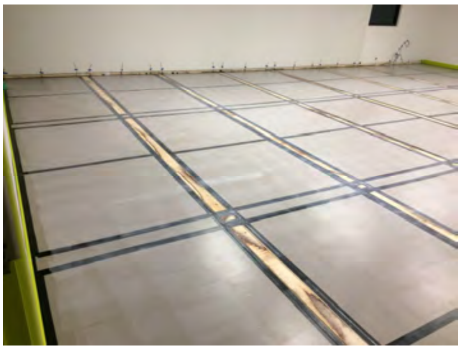


Figure 23: The heating panels installed

Figure 24: The control box #1

<u>Control System</u>
As this heating system was developed by SPECIFIC, it was also necessary to develop a bespoke control system to operate the system.

Several iterations of the control system have been developed for the building. Initially, a large control system was used to reduce the voltage between the power supply and the heating system, which is necessary for compliance reasons and to make the floor safe. To achieve enough breakdown voltage, a series of small transformers were used, which were housed in a box within the classroom space. This had the added advantage of dispelling heat generated by the transformers through power losses into the room as an additional heating source. However, this system suffered many problems whilst in use and the transformers were incompatible with some of the other (Alternating Current or AC) elements of the system, which caused spikes in current, which the inverters experienced as a short circuit, causing the transformers to cut out. There were also issues with the noise from the control system.

The next version utilised switch-mode power supplies, which could be housed in a more compact box. The advantage of this system was that it enabled us to control the voltage more easily and enabled a much finer grain variable output power. Originally the system had more zones, but less levels of power per zone. This evolved system has less zones, but more control over the power of each zone.

The ideal control system is still under development and, to get to an optimum position, it will be necessary to analyse the data from both systems to determine which offers the best performance. The goal is to obtain a power source with the highest efficiency in supplying heat to the space.

Transpired Solar Collector

Half of the south elevation is clad using Tata Colorcoat Renew SC®, an active solar air heating system known as a Transpired Solar Collector (TSC) that provides a renewable pre-heat function for space heating systems.

On this building, there are two TSCs – one feeding into an ASHP and one into the MVHR system. The TSC utilises solar energy to reduce the amount of energy needed to heat the building to the required temperature. It consists of an externally mounted micro-perforated pre-finished steel collector (as shown in Figure 25) that is fixed to the south facing wall on standard cladding rails, with a sealed air plenum box behind.

Temperature and flow rate sensors have been fitted within the TSCs to enable full analysis of their performance, as follows:

- at the air intake duct from the TSC;
- within the plenum at 1800mm above finished floor level (FFL);
- at 300mm above FFL; and on the surface of the TSC at 1050mm above FFL.

TSC with Air Source Heat Pump (ASHP)

Combining a TSC with an ASHP is purported to significantly improve the coefficient of performance (COP) of the heat pump.

An ASHP is a system which transfers heat from outside to inside a building, or vice versa. The COP of a heat pump is a ratio of useful heating or cooling supplied to the work required to supply it. Higher COPs equate to lower operating costs.

The small classroom is heated and ventilated via a Genvex Combi 185, which combines a cross flow heat exchanger with an air source heat pump. Intake air can be drawn through the TSC or from an external louvre on the north of the building depending on the need for heating and ventilation, or ventilation alone. The heat exchanger can extract up to 95% of the thermal energy from stale extract air, while the ASHP provides heat to a 185 litre water tank and ventilation air to the occupied space, with priority being given to the hot water. Data collected from air temperature and flow rate sensors in the TSC and ductwork have demonstrated an improved COP for the unit owing to the increased supply air temperature from the TSC. The absence of a bypass for the heat exchanger has limited the extent of the COP increase due to cooling of the supply air by the stale extract air when the supply air temperature from the TSC exceeds the internal room temperature.

Figure 25: The Transpired Solar Collector

Figure 26: The Genvex unit and air distribution ductwork

4 Technical Design

TSC with MVHR

An MVHR unit is located within the central store room (see Figure 27), feeding the supply and extract air to the main classroom. The heat recovery unit has two intake connections – one from an external louvre on the north side of the building and one from the TSC on the south elevation. The TSC provides a source of pre-heated air for space heating, supplementing the resistive heating system. Although our studies of the MVHR are not as advanced as the ASHP studies, we envisage a similar effectiveness with the MVHR.

Figure 27: MVHR unit and duct entry point from TSC

The MVHR is used to minimise heat losses in the main classroom space. The north intake is intended for summer use when the unit can draw fresh air directly into the space. In the shoulder months, warm air from the TSC is supplied through the MVHR directly into the space. Warm air is supplied from the TSC through the heat exchanger and into the occupied space whenever heat is required. Once again the lack of a bypass in the unit means that the heating potential of the TSC is curtailed when the incoming fresh air exceeds the temperature of the stale extracted air. Nonetheless the TSC provides a valuable increase in intake air temperature enabling a reduction in the electrical energy required for the underfloor heating system particularly in the shoulder months when external air temperatures can be low and solar irradiance levels reasonably high.

We are currently (2020) evaluating both systems to determine the best control philosophy. The intricacies of how the systems work is often equipment specific and the platform we are developing needs to be compatible with multiple different pieces of equipment, which is a significant challenge. Assessing these systems will enable us to consider the different interactions and determine the best mode of control for these combinations of technologies and whether they can be compatible.

Building Services generally

All building services were designed to be exposed throughout the building, for several reasons:

1. To engage with building users and visitors - highlighting how the building works
2. To enable easy access for maintenance and upgrading of services
3. To use less materials and hence less embodied carbon

Exposing services has the added advantage of ensuring installers take greater care in installing equipment neatly compared to how they would if installing a suspended ceiling. In this building project, the SPECIFIC team were responsible for the electrical installation. All the electrical cables were colour coded in relation to their purpose:

- Blue = Small Power
- Yellow = Lighting
- Red = Fire
- Purple = Data

Daylight/Lighting

Windows on the south elevation are shaded from high summer sun, by a large roof overhang, to avoid overheating and glare issues. Conversely, the low winter sun will provide solar heat gains through the windows, reducing the energy consumption of the heating systems. High-level windows are installed on the north side of the building, providing good quality natural daylight for the occupants. All light fittings in the building are LED, so use a minimal amount of power (27kWh/m^2/year in total). These are all on PIR sensors and have daylight dimming features installed, to further minimise energy demand.

The lighting scheme was designed to provide sufficient lighting levels suitable for a teaching enevironment, as set out in Building Bulletin (BB) 90.

Daylight dimming sensors measure the overall light level in the detection area and regulate the output of the luminaires, ensuring the correct lux level (maintained illuminance) for the area and saving energy when natural daylight can be used to replace/supplement luminaires (daylight harvesting)[1]. These can be combined with PIR sensors for maximum efficiency as illustrated by Figure 28 below:

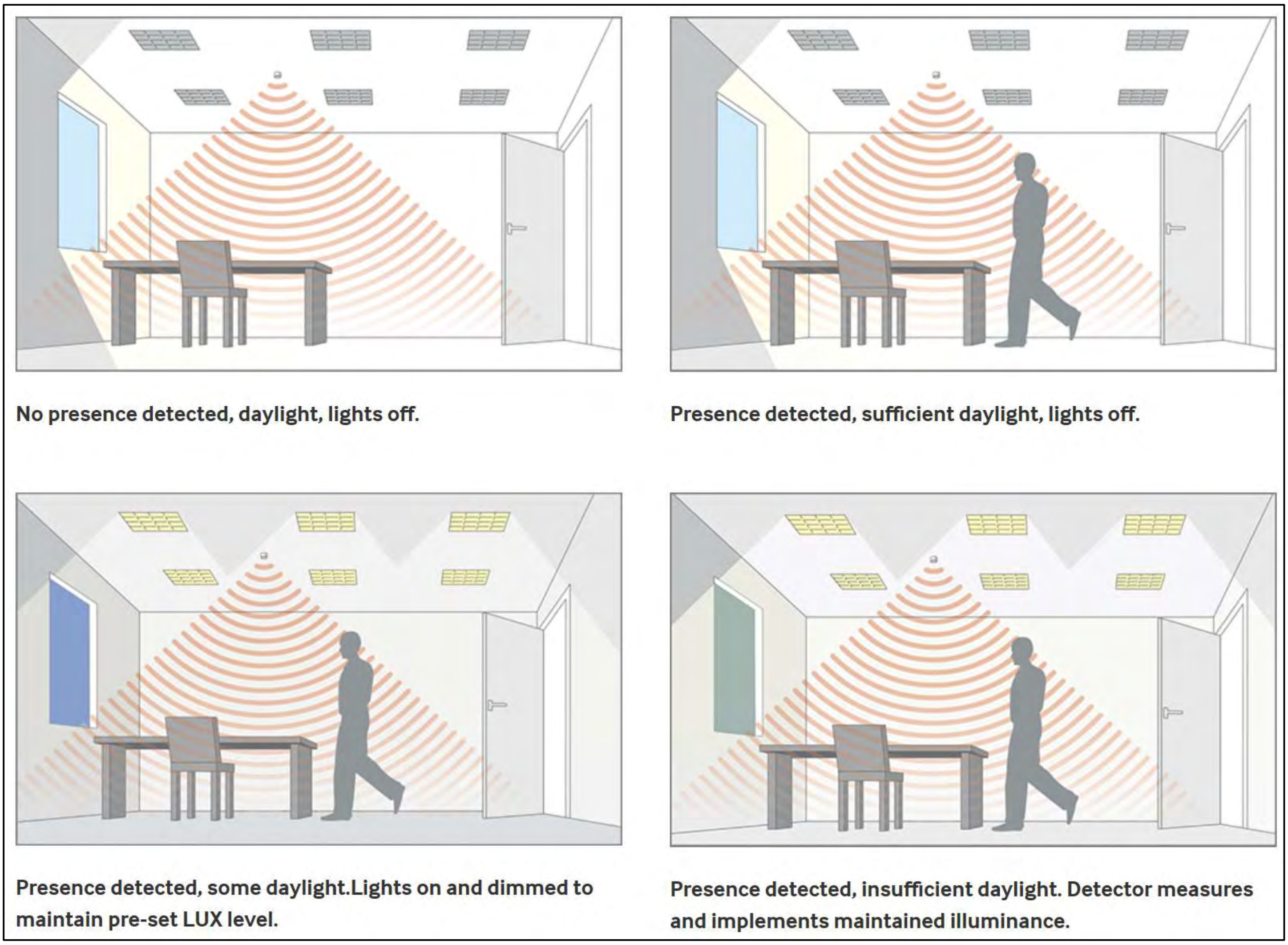


Figure 28: Use of lighting sensors. Source: . https://www.cpelectronics.co.uk/knowledge-hub/direct-dimming-detectors-with-lux-level-sensing

4 Technical Design

Water Use

The domestic hot water system (DHWS) is also heated via the Genvex, which can be controlled to prioritise water heating over space heating. The heat pump within the Genvex is used to prime the water, taking it up to a temperature of 40-45°C, but an immersion heater within the unit is used to bring the water temperature up to the 55°C setpoint temperature, with the occasional cycle up to 65°C to deal with the legionella risk.

