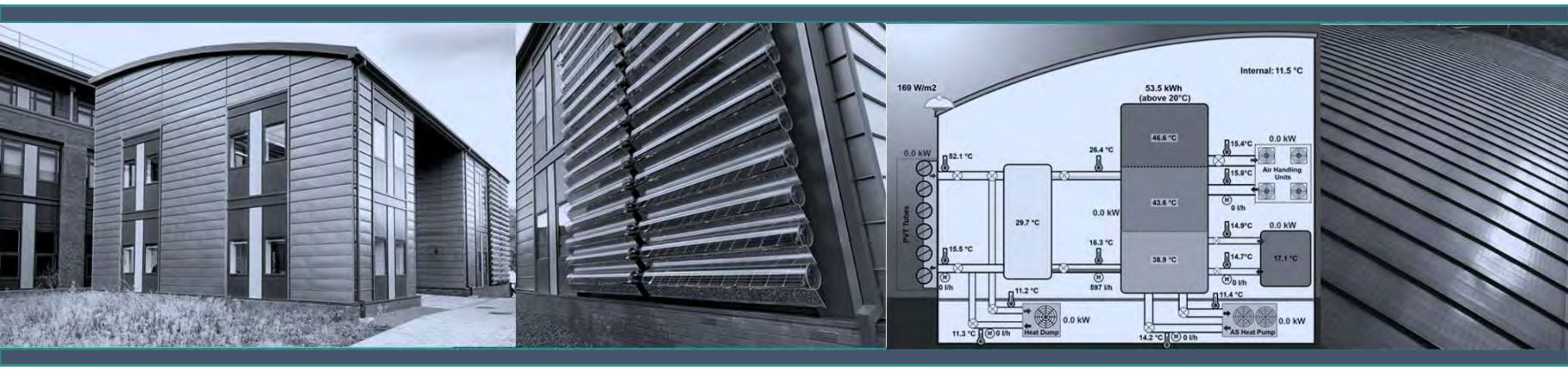
Active Office Case Study

Version 1.0, October 2020



Credits

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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 AkzoNobel - 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 industrial coatings and appropriate deposition technologies, such as printable photovoltaics; a screen printable 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 that ***"support the energy network by intelligently integrating renewable energy technologies for heat, power and transport."***

Following the success of the Active Classroom demonstrator in 2016, in October 2017 SPECIFIC were awarded funding from Innovate UK to construct a second building adjacent to the Active Classroom. Known as the Active Office, this was constructed in 2018 and is shown as the curved roof building to the left of the image in Figure 1 below. Important considerations for the building, stipulated by the funders and also to satisfy SPECIFIC's aims for demonstrating, included that it should:

1. Demonstrate the Active Building concept;
2. Use commercially available, although novel, technologies, integrated to optimise the operation of the building;
3. Be repeatable, offer a solution that could be replicated by existing supply chains;
4. Be used for its intended purpose, i.e. as an office building;
5. Be used as a test-bed to trial different ways of trading energy with the grid – by using intelligent controls and energy storage, the building management system should be able to select optimum times to import and export energy to and from the building, dependant on different factors. This will be discussed later in the document;
6. Integrate electric vehicle charging.

To add to the challenge, the funding needed to be spent by the end of March 2018!

Figure 1: The Active Office, 2018

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 (2018), but technology is rapidly evolving. Therefore, at the time of reading this document, it is possible that some of the more mainstream technologies could 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 Office is located adjacent to the Active Classroom 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 Office, 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.

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 and funding requirements, as highlighted in Table 1 below.

2017	**Key Activities**	**RIBA Stage**
October	SPECIFIC were granted funding from Innovate UK to construct a second building demonstrator adjacent to the Active Classroom on Swansea University's Bay Campus	0
	First engagement with Wernick	3-4
November	Commenced discussions with Wernick and their supply chain partners	3-4
	Started concept design, including discussions with key stakeholders	0
	Commenced discussions with Local Planning Authority	0-3
	Submitted Planning Application	2-3
December	Awarded contract to Wernick using a Fusion 21 Framework Contract	4-5
	Planning Consent was granted	3
2018		
January	Construction and Manufacturing commenced – groundworks and substructure completed	5
	Spatial coordination and technical design were ongoing	3 - 4
February	BIPV roof was manufactured	5
	Modules forming the superstructure were brought to site	5
	Cladding details were resolved	4
	M & E design was ongoing, including discussions with Naked Energy re: PVT tubes	4
March	External cladding commenced and curtain walling installed	5
	First meeting held with the battery installers	4
	M & E first fix commenced	5
April	Ongoing building services design	4
	BIPV roof installed	5
	BMS installer meetings took place	4
May	Cladding and living wall completed	5
	Internal fixtures and fittings design – furniture and internal decoration (branding)	3
	EV chargers installed	5
June	Building construction was completed	6
	Grid connection was completed	5
	Commissioning took place	6
June 2018 - present	Ongoing Building Performance Evaluation (BPE) through monitoring of sensors, thermography and optimisation of systems	7
December 2018	Installation of the PVT tubes	5

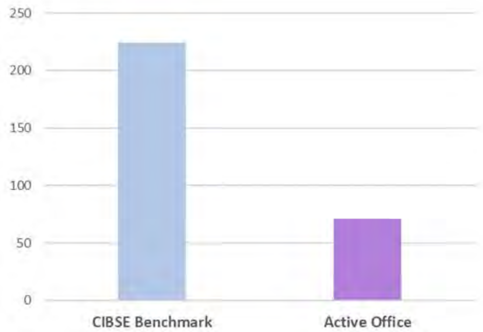
Table 1: Key Activities related to dates and RIBA Stages

Active Office Summary

The following illustrates the Case Study for the Active Office, *1 year post-commissioning (mid-optimisation)*, written 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 offices was 224 $kWh/m^2/yr$ and they collected data on offices using ≤ 112 $kWh/m^2/yr$

Location:	**Swansea**
Year of completion	**2018**
Floor area	**376m²**
Approximate occupancy	**12m²/person**
Client occupier?	**Yes**
Contractual performance target	**Yes**
Design prediction of energy performance	**Yes**

Energy consumption	**61kWh/m²/yr (23,270kWh/yr)**
Energy generation	**60.5kWh/m²/yr (22,851kWh/yr)**
Net energy consumption	**0.5kWh/m²/yr**
Annual carbon emissions	**-9 (design stage)**