The Genvex has the capacity to use two alternative heating sources for the water – one is the 1kWp immersion heater mentioned above; and the other is a coil which can be connected to a solar thermal device, which could be used to augment the temperature. Recent investigations have confirmed that it is possible to prioritise water heating in the summer to maximise use of the temperature uplift from the TSC, i.e. it is possible to supply TSC air to the water only, without also heating the space.

In the kitchen, a small device has been fitted to the kitchen tap that indicates temperature through colour change, acting simply as an engagement tool (Figure 29 below). This is self-powered through a dynamo within the device. The light is activated by water pressure and turns off automatically with the water. While this doesn't contribute to energy savings, it increases awareness of energy use and helps to engage building users with the energy they are using.

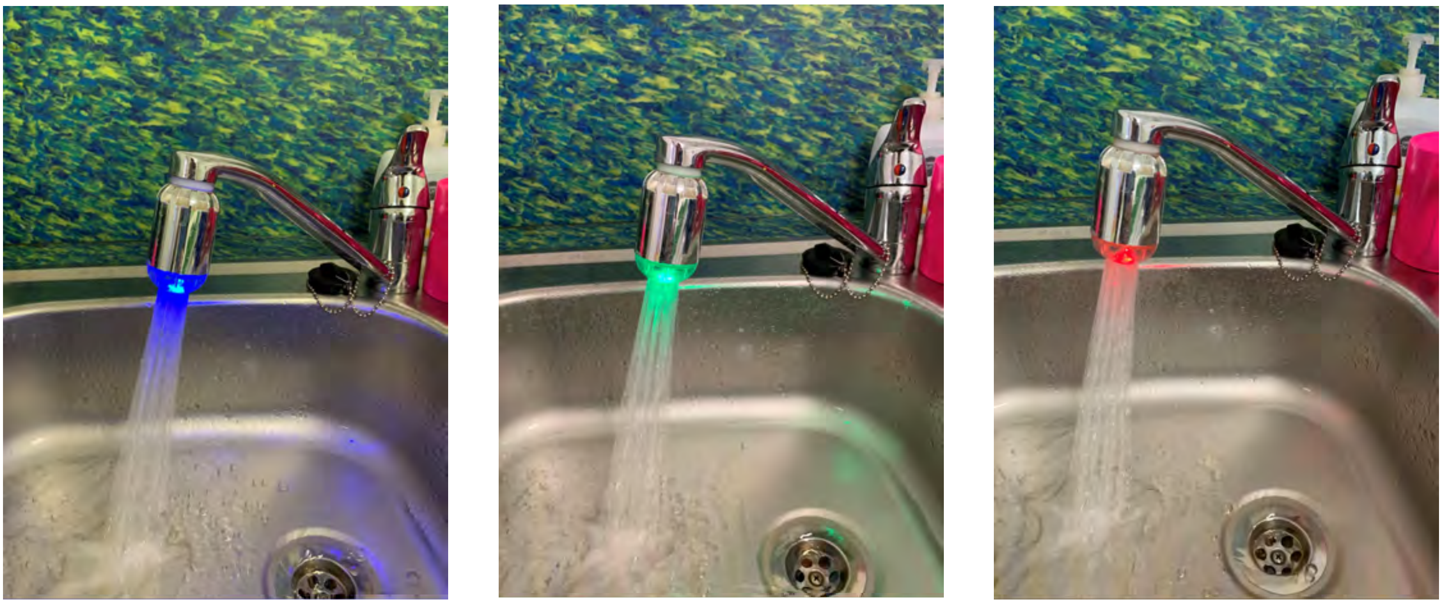


Figure 29: Colour changing device fitted to the kitchen tap – changing from blue to red as the water gets hotter

Rainwater harvesting was considered but ruled out on the basis that it was not the most economic or energy-efficient system to use in a building of this nature, with low water usage (two WC facilities, one laboratory sink and one kitchen sink) and which is cited adjacent to a mains water supply. A suitable system would have been relatively expensive to purchase and additional running costs and demands on the energy use of the building meant it was not a viable option. There are also ongoing maintenance responsibilities with a harvesting system, which would have added to the complexities of the project.

Other water-saving devices employed included a waterless urinal. Composting toilets were investigated, but found to be unsuitable for this project, mainly due to the need to create a concrete chamber below ground, with adequate ventilation provided. It would also need to be maintained to avoid odours and this would have imposed extra responsibilities on Swansea Universities FMT. The temporary nature of the building was also a driving factor.

4 Technical Design

Electrical System

<u>Generation: Photovoltaic (PV) modules</u>

The PV system consists of 135no. 120W <u>BIPVCo</u> CIGS (Copper, Indium, Gallium, Selenide) flexible modules, generating in total 16.2kWp electricity supplied to two 30kWh aqueous hybrid ion batteries; plus, a further 6no. 120W modules, generating a total of 720W, connected to a Moixa Maslow battery. The modules cover the entire south facing roof of the building, maximising the generation capacity. A pyranometer (a device to measure the amount of solar irradiance falling on the building at any time, as shown in Figure 31) is fixed approximately halfway up the roof on the east side of the building. This enables analysis of the PV effectiveness under different climatic conditions.

Figure 30: The BIPVCo roof

The PV modules are bonded to Colorcoat Urban® roof sheeting in a factory environment. In this case, there are three modules per roof pan. At the time of constructing the Active Classroom, BIPVCo were in their infancy as a PV manufacturer and this was their first installation on a building. At this stage, they were only set up to manufacture modules 2.6m long and these were pre-Microgeneration Certification Scheme (MCS) accreditation. This building provided the company with a platform to install their modules at low risk, enabling them to test their manufacturing process and installation technique. The Multi-Contact 4mm diameter (MC4) connectors were fixed to the underside of each roof panel and cables strung together within a roof void and run up the roof to the ridge, then run along the length of the ridge and are fed behind the cladding on the east elevation before connecting to the battery systems.

Figure 31: A pyranometer

<u>Energy Storage: Aquion batteries</u>

Two aqueous hybrid ion batteries manufactured by a company called <u>Aquion Energy</u>, supplied through a UK distributor called <u>Wind and Sun</u>, provide a total of 60kWh of electricity storage. These batteries were sized to be able to run the building for a few days, without any input from the grid.

Figure 32: The Aquion batteries inverters and charge controllers

Local PV installer, Solar Plants' off-grid team were involved with the design and installation of the solar to storage connectivity, working with Victron Energy products and the 60kWh of Aquion batteries. This included:

- 3 x Quattro 8000VA 48V inverter/chargers
- 3 x Bluesolar MPPT 100A/150V charge controllers
- 1 x Victron Colour Control GX/monitored on a VRM portal

Working in collaboration with Solar Plants and SPECIFIC, Wind & Sun supplied two of Aquion's saltwater based batteries together with Victron charger controllers and inverters, to provide the building with an AC power supply. Solar Plants' off-grid engineer attended a training course at Wind & Sun, following which engineers at Wind & Sun worked closely with the team providing pre-sales technical support and advice which continued during the installation. They also visited the site in the latter stages of the install to provide on-site assistance with some final commissioning.

The battery modules, combined with the BIPV modules, provide sufficient stored energy to allow the classroom to operate independently from the grid for the majority of the year. During the winter, when less sun is available, the mains grid provides any additional electrical requirements. As the building is connected to the grid, the system is capable of exporting surplus energy into the grid during summer months, when excess power is being generated.

4 Technical Design

<u>PV and battery system combined</u>

Battery systems are relatively new, particularly at this scale, in part due to the many challenges they face. The PV and battery system used in this building is described in Figure 33 overleaf. Both the PV system and the batteries used on this building were new technologies.

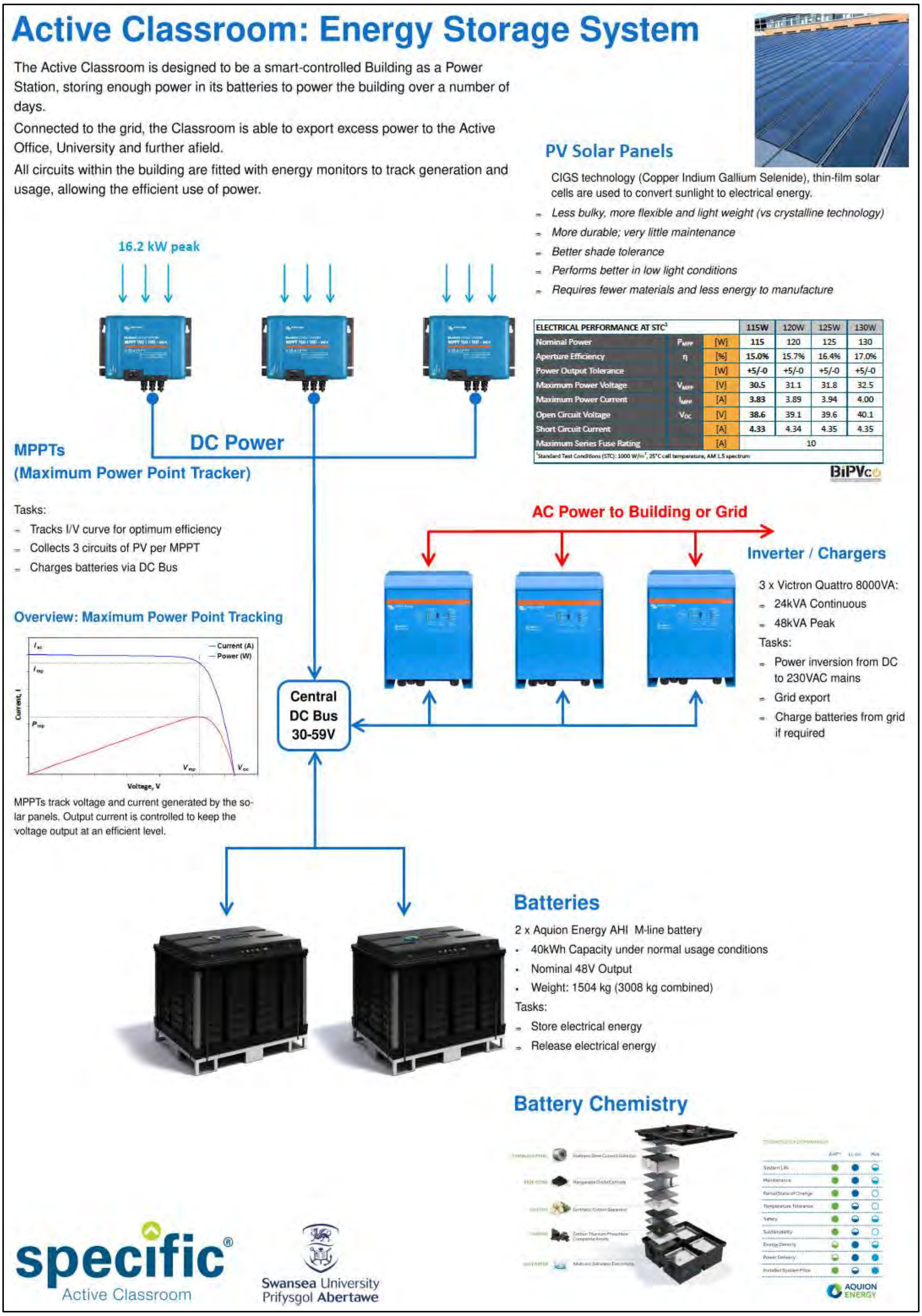
The PV system is unusual, mainly because it is building integrated. Integrating PV into the building envelope creates challenges in terms of manufacturing, transporting to site, and validation. Typical building applied PV arrays are validated during installation using a current-voltage (I-V) tracing box to check their performance is within compliance and to manufactured specifications. However, when the PV is attached to roof sheeting, there are a number of non-specialist operatives involved in the process, who can affect its performance even before the system is connected. For instance, the roofing contractor could damage the PV, or modules could be damaged during delivery, whereas traditional PV panels tend to be delivered in foam encased boxes. The main advantages of the BIPVCo panels are that they are flexible, lightweight and integrated into the steel substrate. However, it is difficult to guarantee their long-term durability currently, which is one of the purposes of demonstrating them on this building.

One of the main considerations of a PV system is to get the string configuration right. This roof consists of three modules connected in series and five groupings of three connected in parallel, totalling fifteen modules connected in one section. There are three sections on the roof, each comprising forty-five modules, connected beneath the roof sheets, with the connections running in trenches within the plywood sheeting.

There are nine PV strings which feed electricity through to some energy meters on the DC side, which enable us to evaluate performance per string. This is known as string level monitoring. The energy meters we have used are not part of the PV installation, as it was important for us to obtain more data than is usually captured. We chose to use 10% granularity, i.e. we can monitor the performance of 10% of the roof sections. Greater granularity requires more cabling, which influenced the level of granularity chosen. The PV power is distributed to the batteries via three charge controllers, which are needed to reduce the voltage from 120V (PV voltage) down to 48V (battery voltage), acting in a similar way to transformers, but for DC to DC power. This regulates the amount of voltage and current going into the batteries, allowing the battery to take as much current as it needs at the voltage supplied to it. To charge the battery, the charge controllers just need a slightly higher voltage than the battery. When the power is taken out of the batteries, through the inverters, the inverters need to be at a lower voltage than the batteries. When the batteries are not full, the DC charge controllers charge them. Ultimately the lifetime of the batteries is dependent on the charge controllers and the rate at which power is taken out of them.

During the design phase, consideration was given to the use of DC throughout the building. However, there are numerous issues with this, including availability of suitable switchgear, and the need for bigger cables, which are consequently more expensive.

Figure 33 overleaf describes the system in more detail.



ELECTRICAL PERFORMANCE AT STC[1]			115W	120W	125W	130W
Nominal Power	P_{MPP}	[W]	115	120	125	130
Aperture Efficiency	η	[%]	15.0%	15.7%	16.4%	17.0%
Power Output Tolerance		[W]	+5/-0	+5/-0	+5/-0	+5/-0
Maximum Power Voltage	V_{MPP}	[V]	30.5	31.1	31.8	32.5
Maximum Power Current	I_{MPP}	[A]	3.83	3.89	3.94	4.00
Open Circuit Voltage	V_{OC}	[V]	38.6	39.1	39.6	40.1
Short Circuit Current		[A]	4.33	4.34	4.35	4.35
Maximum Series Fuse Rating		[A]	10			

[1]Standard Test Conditions (STC): 1000 W/m², 25°C cell temperature, AM 1.5 spectrum

Figure 33: The energy storage system explained, courtesy of Tom Griffiths, SPECIFIC

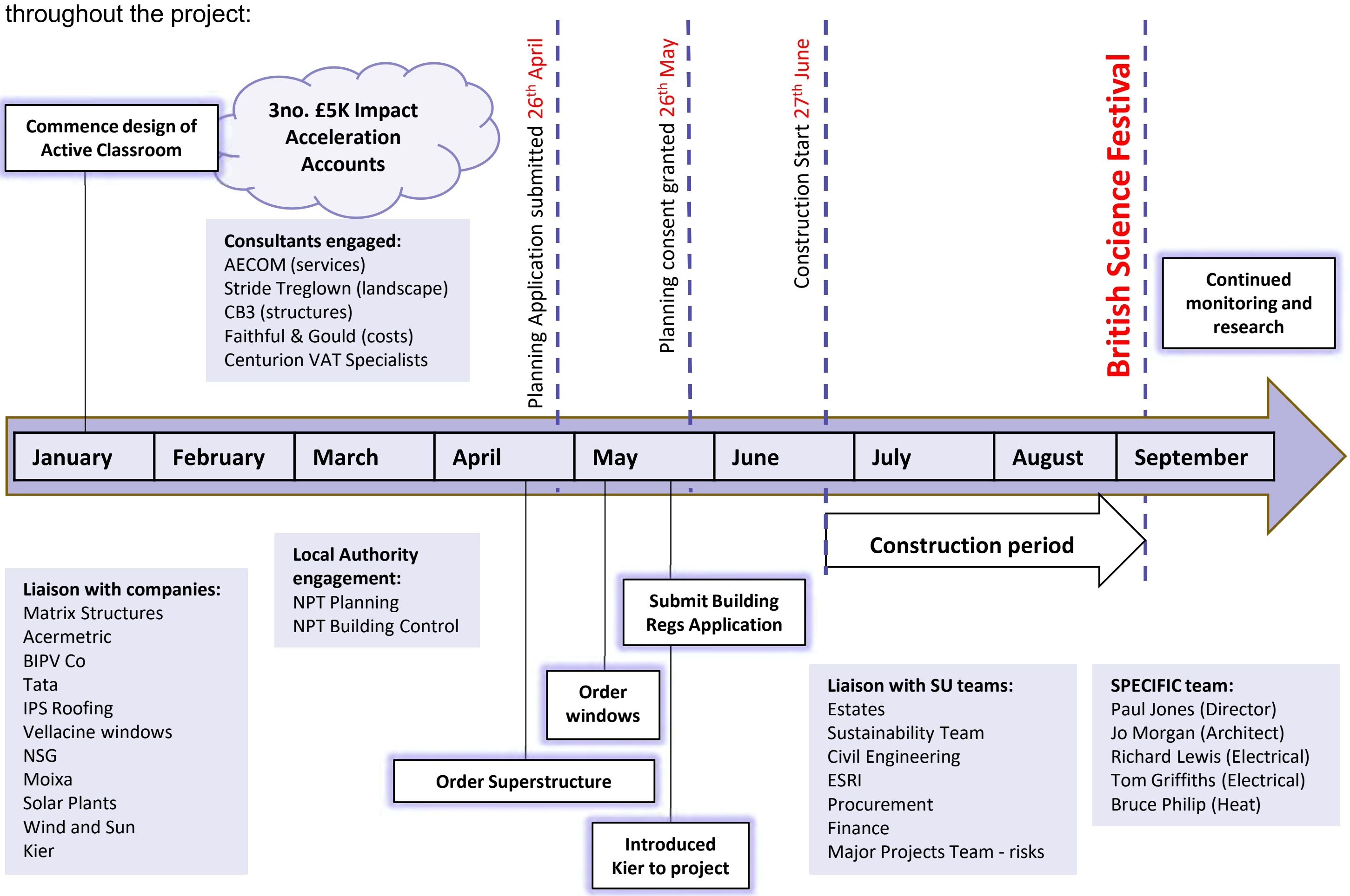
5 Manufacturing and Construction

June – September 2016

Active Building Objectives:

- Deliver Active Building toolbox talks for in-factory and on-site inductions, management and commissioning
- Undertake regular site inspections to support the delivery of the Active Building
- Document installation of technologies and equipment, including site photographs
- Ensure correct installation of MEP equipment aligned with Active Building philosophy
- Ensure rigorous commissioning and testing to ensure systems are performing as per design intent
- Ensure building is connected to the grid to enable controlled import and export of energy

This timeline highlights the tight programme, financial arrangements and number of engagement activities we dealt with throughout the project:



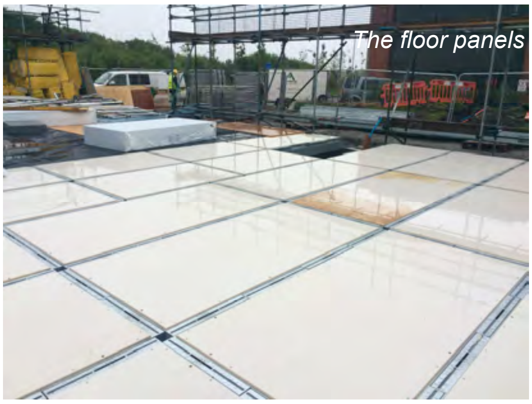
As Matrix Structures were new to construction and this was their first project of this size, we had agreed to assist on site. However, Kier were managing the site and they have a policy that all site operatives must have a Construction Skills Certification Scheme (CSCS) card to prove they have enough training to work on a construction site. A small team from SPECIFIC obtained CSCS certificates to enable us to assist on site. This had the benefit of enabling the Architect (representing SPECIFIC as both the client and Principle Designer) to undertake construction activities; make swift decisions on site; identify issues as they arose; and gain an understanding of how the technologies were integrated together. It also enabled us to identify areas for improvement in the Matrix Structures panel system, which we could then relay to them, assisting their development as a new construction company. One member of the SPECIFIC team undertook Pre-fabricated Access Suppliers' and Manufacturers' Association (PASMA) training, obtaining the necessary qualification to erect mobile scaffold towers, saving additional costs for Matrix Structures, associated with gaining the qualification themselves or employing a third party to erect the towers. This would have been an unforeseen cost for Matrix Structures as they were unaware of the need for this qualification, highlighting the challenges for a company new to construction..

5 Manufacturing and Construction

Site Progress Photos


The site before construction


Foundations and steel grid installed


The floor panels


Superstructure almost complete


The MVHR unit


The living wall troughs and irrigation system


The PV roof installation


The TSC and duct entry point

5 Manufacturing and Construction

Manufacturing the Resistive Heating System

At SPECIFIC, we have a Pilot Manufacturing Centre, where we have a large screen printer capable of printing on a substrate up to 1.2m x 1.4m. This was used to screen print the conductive coating onto the Prisma® coated steel sheets for installation into the floor panels. Once the sheets were coated, electrical braids were prepared and fitted into CNC routed grooves in the plywood sheeting, along with temperature sensors to monitor the performance of the heating system. With the electrical connections in place, the heating sheets were bonded to the plywood sheeting, connecting the electrical connections to the coating. The electrical connections running within the flooring system are then connected back to the control system. An extract from a poster illustrating the manufacturing process followed is shown in Figure 34 below.

Figure 34: The manufacturing and installation of the resistive heating system.

5 Manufacturing and Construction

Site involvement

During this stage, the SPECIFIC project team worked on site daily, with the Smart Systems Engineers taking responsibility for the entire electrical installation – which was certified by a third party before building handover. One of our main responsibilities on site was to oversee work by the different contractors and answer queries as they arose. Speedy responses were needed to queries, as there was no room for slippage in the programme.