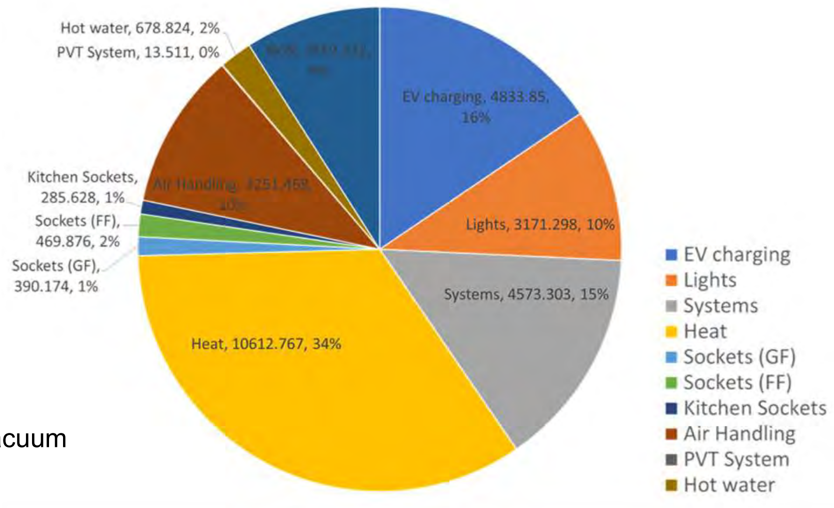
Approximate form factor	**2.19**	External envelope area/floor area
Quality assurance during construction?	**Yes**	Not as much as anticipated
After care and post occupancy monitoring?	**Yes**	Enabled via extensive metering of circuits
Envelope performance	Walls: 0.15W/m²K Roof: 0.12W/m²K Floor: 0.13W/m²K	Design figures
Heating system description	**Electric**	Solar thermal and ASHP supplying a thermal store, dissipated through AHUs
Hot water generation description	**Electric**	Solar thermal, ASHP and immersion heater
Main ventilation type	**Natural**	Supplemented with night time purge ventilation
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 Office Summary

Key statistics on generation and consumption: 1st year of operation (2019)

	Annual Figure
Total Consumption	31 MWh
Total EV Charging	4.8 MWh
Total Building Operation	26.2 MWh
Total Generation	22.6 MWh
Total Generation from BIPVCo roof	18 MWh (16.6 MWh actual)
Total PV Generation from PVT system	1.8 MWh
Total heat Generation from PVT system	2.8 MWh
Shortfall of energy	4 MWh

High Level Performance for 1st year of occupancy



Strategy for improvement

Generation

- Thermal output of Tubes
  - Light intensity triggering added
  - Tubes replaced in march 2019 due to lost vacuum
  - Thermal store temperature reduction
    - Enhanced stratification
    - Lower setpoint – enabled by larger heater batteries in AHUs
  - Temperature following algorithm added to ensure lowest buffer loop temperature
- PV output of Tubes
  - Damaged units replaced (7 of 40)

Consumption

- 6kW immersion was used for a short period of time in error, putting 2.8MWh into store, whereas the ASHP (with a COP of 3.3) would have only used 0.9MWh = 1.9MWh saved (47% of target saving)
- Lighting
  - 10% of all energy used on Lights (3MWh)
  - Better Lighting control will be implemented – centralised DALI controls to be added
  - 10% saving seems achievable (0.3MWh, or 7.5% of targeted saving)
- Thermal efficiency
  - Lower setpoint in thermal store – for the 1st heating season, this was set at 60ºC as the heater batteries installed in the AHUs were sized incorrectly. These were replaced with larger batteries before the 2nd heating season, enabling temperature of store to be maintained at 45ºC.
  - Timer controls will be optimised
  - The heating system will be linked to weather data, enabling better prediction and control of heating needs.
  - Leaks in the AHU and issues with the AHU turning off have been resolved, and pressure control optimised
    - 10% saving (1.3MWh (32% of targeted saving)

At design stage, the Active Office obtained an Energy Performance Certificate (EPC) rating of A+, with carbon emissions predicted to be -9, as illustrated below.

Energy Performance Certificate
Non-Domestic Building

HM Government

MODULAR OFFICE BUILDING - SPECIFIC
Swansea University Bay Campus
Fabian Way
Crymlyn Burrows
SWANSEA
SA1 8EN

Certificate Reference Number:
0030-3992-0318-4964-3124

This certificate shows the energy rating of this building. It indicates the energy efficiency of the building fabric and the heating, ventilation, cooling and lighting systems. The rating is compared to two benchmarks for this type of building: one appropriate for new buildings and one appropriate for existing buildings. There is more advice on how to interpret this information in the guidance document *Energy Performance Certificates for the construction, sale and let of non-dwellings* available on the Government's website at www.gov.uk/government/collections/energy-performance-certificates.

Energy Performance Asset Rating

More energy efficient

Less energy efficient

Technical Information

Main heating fuel:	Grid Supplied Electricity
Building environment:	Heating and Natural Ventilation
Total useful floor area (m^2):	391
Assessment Level:	4
Building emission rate ($kgCO_2/m^2$ per year):	-8.95
Primary energy use (kWh/m^2 per year):	102.41

Benchmarks

Buildings similar to this one could have ratings as follows:

23 If newly built

77 If typical of the existing stock

In a Life Cycle Cost Report undertaken by Faithful & Gould in 2019, the Active Office was shown to produce 1/3 less carbon emissions than a standard office building of the same size. Using data from the building, the SPECIFIC team are working to prove how realistic the EPC rating is in practice. In 2020, once the commissioning phase has been completed, they will commission a Display Energy Certificate (DEC) to determine the actual rating and how it compares with the predicted. If there is a mismatch, the team will use the data collected from the building to identify the factors contributing to the difference.

Active Office Overview

The Active Office was designed to satisfy the criteria for an Active Building and contribute to SPECIFIC's demonstration programme, combining the Active Building principles in one building, as illustrated in Figure 3 below.