Early in the construction period, sequencing was upset by an issue with the superstructure that meant all other work on site had to be postponed while the issue was rectified. Good communication was essential! We had identified a problem with the floor construction which resulted in the need to dismantle the building and rebuild. Although this caused problems at the time, it did prove the de-construction capabilities of the system worked. The problem was an issue with the floor beams that was identified during the first week of the superstructure works - the beams had in fact been manufactured incorrectly, so a remedial solution was needed. In this case, the panel designer was remote from the actual manufacture and construction, which caused issues for Matrix as manufacturers, that they have since resolved. Being reliant on Acermetric to check their work suggested that either Acermetric needed to be more involved in the construction, or Matrix Structures needed their own structural design capabilities. This was discussed with them in the 'lessons learnt' exercise undertaken post project completion and they now have their own design capabilities.

The ambitious programme meant different trades had to work around each other, which caused a few issues, but was dealt with collaboratively, ensuring all parties were updated regularly.

Lessons learnt

What would we do differently next time?

- More due diligence checks on any new contractor, and/or their product – the intention of this project was to help UK companies, which it was successful in doing. However, this necessitated a degree of risk taking.
- More scrutiny of drawings – due to the extremely challenging timescales, a few anomalies on the drawings were missed, e.g. an internal door in the wrong place; incorrect sizing of openings.
- More drawings would have been helpful – again, this was a consequence of tight timescales and the fact that the Architect was responsible for everything from designing, specification, production information, cost control, procurement, technology scouting, project managing, client liaison, and site works.
- Better coordination between subcontractors – this was also a consequence of time and resources.

Having a Tier 1 contractor working closely with a start-up company is unusual in construction projects due to the risks involved. However, that was an important part of this project. Matrix Structures learnt a great deal from Kier, the Main Contractor, particularly in terms of Health and Safety considerations of a construction site, programming and scheduling operations.

We were also able to provide the company with feedback on their system and suggest potential improvements to their processes and product. For example, based on their experience constructing this building, they have now replaced the MgO board in their floor panels with plywood.

5 Manufacturing and Construction

Education

We engaged with a local Comprehensive School, Glan y Mor, in Burry Port, South Wales, during the construction of this building and, during the British Science Festival, we hosted a group of pupils who collected seeds in the adjacent verges and SSSI with Swansea University's Biodiversity Officer and helped to plant these in the living wall. This was featured on BBC Newsround, who filmed the children engaging with the "Classroom of the Future".

Figure 35: Pupils from Ysgol Glan y Mor visiting the construction site and collecting seeds for the living wall

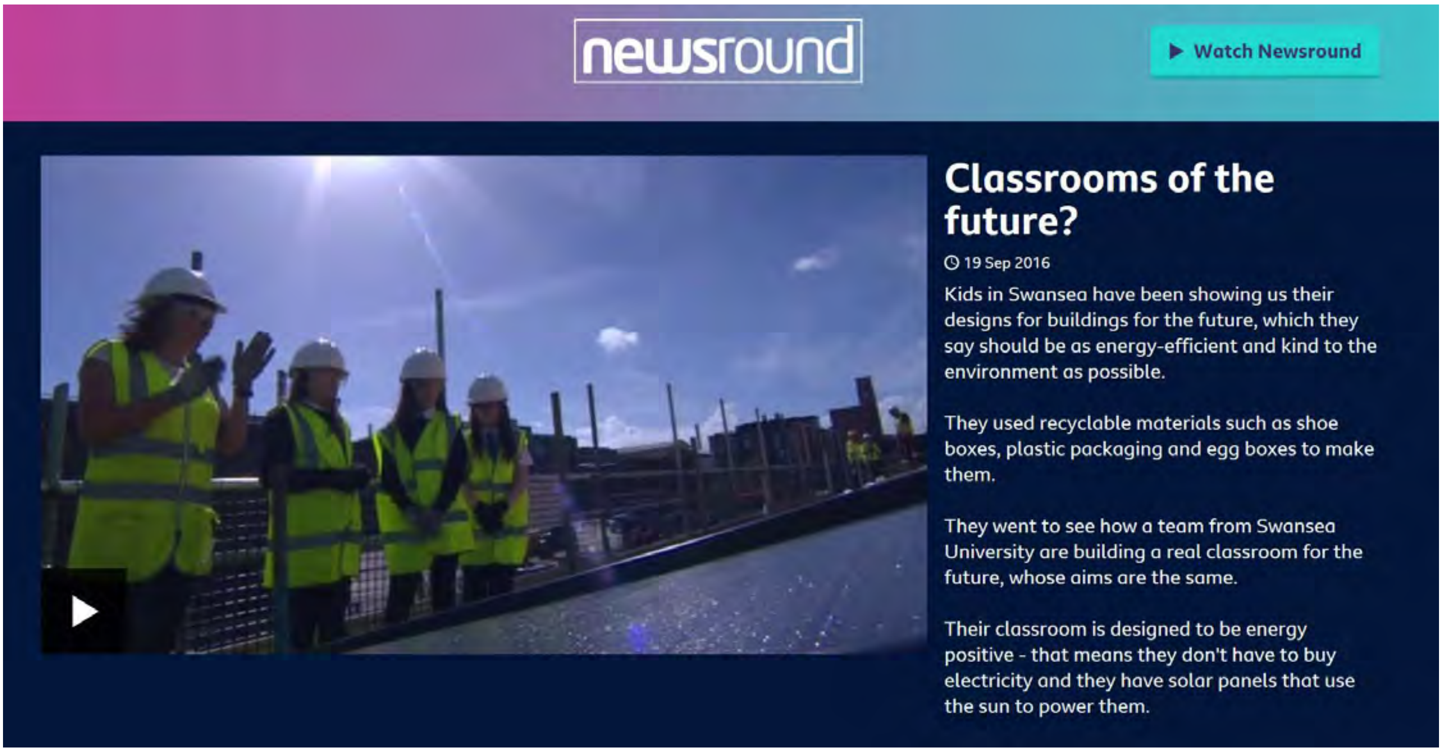


Figure 36: BBC Newsround feature

6 Handover

Active Building Objectives:

- Collect information for Operations and Maintenance (O & M) Manuals
- Review design and construction process with Project Delivery Team and capture lessons learnt
- Undertake post-project review workshop with the Project Delivery Team and other stakeholders
- Deliver handover workshops with building owners/occupiers/FMTs

On most buildings, at handover, the client (or building owner) is handed an Operations and Maintenance (O & M) Manual, which contains all the relevant information needed to operate and maintain the building.

O & M manuals are not generally as effective as they could be, tending to take the form of large files packed with information on the building and its equipment, which are often hard to access and daunting for many building owners.

It is essential in any building project, but especially in an Active Building, that clear information is provided to enable the smooth and efficient operation of the building throughout its lifetime.

This project was slightly different as the SPECIFIC technical team continued to operate, tweak and adjust the energy systems to optimise their performance and to trial new ideas.

During this stage, we liaised with Swansea University's Facilities and Maintenance Team (FMT) to ensure the Active Classroom complied with the University systems, particularly with regards to fire safety, such as linking the building into the overall campus fire strategy.

Some of the unexpected issues we had to deal with on completion of the building included:

- A burst pipe at high level in the central storeroom, where a connector had not been properly sealed – this meant a large volume of water gushed out of the pipes and caused damage to some of the equipment in the store room. However, one of the properties of the MgO board used in the Matrix panels is it's ability to dry out without damaging the board. Had plasterboard been used in the panels, the extent of damage would have been far greater and we would have had to replace all the wall, floor and ceiling panels in the room.
- When asked to read the water meter for the University's FMT, we discovered that the water meter had been installed incorrectly and could not provide the necessary readings.
- Mains grid connection, which took 18 months.

➢ ***Note: most of the problems suffered at handover had nothing to do with the new technologies!***

Lessons Learnt

As a team, we identified ways that Matrix could improve their system and construction works on future projects and we facilitated an end of project review workshop with the team at Matrix to discuss. As one of the aims of the project was to help new companies develop their products and technologies, this was an important part of the process.

Feedback should form part of every building project but, unfortunately does not happen enough. Every building is an experiment and without gaining feedback, there is no way of identifying issues and hence improving products and processes.

6 Handover

Some of the tips provided to Matrix Structures for improvements to their product and systems are applicable to all manufacturers and contractors. These included:

Design Stage

- Excellent communication
- Clear drawings of every part of the building, demonstrating that every detail has been considered
- Co-ordination with other disciplines/designers/contractors
- Realistic Programmes, updated throughout the project to reflect changing circumstances
- Clearly identify the Scope of Works from outset

Panel design

- To minimize site operations:
    - Reduce the number of joints between panels (applicable to all off-site systems)
    - A faster and simpler solution for infill strips between panels
    - Form window and door openings in the factory – maybe even installing window frames, or at least reveals at this stage
    - Use pre-finished substrates where possible
- Floor panels – use of an alternative to MgO board, such as plywood

Manufacture and Assembly Stage

- Quality control measures
- Sequencing of operations
- Number panels in relation to the drawings and construction/installation sequence
- Stack panels on transport vehicles in the order they will be needed (avoiding double handling of panels)

Construction Stage

- Transport considerations – distance from site, use of local storage
- Ensure all panels are already manufactured before site works commence – to enable accurate programming
- Ensure enough site operatives, including trained operatives are available, e.g. for erecting access towers
- Plan ahead – anticipate equipment and skills needed at each point in the installation process
- Health and safety
- Method of construction, including sequence and dividing up responsibilities between site operatives. A site foreman is needed, who is clear on what is to be achieved each day, a method for carrying out the works is clear, there are enough site operatives to complete the tasks, the correct necessary access equipment is available, there are the right tools and sufficient quantity of tools to carry out tasks (for an offsite panelised system to market itself as requiring only one tool for site assembly, every effort should be made to ensure all cutting, drilling, riveting, etc is carried out in the factory)
- Programme review throughout the construction stage

The main purpose of this is to highlight the importance of feedback on what worked and what did not work so well, to enable continuous improvement. This is critical and should take place on all building projects. Following the lessons learnt review, Matrix made a number of changes to their system, including replacing MgO board in their floor panels with the stronger plywood option. Had we not worked collaboratively and shared experiences, they may not have resolved their floor issue so swiftly and could have damaged their reputation if they had repeated mistakes on their next project. The intention of the suggestions made is to ensure the benefits of a panelised offsite system are fully realized.

Active Building Objectives:

- Undertake Building Performance Evaluation (BPE) using installed monitoring equipment
- Capture data in Active Building database and assess optimised performance of systems
- Ensure O & M and building user manuals are kept up-to-date as necessary
- Undertake Whole Life Cost (WLC) reporting, based on Life Cycle Cost (LCC) Comparison Report
- Develop/determine Post Occupancy Evaluation (POE) assessment method and undertake POE with building users and FMT
- Ensure generation and storage technologies are working effectively
- Develop predictive control strategies to optimise building performance
- Develop planned maintenance regimes to ensure technologies and equipment are working optimally

7.1 Building Performance Evaluation (BPE)

According to the Building Services Research and Information Association (BSRIA), “Building Performance Evaluation (BPE) *“is the process of evaluating the performance of a building, with Post Occupancy Evaluation (POE) being one of its major parts.”* In order to undertake BPE, it is essential to ensure monitoring equipment is installed in the building and the data captured is used to analyse and improve the performance of a building.

The success of an Active Building depends on the management of the building and its services. An Active Building will not be successful if the management of the building is poor, so the design should facilitate effective management. One way to achieve this is through the data capture system, where the inclusion of metering and sensing devices enables fault finding.