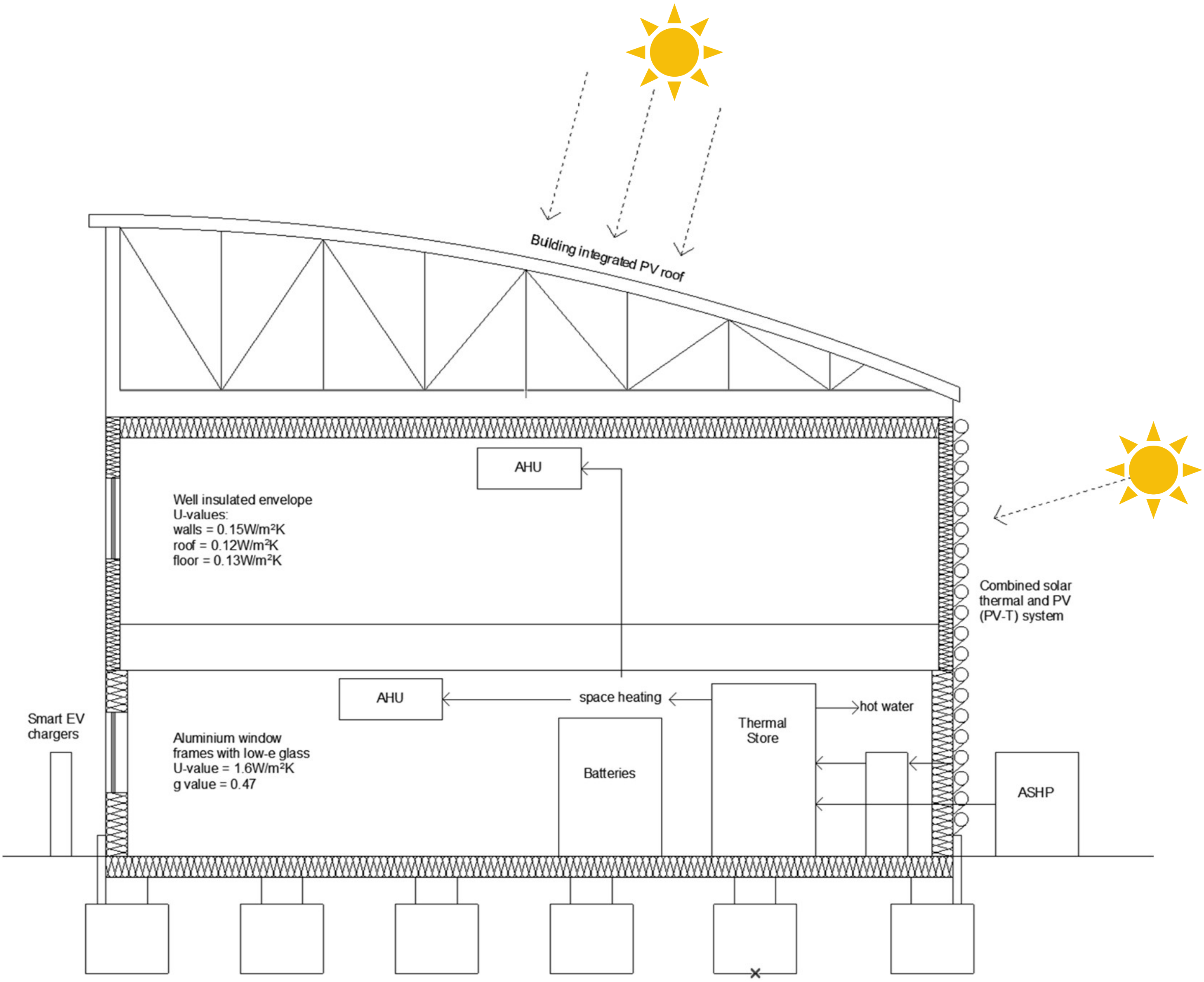


Figure 3: Section showing Active Office Overview

Key components:

- Modular construction on concrete pad foundations
- Thermally efficient building envelope
- South facing aspect – enabling solar energy generation on roof and south elevation, using PV to generate electricity and a combined solar thermal and PV (PVT) system for space heating and hot water
- Electrical and thermal energy storage included to enable control of import and export of energy to and from the building
- Provision to retrofit a thermo-chemical storage system currently under development by SPECIFIC
- Electric heating system (no gas connection)
- Smart EV charge points, working as part of a remote virtual power plant
- Extensive data monitoring for optimisation of building performance

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 repeatable demonstration building to showcase commercially available, innovative technologies, integrated to optimise the operation of the building.

Key Priorities/goals: The building must:

- Demonstrate the Active Building principles and aim to generate more energy than it consumes over an annual period
- Use innovative products and technologies
- Be completed by June 2018

Building Type and Purpose: The main purpose of the building was to demonstrate the Active Building concept, using lessons learnt from the Active Classroom, to optimise the building control systems, to be capable of trading energy with the grid in a controlled manner. The building would provide a platform to test different ways of trading energy, depending on factors such as energy prices, carbon intensity (CI) of the grid, occupancy, and weather predictions. It would incorporate both electrical and thermal storage, as well as electric vehicle charging.

During it's first year of operation (2019), the building temporarily housed the Active Building Centre team, during their establishment as part of the Transforming Construction Challenge set out in the UK Government's Industrial Strategy, which was launched in May 2018. They relocated during 2020, at which time the plan was for the SPECIFIC team, and several other related project teams (SUNRISE and SUSTAIN) to move into the building. Occupying the demonstration building provides an ideal opportunity for SPECIFIC to monitor and adjust the building's operation.

(Note: due to a Global pandemic in 2020, full occupation of the building by the SPECIFIC, SUNRISE and SUSTAIN project teams was delayed until 2021. However, post-optimisation data is available up to the date prior to the building being put into lockdown, so represents normal operation for that rolling 12-month period)

Key briefing points: Although there was a highly accelerated programme, this building project took learnings from the Active Classroom and improved the process:

- Main Contractor employed from outset
- Combined Solar Thermal and Solar PV, with metering
- Integrated Electric Vehicle (EV) charging
- Two storeys – surface area to volume ratio more challenging
- Thermal store – ability to time-shift heating demand
- Flexibility and option to add a thermo-chemical store at a later date

0 Strategic Definition

Process: In order to design and deliver this building to the extremely challenging timescales, it was necessary to start working with a main contractor as early as possible. Use of offsite construction methods and a local supply chain were also considered in a bid to speed up the process. The fact that SPECIFIC have their own in-house Architect and a strong technical team helped the rapid design of the building and its systems.

Once the funding award was confirmed, the Architect embarked on designing a building that would fit in architecturally with both the Active Classroom and the adjacent Energy Safety Research Institute (ESRI) in terms of aesthetic style. At the same time, discussions with local Modular Building Contractor, Wernick, commenced and regular meetings established to enable the design to progress swiftly using their module dimensions. Meanwhile, the technical team were sourcing suitable technologies to include, and the building was modelled to determine shading impact on the south elevation.

To formally appoint Wernick, without going through a time-prohibitive full tender process, we used a **Fusion 21** framework agreement, which enabled compliance with Swansea University's procurement rules – Wernick were the only contractor in the band £750 - £3million project value. They were appointed in mid-December 2017.

Just one month after starting the design of the building (**14th November 2017**), Wernick submitted a planning application using drawings prepared by SPECIFIC, and we obtained planning consent on **22nd December 2017**.

A contract was signed with Wernick on **14th December 2017**, which enabled them to mobilise works in their factory to start manufacture of the modules and establish a site team to start construction works on site in January 2018. This was prior to achieving planning consent. However, we worked closely with the planning officer during the pre-planning stage to mitigate risk and ensure the design was likely to be agreed.

Budget: Innovate UK awarded SPECIFIC £800,000 for a two-storey office building. The driver for the size of the building was the need to accommodate a minimum of 25 people, with the associated ancillary accommodation, such as toilet and shower facilities, a meeting room and a kitchen space. Using standard module dimensions determined how many modules were needed to provide this accommodation. Due to these constraints, coupled with the desire to use innovative technologies, the budget had to be increased slightly. SPECIFIC were able to use £100,000 of their demonstration budget, provided by the Welsh European Funding Office (WEFO) grant for SPECIFIC, and the remaining £200,000 needed to meet the brief was sourced through the College of Engineering within the University.

As the building was to be used as a base for research, it was VAT exempt, which helped significantly in enabling us to design and deliver a building within (or close to) the original budget allocated.

The total value cost for Wernick's contract was approx. £830,000 (ex VAT).

The battery contract was let separately, procured directly by SPECIFIC via a competitive tender process, identifying a 100kWh minimum battery storage system within the defined space of the Plant Room. This was approx. £100,000.

Contract variations and additional works were covered by the College of Engineering.

NOTE: It was anticipated that this building would cost more than a standard office building of the same size, due to the innovative technologies and products, the timescales, the additional metering needed for capturing data, and the complications of the energy strategy to ensure energy resilience. These initial additional capital costs should be offset during the lifetime of the building through reductions in running costs. In 2019, Faithful & Gould were appointed to undertake a Life Cycle Cost Comparison (LCCC) Report of the building, comparing it to a standard office building of the same size. The results of this exercise are discussed later in the document in Stage 7.

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

1.1 The developing brief

At this stage, the plan was to build a two-storey office building to satisfy the Innovate UK funding requirements, provide sufficient space for the growing Active Building Centre team, and meet SPECIFIC's demonstrator objectives. Immediate priorities were:

1. Determine the construction system – early liaisons with local modular building company, Wernick Buildings Ltd, who we had already started to build a relationship with.