All environmental services should be sub-metered to allow the use of lighting, fans and pumps, space heating, hot water supply, etc to be distinguished. This will enable fault finding, the development of planned maintenance strategies and eventually development of predictive control strategies. Sub-metering provides a greater insight into how a building is performing, including energy consumption and generation, and a measure of the energy efficiency of the building fabric and services. Sub-metering will allow excessive consumptions to be diagnosed more readily and provides the opportunity to make optimum use of energy generation.

Monitoring enables:

- Fast fault finding by identifying and resolving issues quickly
- Provision of feedback on actual performance of individual systems or technologies, and overall building performance
- The development of planned maintenance regimes
- Optimisation of systems
- The development of predictive control strategies
- Education of building occupants on their energy consumption and how this compares to the energy generated by the building

Data collection from sub-metering is an essential component of an Active Building. The following pages describe some of the specific testing procedures that have taken place since the Active Classroom has been operational.

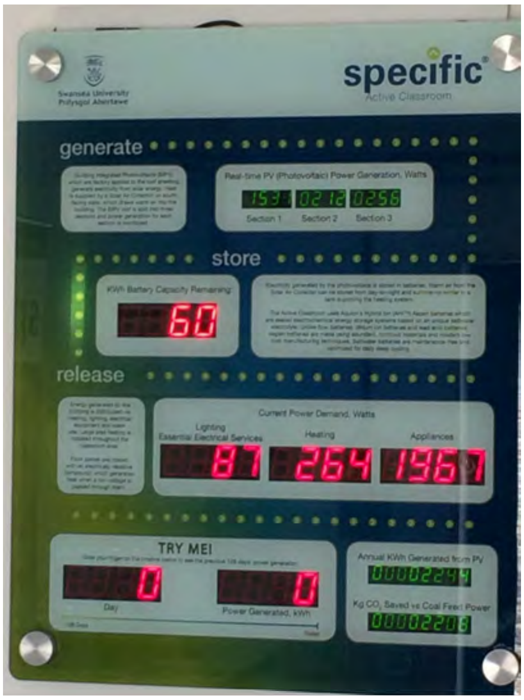


Figure 37: Display screen linked to the monitoring system

7 Use

7.2 Pressure Tests

The Active Classroom was designed to an air permeability of 3.09m³/m²h at 50Pa, approximating 0.1 air changes per hour (ach). An air tightness level of <3 ach is required for MVHR systems to work effectively, so it was important we achieved this level or better.

We carried out an air test on the building with Dr John Littlewood of Cardiff Metropolitan University, in March 2018, and found the building actually has an air permeability of 1.52m³/m²h. It is likely this is due to the taping of the metal frames with insulated tape and the sealant applied at every panel joint.

Figure 37: Dr John Littlewood undertaking air pressure testing using the door blower method

7.3 Continuity of Insulation and Thermal Bridging

Despite the design intention to minimise thermal bridging through the design of the panels, it is apparent that thermal bridging takes place throughout the building. To validate this, a Thermographic Survey was undertaken in March 2018. This was carried out between 19.30 and 21.30 when the external air temperature was 1.5°C and wind speed was low (between 2 and 3m/s). It was a dry, clear evening with relative humidity at 56%. Indoor temperatures ranged between 16.5 and 19°C.

The survey highlighted significant areas of heat loss particularly at the panel junctions, suggesting thermal bridging through the steel frames. Heat loss was also observed around the window frames and air intake ducts, as well as through the steel fire exit door to the main classroom. The north facing roof showed higher heat losses than the south facing roof, which is likely to be due to the additional layer of battens and plywood used on the south roof. Where MgO board flooring had been replaced with plywood, less heat loss was evident.

Unheated spaces within the building showed evidence of draughts.

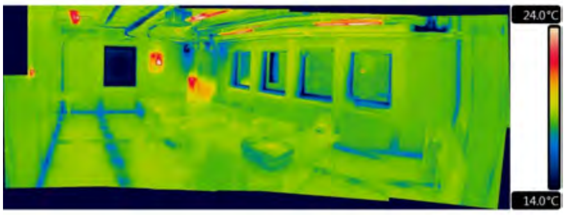


Figure 38: An extract from the Thermographic Survey shows thermal bridging at panel junctions and around window openings (blue and darker green. The red and white areas of the thermogram show the higher temperatures of the lights, water tank within the Genvex heat pump and the solar window display panel.

This image is representative of the whole building. Image courtesy of Dr Bruce Philip, SPECIFIC.

7.4 Temperature monitoring of the resistive heating system

All underfloor heating systems are required to have a temperature sensor within them to ensure the surface temperature of the floor does not exceed 31°C. However, the requirement is to include only one sensor and, as such, the data gleaned from this could be unreliable and offers no ability to determine where any faults occur. Therefore, the performance of most underfloor heating systems is dependent on where the sensor was installed, which is why performance data for electric underfloor heating is so variable. In our flooring system, sensors are placed within every individual heated tile, which adds to the complexity of the control system, but is necessary because every individual tile is deemed an individual heating appliance. Figure 39 below shows the temperature of each individual tile identified by the individual temperature sensors.

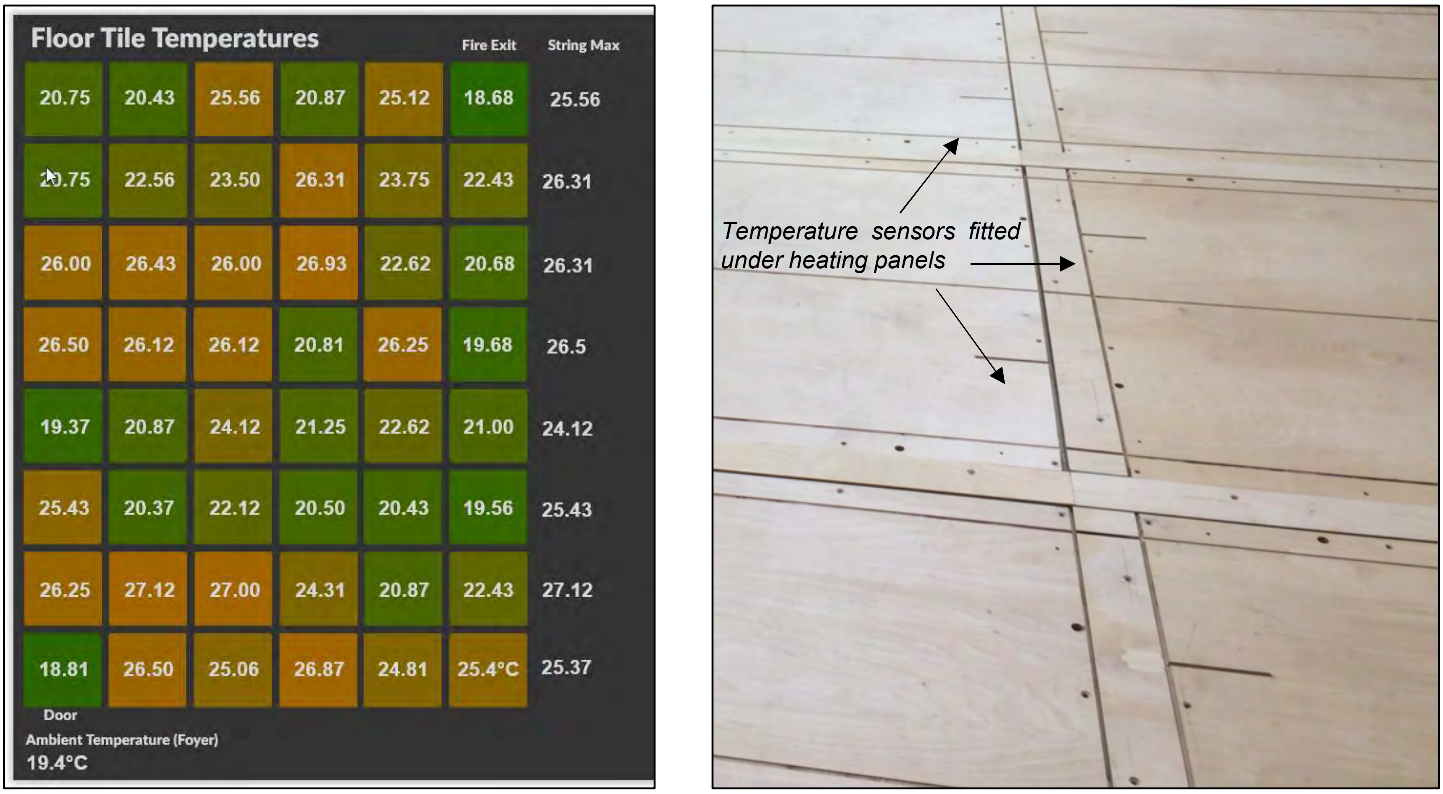


Figure 39: Temperature map of floor tiles (left) and temperature sensors (right)

7.5 Analysis of the performance of the TSC with the ASHP

Within the TSC system, temperature sensors measure the temperature of the plenum at high and low level – roughly 300mm above FFL and 1800mm above FFL - with a surface sensor in the middle. As previously mentioned, the absence of a bypass for the heat exchanger in the Genvex limits the additional heat that can be supplied into the air source heat pump and the occupied space when the supply air temperature from the TSC exceeds that of the stale extracted air. Further investigations are required to determine the magnitude of this lost potential. However, early data analysis has demonstrated an uplift in COP from 2.4 without the TSC to 2.6 with the TSC, equating to an 8% increase in annual performance. We believe this could be higher if the Genvex included a bypass and have been advised that newer models with a bypass have now been developed. Although our analysis to date has shown that the current model is not fulfilling our requirements, it was the best available to us at the time of installation. We would expect to achieve a higher COP increase with this newer model.

We have observed the air temperature being supplied into the Genvex is generally 2-3°C above ambient external air temperature, even on overcast days, which may, in part, be due to heat loss through the building walls warming air in the plenum behind the TSC and being drawn back into the occupied space. On sunny days in November, we have observed temperatures up to 38°C, and in the summer in excess of 40°C. Some optimisation of the system is required, as when hot water is needed in summer months, the air is being supplied from the north bypass as heating is not required. This conflicts with the benefits that could be generated from the TSC. We are investigating whether the hot water feed can be separated from the warm air supply feed to maximise the potential of using summer solar gains for the hot water, without heating the space. *[We have recently (2020) learnt that a newer model now available from Genvex includes this capability]*

In order to understand the actual benefits of the TSC, it has been necessary to retrofit temperature sensors in different locations within the system. They have been fitted in the cavity and ducts connected to the TSC, as well as on the external surface of the TSC.

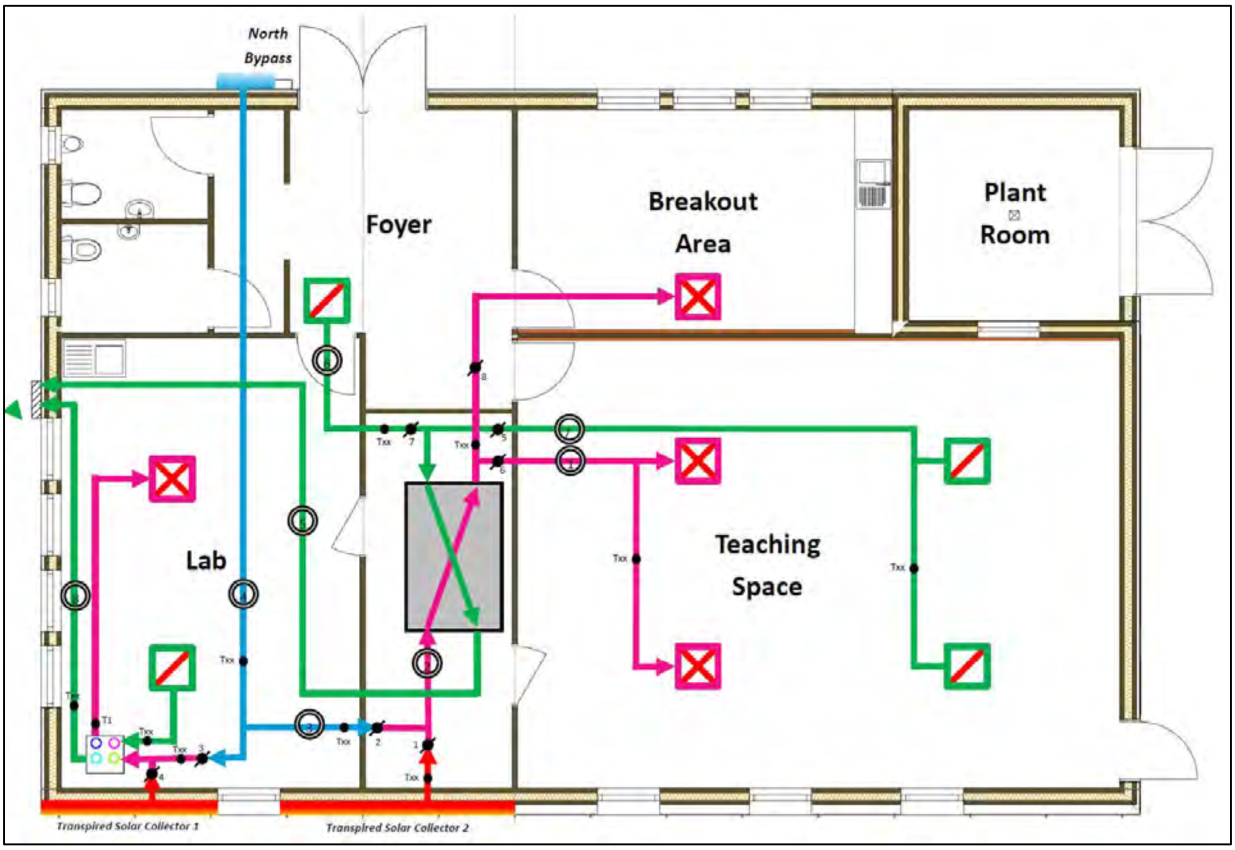


Figure 40: Diagram showing ducts and positions of Variable Air Volume (VAV) units and temperature sensors

7.6 Contribution to Further Research Projects

One of the main purposes of demonstrator projects such as this is to educate society, from school children right through to UK and Welsh Government departments, as well as building users, developers, designers and contractors. The building has drawn a lot of third-party interest, including media attention, which has also helped raise the profile of the University by demonstrating the breadth of its research work. Media articles in publications such as the Manufacturing and Engineering magazine, BBC Online and The Independent have played a role in promoting its sustainable credentials to stakeholders.

As well as general interest, the Active Classroom has led to collaborative work with companies, such as Nissan, whose interest was sparked when they saw a photo of a Nissan Leaf being charged from our batteries. Nissan visited the building and integrated some of the products demonstrated on their own manufacturing facility in Sunderland.

During both the design and delivery stages, public engagement was essential for us, particularly as the building was to feature in the British Science Festival (BSF) programme. For us, this involved a number of different aspects: developing our own marketing material; setting up timelapse footage of the construction; producing a video describing the project; presenting on the Active Classroom to various groups such as Low Carbon Swansea Bay, at the BSF, at a ‘Buildings as Power Stations’ conference, to Forum for the Built Environment (FBE) groups, to government departments, such as the Ministry for Housing, Communities and Local Government (MHCLG); liaising with BSF organisers and the SPECIFIC Communications Team, as well as photographers and film crews; co-ordinating tours of the construction site and then the completed building. All of this was necessary in order to raise the profile of energy use in buildings in an accessible way to wide audiences.

The Active Classroom has acted as a catalyst for several other projects, some of which are described below:

SUNRISE (Strategic University Network to Revolutionise Indian Solar Energy)

Led by Swansea University, the SUNRISE project unites several top universities and industries from the UK and India to develop and implement the technology necessary to build a minimum of five solar-powered building demonstrators in rural Indian villages. The successful award of £7m of funding from the Global Challenges Research Fund (GCRF), a UKRI fund established to support research that addresses challenges faced by developing countries, can be partly attributed to the Active Classroom. To demonstrate how the technology developed by the SUNRISE investigators can be applied in real-life contexts, a series of building-integrated sustainable energy systems will be built across India. These buildings will be modelled on the Active Classroom but adapted to the needs and challenges of new environments throughout India.

JUICE (Joint UK-India Clean Energy Centre)

JUICE is funded by the Engineering and Physical Sciences Research Council (EPSRC) in the UK and the Department of Science and Technology (DST) funds both the India-UK Centre for Education and Research in Clean Energy (IUCERCE) and the UK-India Clean Energy Research Institute (UKICERI) in India, which collectively form the Joint Virtual Clean Energy Centre. The centre brings together leading energy researchers from ten UK universities with their counterparts across India to share experience and develop technologies critical to the future of sustainable energy systems. The purpose of establishing the centre is to help both the UK and India meet their ambitious targets to deploy renewable energy, while addressing the challenges of integrating these intermittent sources into the built environment.

To aid investigation of integrating energy generation and storage techniques into the built environment, part of this project involved analysing the long-term dataset produced by the Active Classroom, to investigate the potential of integrated technologies to meet the electrical and thermal load requirements of the building. The potential of utilising such technologies to provide electricity to remote rural locations in India is explored, based on the data collected from the classroom.

7 Use

Demand Side Response (DSR) projects

The system integration implemented on the building has helped in the success of funding bids and collaborative projects with industry partners, such as a domestic DSR project through BEIS, with a company called MyEnergi, Evergreen Smart Power, run by the Energy Systems catapult. This project has a slant towards electric vehicle (EV) flexibility. Using the Active Classroom and the more recently completed Active Office as a flexible platform, it is anticipated that we will be able to install and demonstrate a variety of technologies and philosophies that aim to gather evidence on the viability of domestic DSR. Capabilities such as the pre-programmed consumption profile that follows a typical domestic usage pattern and the validation of DSR outcomes, the ability to turn up and turn down car charging power depending on the building consumption/generation and in response to an external signal that might take a wider view of grid power availability.

Another project is an OpenLV project through a Network Innovation Award (NIC), with Western Power Distribution (WPD), EA Technology and Grid Edge. This involves monitoring the 450V LV substation on Swansea University's campus, from which data will be collected and used to develop an event triggering application. The aim of the project is to create an open intelligence platform at substation level which will enable real time assessments of substation capacity and management. It will also aim to establish a community engagement scheme which enables local communities to better understand their energy use and open up the substation data to academics and companies to create innovative services for the network. This sub-station monitoring and event triggering could form the basis for a domestic aggregated DSR platform and capability.

7.7 Use of the building as an education tool

As well as being used for teaching within the University, the classroom also acts as an educational tool to other establishments, some of which are highlighted below:

Pontarddulais Primary School, Swansea

Figure 41 shows a group of Year 5 pupils from Pontarddulais Primary School who visited in June 2018, as part of their STEM week. During their visit, they learnt about solar energy and the future of the built environment, through having a tour around the building and carrying out activities to make solar-powered windmills that they then tested outside and completing puzzles on solar energy.

Figure 41: Pupils from Pontarddulais Primary School outside the Active Classroom

Oldcastle Primary School, Bridgend

In November 2018, the Manager for Wales at Innovate UK was approached by Oldcastle Primary School who were looking for interesting activities to include in their STEM week. As they were focusing on the theme of sustainability and well-being, he brought them to the Active Classroom where they identified the living wall as being an element of interest. The school had very little green space within their grounds, so loved the idea of planting some living walls, which would provide a vibrant mix of colour and plants to encourage wildlife. Children from Year 6 were involved in the painting and preparation of the plant walls, and children throughout the school were then able to arrange the plants as part of their STEM week celebrations, as shown in Figure 42.

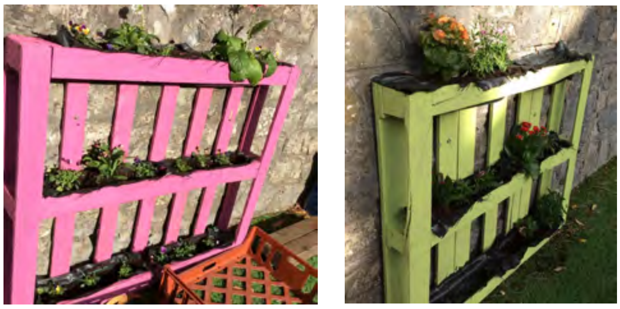


Figure 42: Living wall construction at Oldcastle Primary School

We also host regular groups of students from the architecture department at the Swansea-based University of Wales Trinity St David.

7.8 Maintenance

Regular maintenance of systems is critical to enable them to continue to work effectively. The MVHR and ASHP systems need regular routine maintenance to optimise their performance, including changing filters to ensure good standard of Indoor Air Quality (IAQ) is maintained.

The living wall was designed to be accessible for maintenance, with the top troughs reachable from a step ladder. It also has an in-built irrigation system, ensuring the soil is always moist.

7.9 Change of Use

Ideally, all buildings should be designed to be adaptable.to new uses to suit occupation demands. In 2017, the small classroom space was converted to an office for the SUNRISE team, which increased the overall building consumption, due to the different occupancy and equipment as highlighted below:

	Classroom	Office
Occupancy	Teaching only – up to 4 days a week for a few hours at a time	Continuous 08.00 – 17.00 use, 5 days per week
Equipment	1no. laptop	4no. laptops
	1 no. projector	4no. screens
		Printer
		Toaster
		Electric heater to boost the temperature in the room occasionally – the heating system had been designed to operate at a lower temperature than required for an office.

The kitchen loads also increased, due to the increased number of times the kettle was boiled and the microwave used.

In July 2019, the kitchen was given a dual purpose, doubling up as a meeting room. This has not significantly affected the energy consumption, as it is still used intermittently.

In July 2020, conversion of the Active Classroom to a site office to support the construction of an adjacent building commenced. This is currently ongoing (September 2020).

7.10 Retrofit of technologies

Low Temperature Radiant Panel Heaters

In 2018, two low temperature infrared heaters were fitted in the kitchen, located below the windows on the north external wall. Their average surface temperature is 38°C. These heaters have been developed and manufactured by a Welsh-based company called Warmth and Wellbeing and are known as SmartWarm™ panels, which the company describes as *"a low-cost alternative to traditional heating methods…..which offer a higher thermal comfort by warming the solids in the room instead of the air."* They are manufactured from Tata Coretinium®, providing another use for the new product. The main purpose of installing the panels in the kitchen is to enable evaluation of their effectiveness in heating spaces.