2. Liaise with Swansea University Estates who appointed a Project Officer to assist the project development

3. Liaise with Swansea University Procurement team to identify a suitable procurement method that would satisfy both Swansea University's and the funder's procurement rules, whilst enabling a contractor to be appointed swiftly to meet the timescales imposed by the funders.

4. Liaise with Local Authority Planning Department – to establish the possibility of constructing a second demonstrator building adjacent to the Active Classroom.

5. To determine the size of the building, based on the proposed number of occupants and the budget allocation – balancing spatial requirements with a tight budget and tight timescales, liaising with SPECIFIC's Senior Management Team.

6. To determine the purpose of the building from SPECIFIC's point of view, i.e. what should this building demonstrate that the Active Classroom didn't:
    - BIPVCo roof on a curved profile, demonstrating its flexibility
    - A novel combined solar thermal and PV (PVT) system developed by a UK company called Naked Energy
    - Thermal storage as well as electrical
    - Resilience in energy systems to ensure required levels of heating can be delivered to the internal spaces at all times of year, combining renewable energy technologies with storage and intelligent controls.
    - The ability to develop smart control strategies
    - Use of existing supply chains, such that the building could be replicated if required, to demonstrate roll-out possibilities

7. Establish SPECIFIC's data requirements.

8. Liaise with SPECIFIC Industry partners, to ensure they were involved and had an opportunity to trial their products:
    - Tata:
        - Coretinium® wall cladding – for 'idea' walls, demonstrating different configurations
    - NSG:
        - High performance glazing – Energikare™ Advantage
    - AkzoNobel:
        - Pollutant absorbing coatings

2 Concept Design

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
- Design for EV integration, including charging facilities, e-bike storage shelters, PV parking canopies
- Determine electricity network connection locations and positioning of data hub

2.1 Site considerations

Building Position on site:

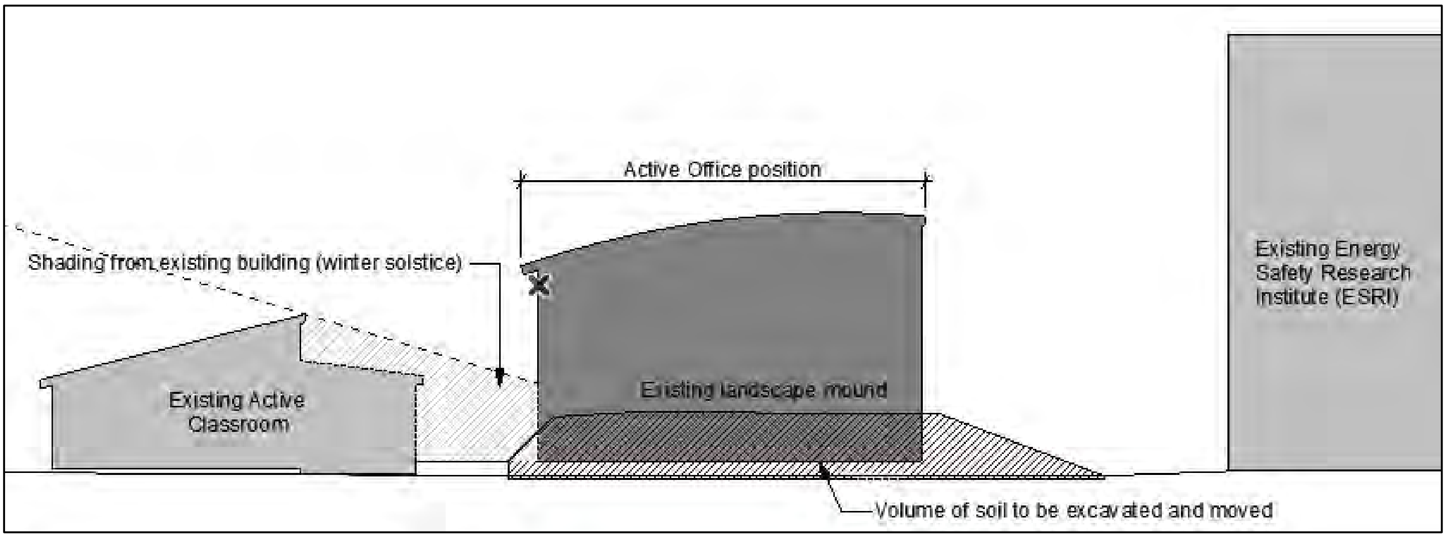


Figure 4: Site section

This cross section through the site shows the balancing exercise undertaken to optimise the position of the building, balancing distance from other buildings to minimise shading of the south elevation and avoiding blocking light from the adjacent Energy Safety Research Institute (ESRI) building.

The excavated soil was redistributed to other parts of the University campus, avoiding the need to take the material offsite. At the time of construction, there were other construction works ongoing within the campus, so the soil could simply be transported to other areas, avoiding potential time delays and additional costs.

Existing trees located within the site area were removed and replanted within the University campus.

2.2 Site Constraints Checklist

Potential site constraints for consideration in establishing a suitable energy strategy and undertaking early modelling are conveyed in Table 2 below:

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		✓	

Table 2: Site Constraints Checklist

2 Concept Design

2.3 Site Analysis

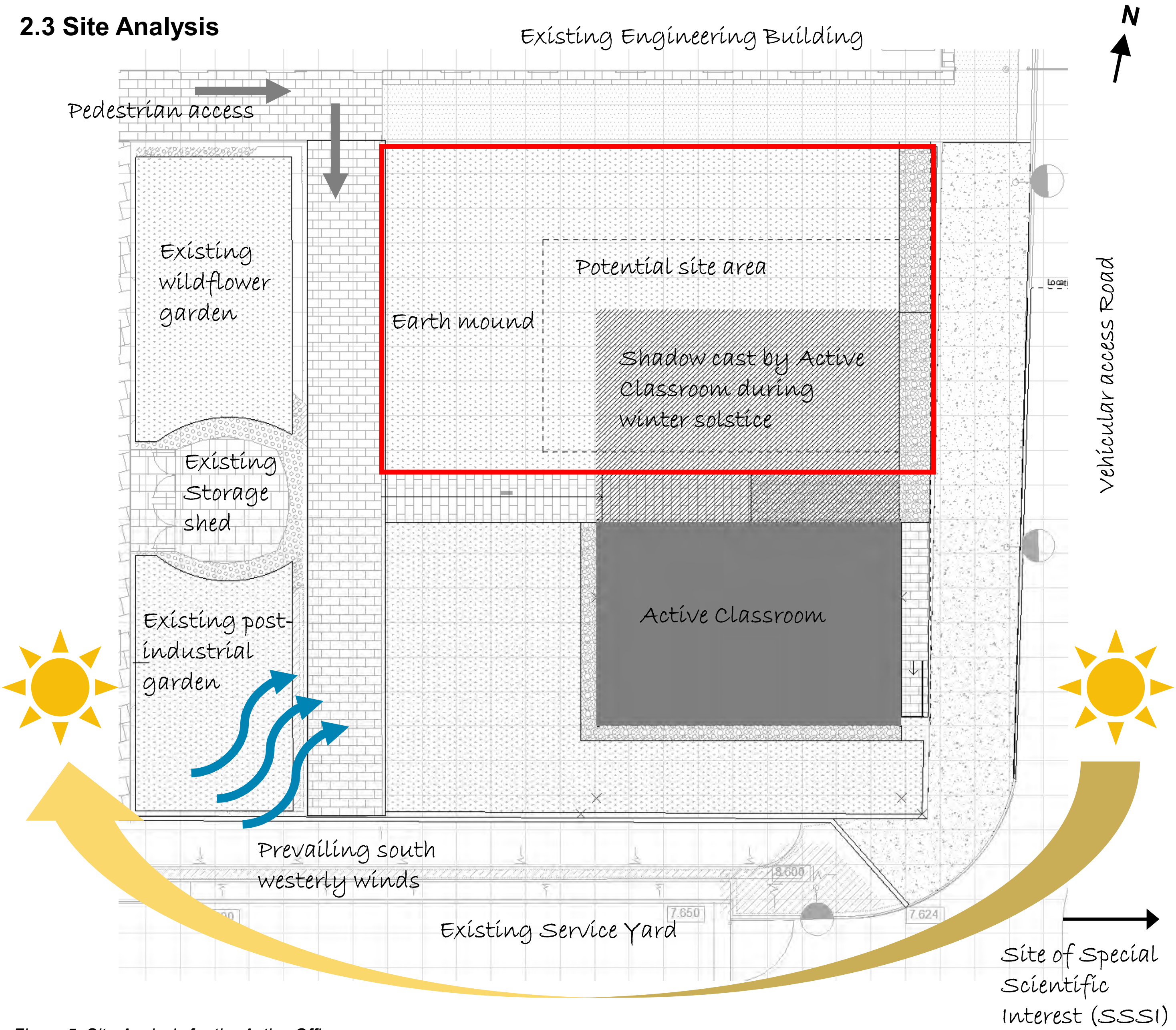


Figure 5: Site Analysis for the Active Office

Figure 6: Photos of the existing site

2.4 Early design considerations

Offsite Modular System

To meet the tight programme for this project, we identified a suitable offsite modular system to use as the main construction method at an early stage in the process. This enabled us to work closely with the module manufacturer to design the building to the module dimensions from the outset, avoiding any redesign work later on in the programme, streamlining the design and delivery process..

At this stage, the exact size of the building was yet to be determined, although it was proposed to build a two-storey building. The exact size would be dictated by costs and minimum occupancy requirements. The initial design consisted of 16 modules, but the final design was reduced to 12 modules to enable the building to be delivered within the budget set by the available funding.

Table 3 below shows how the original brief was adapted to suit the budget. This process highlighted the need to question whether spaces are actually needed in a building, particularly if the building forms part of a wider campus. For example, the client initially wanted to incorporate a boardroom. However, when the initial costs were over budget, the brief was reviewed and the client realised that they could use space in the adjacent building for large meetings, or find another suitable meeting space within the campus. Similarly, the campus has many hot desking spaces which are available to all staff at the University, so there was no need to provide these within the building. This process required some ‘lean thinking’.

Original Accommodation Brief	Reduced Accommodation Brief
Ground Floor	**Ground Floor**
Boardroom for up to 20 people	Chief Executive Office for 1 + meeting space
Chief Executive Office for 1 + meeting space	Administration Office for 2 people
2no. Meeting pods/hot desk offices	Entrance Foyer (no reception desk)
Administration Office for 2 people	Unisex WCs + accessible WC + shower
Reception desk within the main entrance foyer	Cleaners Store
Separate WC facilities for male, female, accessible + shower	Comms Room
Breakout space	Plant Room
Plant Room	Breakout space
1no. Store Room	
First Floor	**First Floor**
Open plan Office for 18 people + meeting area	Open plan office for 14 people
Senior Management Team Office for 4 people	Open plan office for 8 people
Open plan Office for 6 people	1no. Store Room
2no. Store Rooms	
16 modules	**12 modules**

Table 3: Comparison of Original and Reduced Accommodation Briefs

3 Spatial Coordination

November – December 2017

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

3.1 Introduction

The route to procuring Wernick as the Main Contractor to provide us with a turnkey solution for the design and construction of the building was critical, as we needed to appoint Wernick very quickly, while adhering to the University's procurement rules. Although SPECIFIC's Architect had produced initial designs on behalf of SPECIFIC, we needed Wernick to take the preliminary designs and use them to produce detailed design drawings for planning, manufacture and construction. They would also be responsible for submitting a Planning Application, which needed to be submitted well before Christmas, if we were to commence construction works in the new year.

The University often uses Frameworks to procure contractors and we were able to identify a framework agreement called Fusion 21, which Wernick were already registered with. They also happened to be the only contractor for this value of works within the agreement, which enabled us to appoint them before Christmas 2017. Due to our strong relationship with Wernick, they progressed design works and submitted the Planning Application before their formal appointment. The Planning Application was submitted as a temporary planning consent for up to 5 years, due to the already established wider masterplan for the university campus.

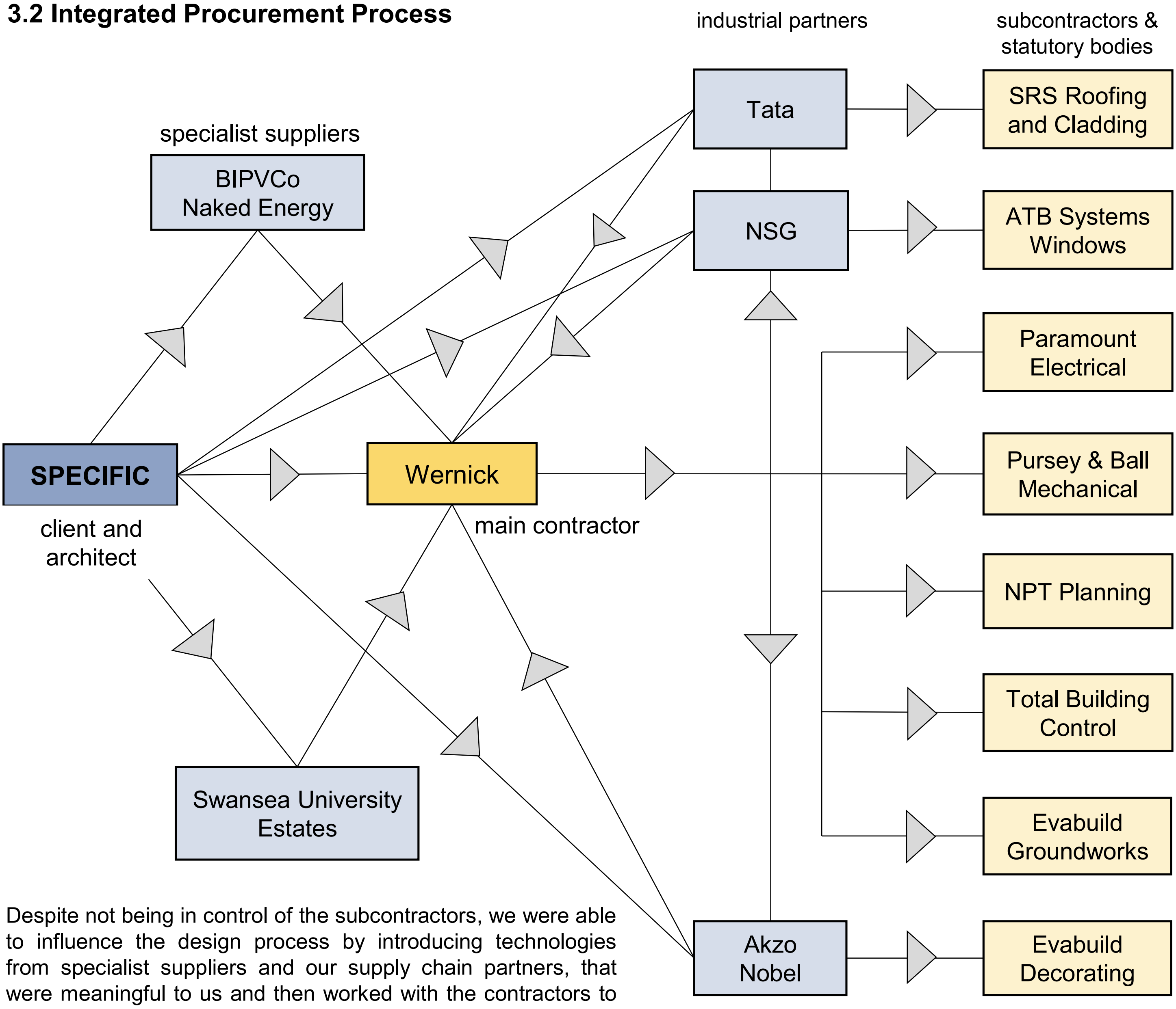
We were keen to use Wernick, as they are local, just 8 miles from the University campus and we had already been discussing the possibility of utilising the Active Building concept on their modular buildings, offering an additional service to their clients.