Figure 43: Warmth and Wellbeing Low Temperature Radiant Panel Heaters

Batteries

Aligned with our continued research into novel battery technologies, in 2019 we were given the opportunity to trial the first UK installation of flow batteries from a company called Redflow in the Active Classroom. One of the perceived risks of installing new technologies in buildings is whether they can be upgraded when newer technologies become available. Replacing the Aquion batteries with the flow batteries enabled us to demonstrate the relative ease of upgrading and retrofitting energy storage technology in buildings.

Going forward, we intend to continue evaluating the operation of the Aquion batteries in another building to investigate their lifetime reliability.

Figure 44: Flow batteries

New Charge Controllers

In July 2019, due to the effects of climate change, the performance of the rooftop PV array was found to be better than originally anticipated. Hence a decision was made to upgrade the MPPT charge controllers and subdivide the roof further into 5 strings, instead of the original 3 strings. This allows more evaluation per sub-section of the array.

Whereas the original charge controllers limited generation capacity to 17.6kWp, we can now achieve approximately 20kWp. This stands us in good stead for any further increases in available solar energy.

Control system for resistive heating system

There have been three iterations of the control system, as discussed in section 4, demonstrating continuous improvement using data generated from the building.

The display screen shown on page 40 has been decommissioned, as it proved to be difficult to update. This will be replaced with a display screen as used in the Active Office, which pulls data directly from the database to display on a real-time display presented on a television screen. Displaying energy usage and consumption is a critical part of our demonstrator buildings, connecting building users with their energy consumption and how they could align this with weather conditions, for example.

PV window

In September 2017 we retrofitted a prototype PV window developed by one of our main industrial partners, NSG, as shown in Figure 45 below. This is called Pilkington Sunplus™ BIPV and consists of narrow strips of silicon wafer embedded into the double-glazed unit, covering 50% of the window pane, which is 830mm^2. As this window represents micro-generation of electricity (max 77Wp), rather than run lengthy cables from the window to the battery system, which would have resulted in significant losses of power, the window is connected to a small display screen adjacent to the window, via a micro-inverter, which displays its power generation. We were advised that the design performance of the window under standard test conditions was 77W. The window was manufactured using a 50% opacity figure, i.e. 50% of the visual area was obscured by the thin Silicon devices.

Figure 45 External (left) and internal (right) views of the PV window

For the period between 23/09/2017 and 07/10/2019 a reference panel was erected next to the Sunplus window in order to help assess the impact of the shading present from the deep window reveals. The methodology used was to compare the power output as a percentage of the peak output as measured under standard conditions (or advised on the data sheet). Figure 46 below shows the peak power throughout the monitoring period in watts. Figure 46 illustrates the difference in performance during the day as a direct result of the shadowing on the sunniest days at either end of the test window.

Three main aspects are being tested:

- Installation
- Performance
- Aesthetics

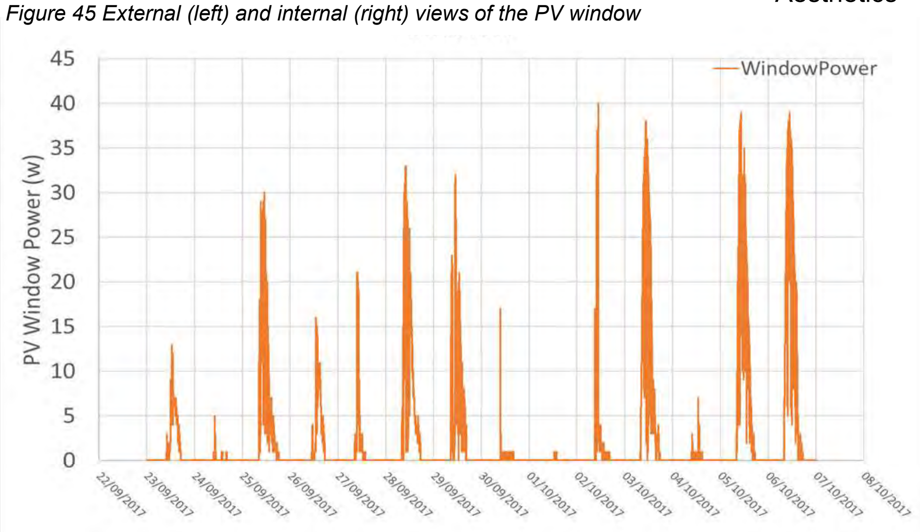


Figure 46 : Absolute power output of the Sunplus window during the test period

7 Use

As shown in Figure 47 below, the window achieved approximately 50% that of the reference panel in terms of rated output and, during the test period, there appears to be an increase in relative performance as the sun is lower in the sky. This fits with the solar shading design of the window reveals, which are designed to shade the window during the summer months and allow solar heat gain during the winter months. Although the test period is relatively short, it does appear that the lower sun has reduced shade on the panel so that the relative performance is improved. This is illustrated in Figure 48, where the difference between the reference panel and the Sunplus window is plotted for the two sunniest days at the start of the test period and at the end. This clearly shows that on the 05/10/2017 there is a reduced performance deficit when compared to the 25/09/2017.

Based on this experiment it is clear that in order for products such as this to be successful, it is important to take into account the building design when specifying the Sunplus product, and that a different electronic design, whereby shadows could be predicted and somewhat accounted for in the electrical connection design, such that partial shading around the perimeter or at the top or bottom of the window could use a different maximum performance tracker, or via the inclusion of bypass diodes such that minor shading does not have such a large increase in terms of overall performance. This learning can be relayed back to the window manufacturer to inform their product development.

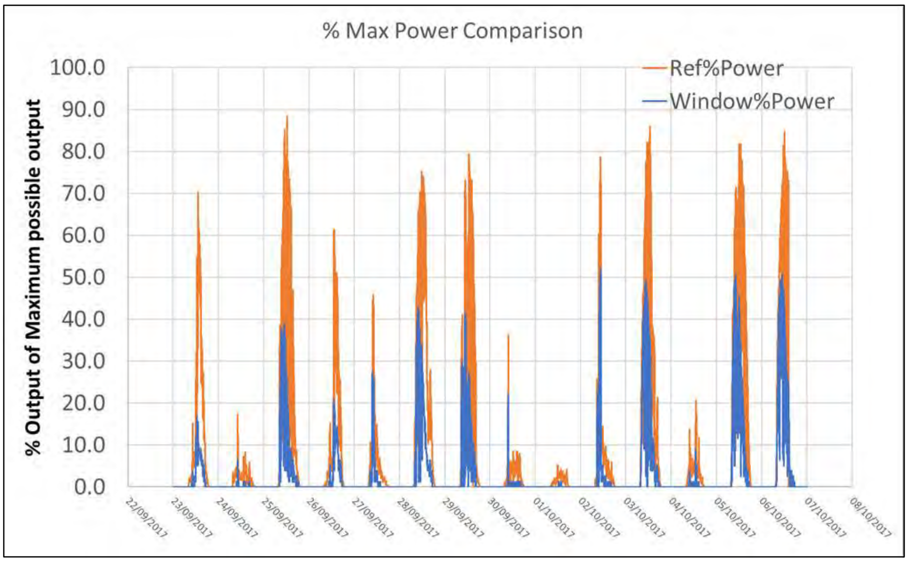


Figure 47: The power output of the Sunplus window expressed as a percentage of the peak output under standard test conditions, compared to a reference panel (250w Si) denoted in the same way.

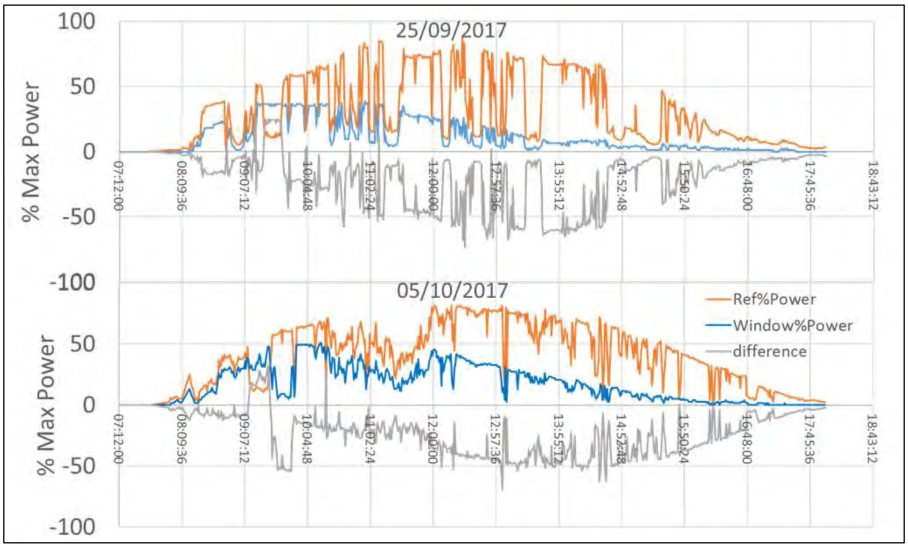


Figure 48: Percentage peak performance of the Sunplus window on two sunny days at either end of the test period.

7.11 Evolution of the Building Management System

The Building Management System (BMS) for the building has been subject to several iterations, mainly because there was no suitable off-the-shelf BMS available at the time of designing the building. The initial idea was to procure a standard BMS, but this proved difficult as we were not BMS installers and considered an end-user. This meant it was difficult to obtain the necessary equipment and documentation from BMS providers.

1. Our first stage was to procure a Siemens Programmable Logic Controller (PLC) off-the-shelf, which was industrially robust. However, this came without technical support, so our Smart Systems Engineers worked with this, adapting it for a purpose it wasn't necessarily designed for, i.e. building control. PLCs were first developed in the automobile manufacturing industry and have since been used for applications involving logic-based, repetitive processes. Our engineers set up the PLC to work with the display panel they had designed, enabling the two devices to communicate.

2. The second stage migrated this system to a Schneider EcoStruxture BMS, which was compatible with the wider university infrastructure, and is more flexible and scalable across building projects. It is also suitable for large scale control. However, the downside was that it is expensive and difficult to get a license for, as licenses are only available to controlled partners. Without a full-access account, not all features were available to us, which was frustrating and hampered our progress.

3. The system has now migrated to a Cisco Kinetic Edge and Fog Processing Module (EFM), which is a distributed system of software designed specifically to extract, compute and move data from devices that make up the Internet of Things (IoT) to the various applications where it can provide value. There is some reticence about running the BMS through software via a Personal Computer (PC), so we are currently using Raspberry Pis, which are low power PCs with minimal components, so there is less to go wrong and less likelihood of hardware failures – these act as a bridge. BMSs are reliable as they are not connected to the IoT, whereas once connected to the internet there is more potential for problems.

At this stage, the different systems are being evaluated, to determine which is the most robust. However, the main problem with evolving the BMS in this way is that it is difficult to validate each system now, due to the short length of time each has been operational. In addition, there are many variables to the operation of the building generally, adding to the complexity of accurately analysing data collected.