Close collaborative working was essential between SPECIFIC, Wernick and their supply chain partners during this early stage, in order to develop a scheme that fulfilled the brief, whilst meeting the extremely tight programme. Regular meetings with Wernick and their team were held, working up the design to meet the brief and stay within budget, without compromising the overall programme.

The only downside for us of using a turnkey solution, was that we would not have direct control of the subcontractors. However, Wernick had a strong relationship with their subcontractors, who were all open to working with us and introducing new technologies from specialist suppliers and our supply chain partners. We continued to work closely with Wernick and their subcontractors throughout the design and construction stages to ensure all the elements we wanted to use could be incorporated.

The procurement route through the Fusion 21 framework is described overleaf.

3.2 Integrated Procurement Process



Despite not being in control of the subcontractors, we were able to influence the design process by introducing technologies from specialist suppliers and our supply chain partners, that were meaningful to us and then worked with the contractors to ensure these could be incorporated

FUSION 21 KEY PERFORMANCE INDICATORS:

1.	**Construction Time**:	Offsite construction; Collaborative working
2.	**Construction Cost**:	Offsite process, reduced labour hours and less construction site overheads; Collaboration with contractors and supply chain partners
3.	**Construction Quality:**	Offsite construction = controlled environment, so better quality; Strong relationships with local contractors and their supply chains
4.	**Health and Safety:**	Factory environment = safer working conditions, less work at height, less affected by weather conditions
5.	**Impact on the Environment:**	Offsite construction = less environmental impacts, less waste generated; Use of renewable energy technologies = energy positive; Inclusion of biodiversity elements

3 Spatial Coordination

3.4 Substructure

The building sits on concrete pad foundations. Whilst this type of lightweight building lends itself to use of steel screw pile foundations, the programme dictated that we use Wernick's current supply chain partners, so there was no scope to introduce a different type of foundation than was their standard. This highlights one of the compromises encountered when trying to deliver a low carbon building within a tight programme.

Figure 7: Concrete Pad Foundations

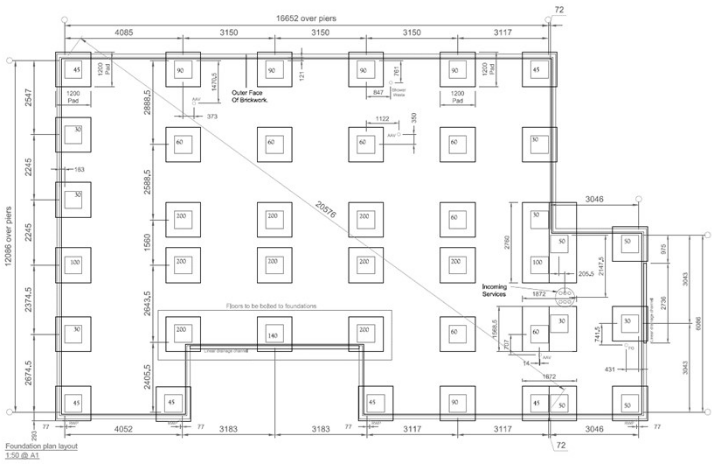


Figure 8: Substructure Layout

3.5 Superstructure

The building utilises Wernick's Rapidplan™ system, comprising 12No. steel framed modules manufactured in a controlled factory environment. Within the steel frame, sit 1.2m wide composite panels, constructed using 100 x 50mm timber frame sections at 600mm centres, with 95mm thick EHD polystyrene insulation fitted between the studs and 25mm thick EHD polystyrene insulation laid over the timber studs behind a plasterboard finish.

External walls use Multipro XS magnesium oxide (MgO) boards with embedded layers of reinforcing mesh as an outer layer, providing fire resistance from inside to out. This is covered with a plastic coated steel finish which can form the exterior finish. For the Active Office, we chose to over-clad this using Tata Colorcoat Urban® plank profiled cladding, for improved aesthetics.

Internal partitions are formed using 12.5mm plasterboard on 72mm metal studs.

The ground and first floors consist of 38mm chipboard on a frame of galvanised steel beams and cross joints, with a combination of Stylite Plustherm EPS and Rockwool insulation between the structural elements.

The roof comprises an insulated warm deck flat roof, consisting of Kingspan KS1000DR composite sheets, as part of the modules, with timber trusses above to form the curved profile. The curved trusses are covered in Tata Colorcoat Urban® plank sheeting with integrated PV bonded to each 'plank'.

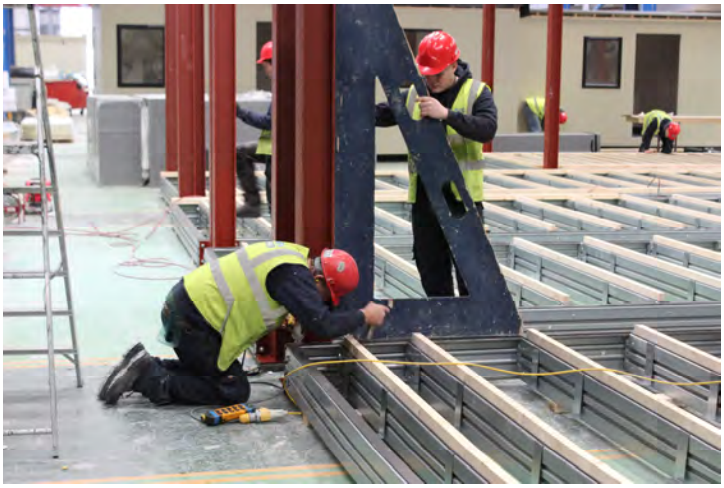


Figure 9: Module manufacture in the factory

Element	U-value (W/m^{2}K)
Floor	0.13
Walls	0.15
Roof	0.12

3.6 Building Finishes

External

The elevations were designed to respond to both the Active Classroom and the adjacent engineering building. To achieve this, the same cladding colours as those used on the Active Classroom were selected, albeit in a different profile. The cladding colours were originally selected to match the materials used on the adjacent and other engineering buildings within the campus. The curtain walling detail of the engineering building was mimicked. Although we had to omit the curtain walling from the final design due to costs, we achieved a similar appearance using individual windows and cladding panels.

Figure 10: Elevation treatment

Living Wall

A living wall was incorporated onto the East elevation of the building, to provide a biodiversity element, to link the building to the adjacent SSSI, and for use as an engagement tool. During this project stage, local primary schools were visited, taught about Active Buildings and took part in seed planting for the wall.

Figure 11: Seed planting for the living wall

Internal: Coretinium® 'Idea' walls

Some of the walls within the office spaces were clad in Tata Steel's Coretinium®, installed by Reform Systems Ltd who became the main installer for Coretinium® within the UK, using their novel flexible fixing system, after installing the system in the Active Classroom.

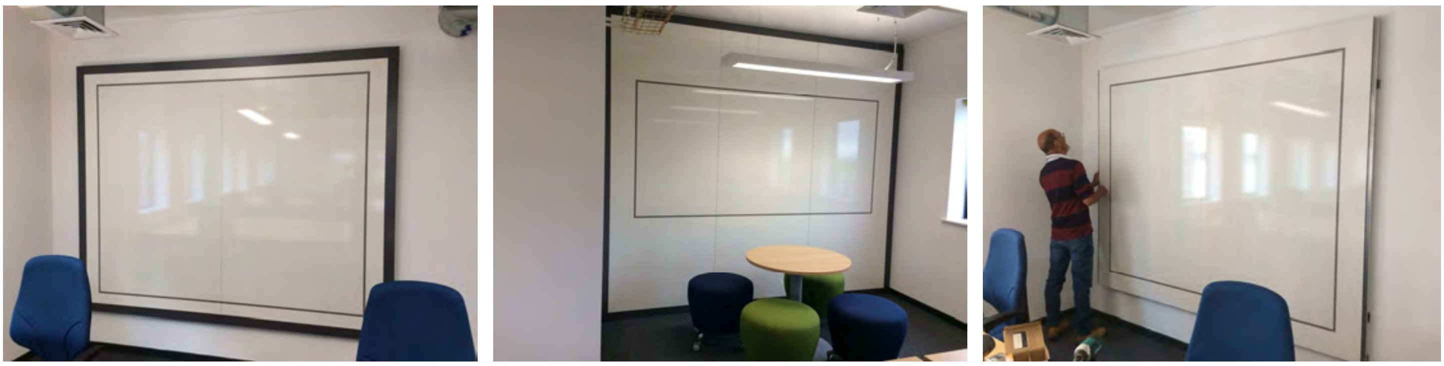


Figure 12: The 3 installations of Coretinium®

3 Spatial Coordination

3.7 Roof

To form the curved roof profile above the standardised, rectangular module, Wernick commissioned a timber frame company to manufacture curved roof trusses, which would be fixed to the top of the first floor modules.

Over the double height entrance foyer, a slightly different solution was needed, as the curved profile would be exposed in this area. For this section, a series of glulam beams were used. It would have been desirable to expose these. However, there was no scope to add an insulation zone above the beams. Instead, insulation was fitted between the beams and covered with a plasterboard ceiling.

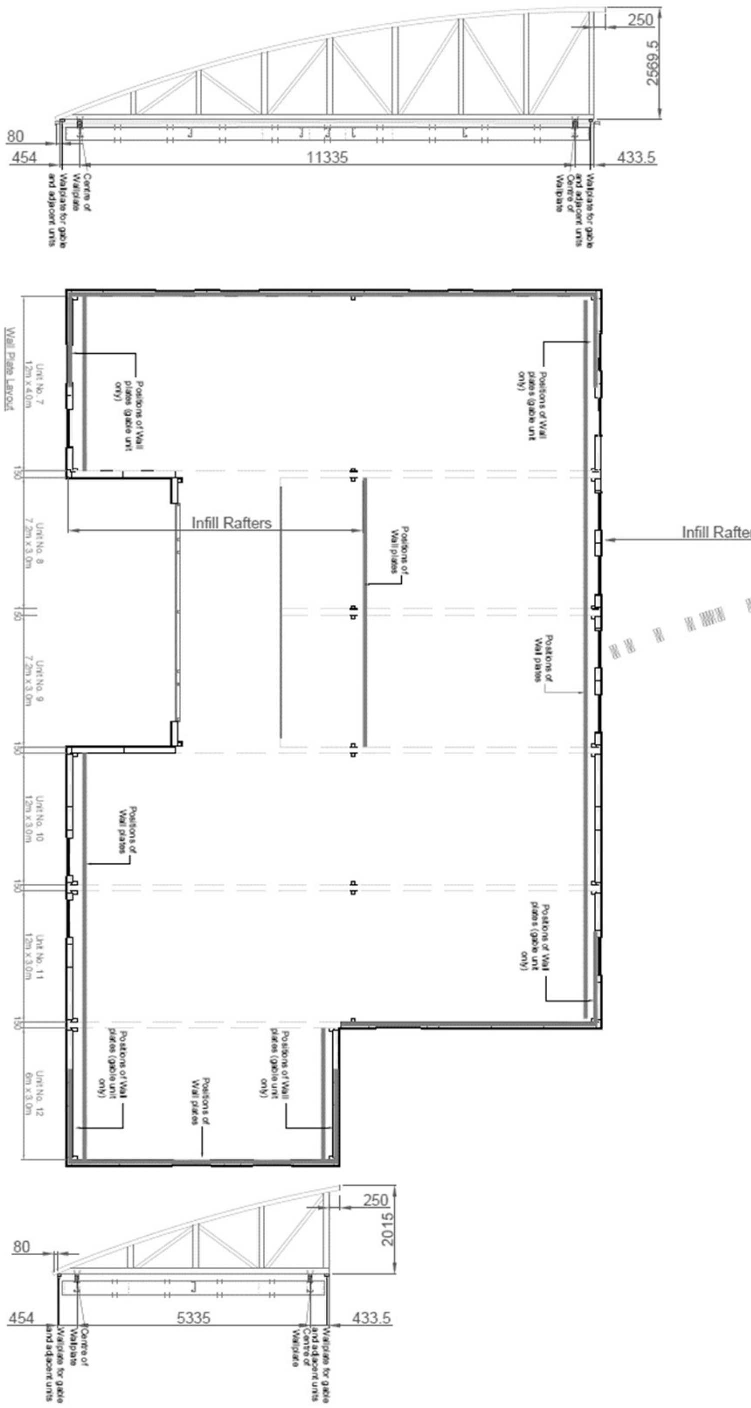


Figure 13: The glulam beams above the entrance foyer

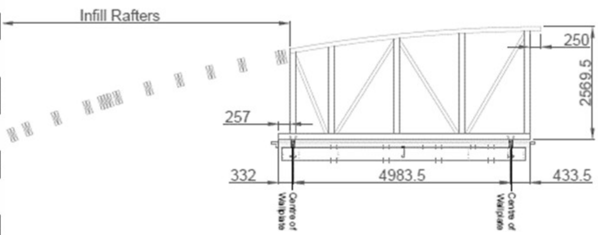


Figure 14: The curved roof truss design

Figure 15: Inside the double height entrance foyer

3.8 Windows

Due to the nature of the contract and the need to adhere to the programme, we were unable to influence the type of windows used, instead using the polyester powder coated (PPC) aluminium windows from Wernick's existing supplier.