In terms of data collection, most BMSs collect 15-minute data, which is relatively easy to analyse, but with 15-minute sampling there is potential for significant data, such as changes to room temperature and weather changes, to be lost. For this reason, we are collecting 1-second data for power and 5-second data for environment. There is little point in collecting 1-second data for environmental conditions as changes to room temperature, for example, will not take place within 1-second intervals. Higher resolution data enables identification of problems such as whether a particular sensor is working, which could be missed with 15-minute data. This is useful in identifying why things happen, using the many data points to determine trends in data and highlight anomalies.

Currently data is collected across two systems – the Cisco EFM is collecting most of the data, but we also use our own system. The Cisco EFM is collecting data at a lower rate than our bespoke system, mainly because of the storage capacity of the PC it runs on. Because we want to validate things, we are also transferring data back to the bespoke system at a higher frequency.

To visualise data, we are using software called DG-Lux. The Cisco EFM and DG-Lux are capable of interfacing with many BMS systems. The use of these combined packages allows very fast access to the data and the ability to show trends in data. They can also be used to instil control and add intelligence into the system, becoming the BMS brain and control algorithm.

7 Use

For the bespoke system, programmed by our Smart Systems Engineers using Java, we have a number of Raspberry Pis that act as a proxy to get the data. There is a processor in the Raspberry Pi which has the responsibility to contact all the equipment. This enables all the data to be bundled together in a way that is agnostic to the equipment/vender and extracted from the data, so we end up with a data stream that just looks like data, referenced by where the data has come from. That is saved in the database on our server and we interpret it and send it back out. If we lose a connection, then it saves it locally and then re-synchronises when the connection is reinstated. Because our main objective is to collect data every second and guarantee it gets somewhere every second, if it doesn't save on our server, we can send it later. Achieving that is difficult because there are so many things that could go wrong, such as people turning equipment off, devices restarting, the network going down, or operating system updates, for example.

The world of data is moving and changing all the time so making something that is generic and will function with any device and remain robust is challenging. The reason for using Java is that it is portable, i.e. it runs on most devices, and it is relatively easy to make user interfaces with. It offers a common platform to write software that will run anywhere, so it doesn't matter what make the PC is, it should always run. The main reason for this is to fulfil our requirements for large data capture, something that doesn't normally happen on buildings, but enables us to do analytics.

7.12 Energy use within the classroom

Figure 49 adjacent shows that 60% (4.8MWh) of the building's energy consumption was consumed by the heating system in 2017. Based on the design U-values, a lower percentage would have been expected, although 60% is typical of most buildings. Overall, energy consumption of the classroom is lower than average. The Thermography Survey carried out during March 2018 identified significant thermal bridging which will result in a higher U-value than designed for. This will be calculated during the current heating season.

Metering in the Active Classroom now includes thermal output, enabling custom control of high load devices, such as: the 10kWp resistive heating system, the 1kW ASHP and the radiant heaters.

The system also enables the simulation of custom usage profiles and provides a platform for assessment and frequency events.

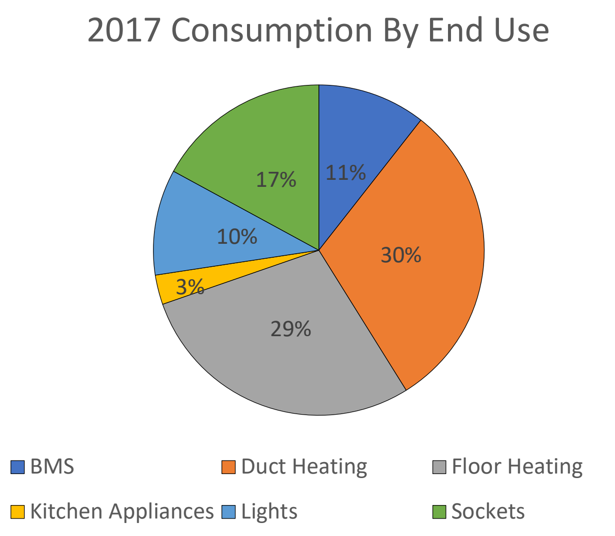


Figure 49: Consumption by end use for 2017, Courtesy of Dr Justin Searle, SPECIFIC

7.13 Carbon

In 2019, a PhD student at the University of Bath commenced a research project in collaboration with SPECIFIC to undertake a Life Cycle Assessment (LCA) of the Active Classroom. For a full LCA, a vast amount of information on the building is required, including site operations, transport, materials, operational data.

To just highlight one example of the complex nature of an LCA, in terms of transportation, the system Matrix manufacture for the superstructure could significantly reduce carbon emissions associated with transporting construction materials to site. Matrix are based in Telford. For this project they travelled to Swansea several times a week and, due to the fact that they were in the early stages of establishing their manufacturing processes and the short timescale for the project, were unable to have made all the necessary panels prior to commencing site works. Therefore, the panels were transported to Swansea in several separate loads. However, their system lends itself to significantly reducing carbon emissions from transport. With its flat-pack nature, the whole building could be transported to site in one load and erected in just a few days. This potential was not realised on this project, but will be for all future projects Matrix deliver, once their manufacturing process is finetuned.

The PhD project will not be completed until 2023, but regular contact with the student means we are able to identify the main issues identified as he analyses the data available from the building. If any data is missing, we will be able to ensure we capture this for future projects. As the doctoral project progresses, the student will be preparing academic papers as the research progresses for presentation at international conferences and publication in journals.

7.14 Key Learnings

- For an Active Building to operate effectively, a fabric first approach is essential. We used a new form of construction which could not guarantee the fabric efficiency needed For more certainty and improved performance, fabric efficiency is paramount.

- Always ensure robust contractual arrangements are in place. Due to the nature of the project, Matrix Structures were not appointed under a particular construction contract, but were simply procured, using Swansea University's compliant procurement process, via a Single Stage Tender. In this case, it was not possible to nail all the details before awarding the contract, but this is risky and not advisable for construction projects.

- Collaborative working and good communication with all stakeholders is essential in all building projects, but especially when the project involves innovative products, technologies or processes.

- Install more metering equipment, particularly within the solar thermal system (the TSC).

- Build more resilience in to the heating system. It has been a struggle to provide sufficient heat to the building during cold weather spells.

- Undertake occupant surveys. This was difficult on this particular building, due to the occupancy patterns and the use by different groups.

- Much learning comes from mistakes and unplanned events. This should form a positive part of an end-of-project review and not be covered up or brushed aside.

- Products and technologies (particularly innovative ones) are not always as advanced as the manufacturers initially state. It is important to proceed with caution with any new product or technology.

- When installing a BIPV roof, the dimensions of the roof panels dictate the overall roof size; cable runs from the roof panels must be designed in – the BIPV product will affect the roof build-up.

- If installing small amounts of PV, e.g. PV window, thought must be given to how the power from that element will be used, how much power is being generated, what can it usefully contribute to.

Summary Checklist

Active Building Principle	Actions	Issues identified

Principle 1	• South orientation with unshaded roof
	• Simple building form
	• Use of natural, cross ventilation
	• Plenty of good quality, natural light
	• Air-tight building envelope
	• Thermally efficient envelope
	• Thermally efficient windows – timber/ aluminium hybrid with Pilkington energikare advantage glass
	• Living wall for biodiversity and reduced run-off
	• Integral bird boxes for biodiversity
	• Construction method: off-site, panels
	• Materials:
	    • Steel screw pile foundations
	    • Steel cladding
	    • EPS insulation
	    • Magnesium oxide board
	    • Recycled plastic worktops
	    • Re-used carpet tiles
	• Welsh or UK suppliers used where possible
		• South elevation partially shading during winter months
		• Thermography indicates thermal bridging around panel joints, junctions and window frames

Principle 2	• MVHR and ASHP (Genvex) combined with solar thermal system
	• Low energy lighting with daylight dimming and proximity sensors
	• Novel underfloor heating system
	• Novel radiant panel heaters
	• Water saving appliances:
	    • Low water use toilets
	    • Air-flush urinal
	• Sensors and other monitoring devices installed to allow data collection
		• Benefits anticipated from linking the solar thermal system to the Genvex unit were not realised

Principle 3	• Building integrated PV (BIPV) roof • Transpired solar collectors • PV window	
Principle 4	• Electrical storage – 60 kWh aqueous hybrid-ion batteries • Small thermal store in MVHR/ASHP unit	• Batteries failed after three years, so were replaced with 120 kWh Flow batteries (March 2020)
Principle 5	• External smart socket for EV charging – will only charge EVs if batteries over 60% full	
Principle 6	• Bespoke building management system which makes decisions on energy flows to and from the grid	

Awards and Recognition

Awards
- Constructing Excellence in Wales 2017 – "Innovation"
- Wales Green Energy Awards 2017 – "Contribution to Skills and Training"
- RICS Wales 2018 – "Design through Innovation"
- RICS Wales 2018 - "Project of the Year"
- 2018 Building Excellence Wales Neath Port Talbot, LABC Wales – "Best Public Service Building"
- Swansea University Research and Innovation Award 2018 – "Outstanding Research and Innovation Collaboration"

Articles
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An innovative case study of a newly constructed building that generates more energy than it consumes.

Buildings as power stations
A case study:
The Active Classroom

Article in BSRIA Delta T magazine


Schoolchildren planting the Living Wall during Newsround filming

"The Active Classroom is one of those rare projects that embodies the concept of innovation. It offers a clear path to the future of construction and power generation in the same package. It offers a "flat pack" building system that could be erected speedily almost anywhere with little need for the groundwork & wet trades associated with conventional construction. As a pioneer project it points a way forward for domestic and commercial construction with an adaptable and rapidly constructed modular system that lends itself to use in virtually any part of the world. It is quite reasonable to state that the development of this technology offers life changing benefits for all." *RICS Wales Project of the Year 2018*

"The judges applauded the clarity of the project's goals, the intelligence of the execution, and the teamwork involved in designing and building a structure with so many unknowns. The result is a facility with the potential to bring about a real change in the way buildings are conceived, designed and constructed." *Constructing Excellence in Wales Innovation Award 2017*

Appendix 1 – List of companies involved

Company Name	Responsibility
AcerMetric Ltd	Panelised offsite construction system designer
AECOM	Building Services Consultant
BIPVCo Ltd	PV panel supplier
BOF	Internal furniture supplier
CB3	Structural Engineers
Faithful & Gould	Cost consultants
IPS Roofing	External cladding supplier and installer
Kier Group plc	Main Contractor
Matrix Structures Ltd	Superstructure Manufacturer and Installer
Moixa	Prototype battery supplier
NSG	Glass supplier for external doors, windows and curtain walling
Redflow	Flow battery supplier
Smile Plastics	Manufacturer and supplier of kitchen worktops
SolarPlants	PV and battery system installer
Stride Treglown	Landscape Architects
Tata Steel	External Cladding manufacturer, including Transpired Solar Collector (TSC) Internal Coretinium “Idea Wall” supplier
Total Home Environment	Supplier of Genvex Air Source Heat Pump (ASHP)
Treebox	Living wall supplier
Vellacine	Window and external door supplier and installer
Wind and Sun	Battery System supplier, specialist system design and installation support