We were, however, able to ensure the glass used in the windows was supplied by our industry partner, NSG. The glass is Pilkington energikare™ Advantage, which offers excellent thermal efficiency, with a Ug-value of 0.9 W/m²K, equivalent to triple glazing but in a double-glazed unit.

Also outside of our control was the position of the windows within the external skin of the building. To reduce thermal bridging, windows should be positioned in the insulation zone. However, Wernick's detail positions the windows towards the outside skin of the module. This could potentially cause thermal bridging issues. As the adjacent detail shows, additional insulation could be provided at the window head and within the webs of the structural members to enhance thermal efficiency and prevent thermal bridging.

The same glazing specification was used in the curtain walling at the main entrance.

Figure 16: Curtain walling at main entrance

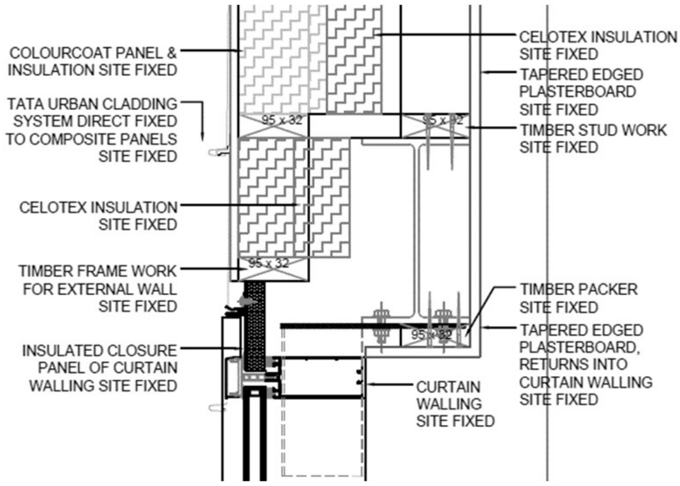


Figure 17: Window positioning within the external wall

4 Technical Design

November 2017 – April 2018

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

The technical design commenced during Stages 2 and 3 for this project, due to the accelerated timescales.

As the construction method used was an offsite modular build system, the only fabric details left to resolve at this stage were the cladding details. Attention was instead focused on the building services or energy strategy.

4.1 Energy Strategy

The driving force behind the Energy Strategy was to determine the feasibility of achieving energy positive status. It was therefore critical to include as much energy generation on the building envelope as feasible. The building fabric had already been designed to the highest U-values possible with the Wernick system and the building was orientated due south. Energy storage would also play a crucial part in balancing supply and demand of both electrical and thermal energy, together with the integration of smart EV chargers. Finally, a robust data collection and monitoring strategy was essential to enable the development of system optimisation measures and predictive control strategies.

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 also necessitates ‘lean thinking’, designing the most direct routes for services and ensuring there are no clashes, which could not be hidden above a suspended ceiling. It also demands services are installed neatly, as they will be visible and form part of the interior decoration.

4.1.1 CIBSE TM:54 Study

During this stage of the project, Arup worked with the SPECIFIC team to develop a detailed thermal model of the building, which would lead to an energy prediction calculation for the building in line with *CIBSE TM:54 – Evaluating Operational Energy Performance of Buildings at the Design Stage*. TM54 is a methodology developed by CIBSE to accurately predict the energy consumption of a building at the design stage utilising a thermal model.

Purpose of using CIBSE TM:54

- Understand energy consumption, carbon, costs
- Align with actual energy use – find & explore issues
- Test alternative scenarios virtually – e.g. reduce plant operating times
- Test against future climate scenarios

The outputs of this model would provide a timely case study for comparing operational energy performance of buildings to design stage predictions, of particular interest as the draft for the new BREEAM 2018 included more emphasis on a more accurate prediction of both regulated and unregulated energy emissions, in order to gain Ene1 credits required for a high BREEAM scoring.

The intention was that comparing model data to real world data would assist in diagnosing issues that might arise (e.g. higher than predicted energy consumption). Once the model aligns with reality the real benefit is to perform further test scenarios such as evaluating the impact of changing how the plant works, or testing against future climate scenarios.

To our knowledge this was to be the first building following the TM54 methodology that has such complex HVAC interactions – such as understanding the impact of how the PV will charge the batteries, and how the hot water generation will be either via solar thermal, ASHP or an immersion heater, depending on environmental conditions.

Arup were keen to undertake this case study as it would provide them with a methodology for undertaking better-informed calculations of energy use in operation, while demonstrating that energy performance is dependent on how a building is run and maintained, as well as how it is designed and constructed.

While we did get some initial results from the model, which were used to resolve potential overheating risks in some of the spaces, Arup were unable to complete the exercise, due to other priorities and timescales for needing to progress the design. However, working through the methodology aided in clarifying the design goals and strategies to achieve them.

ARUP

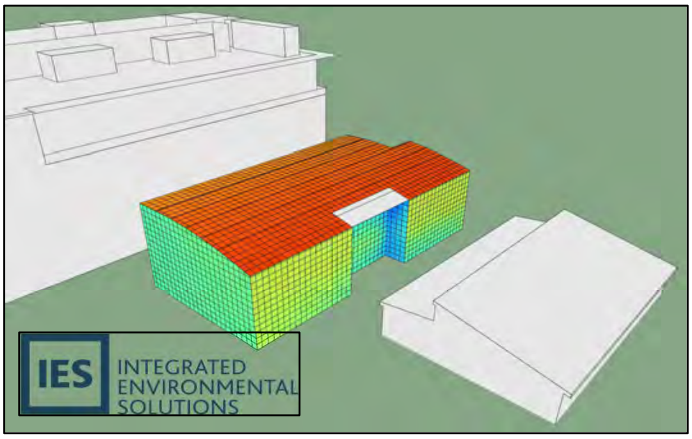


Figure 18: Image from an early thermal model

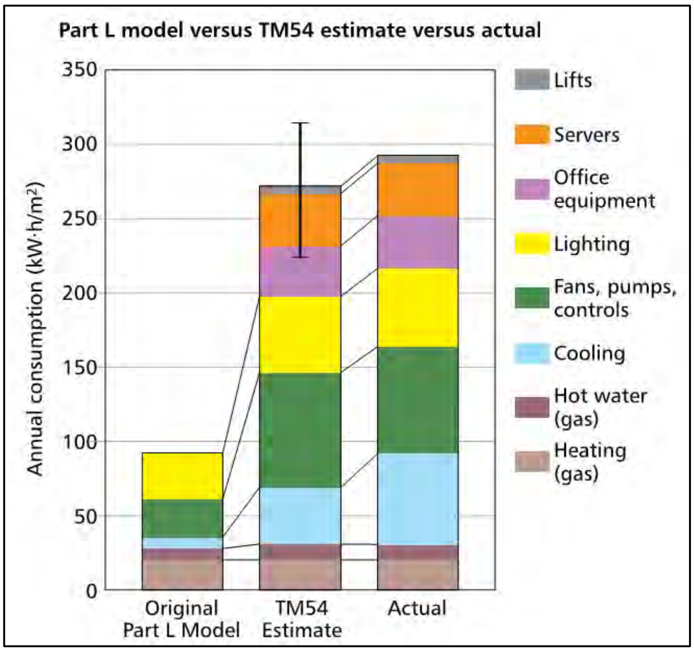
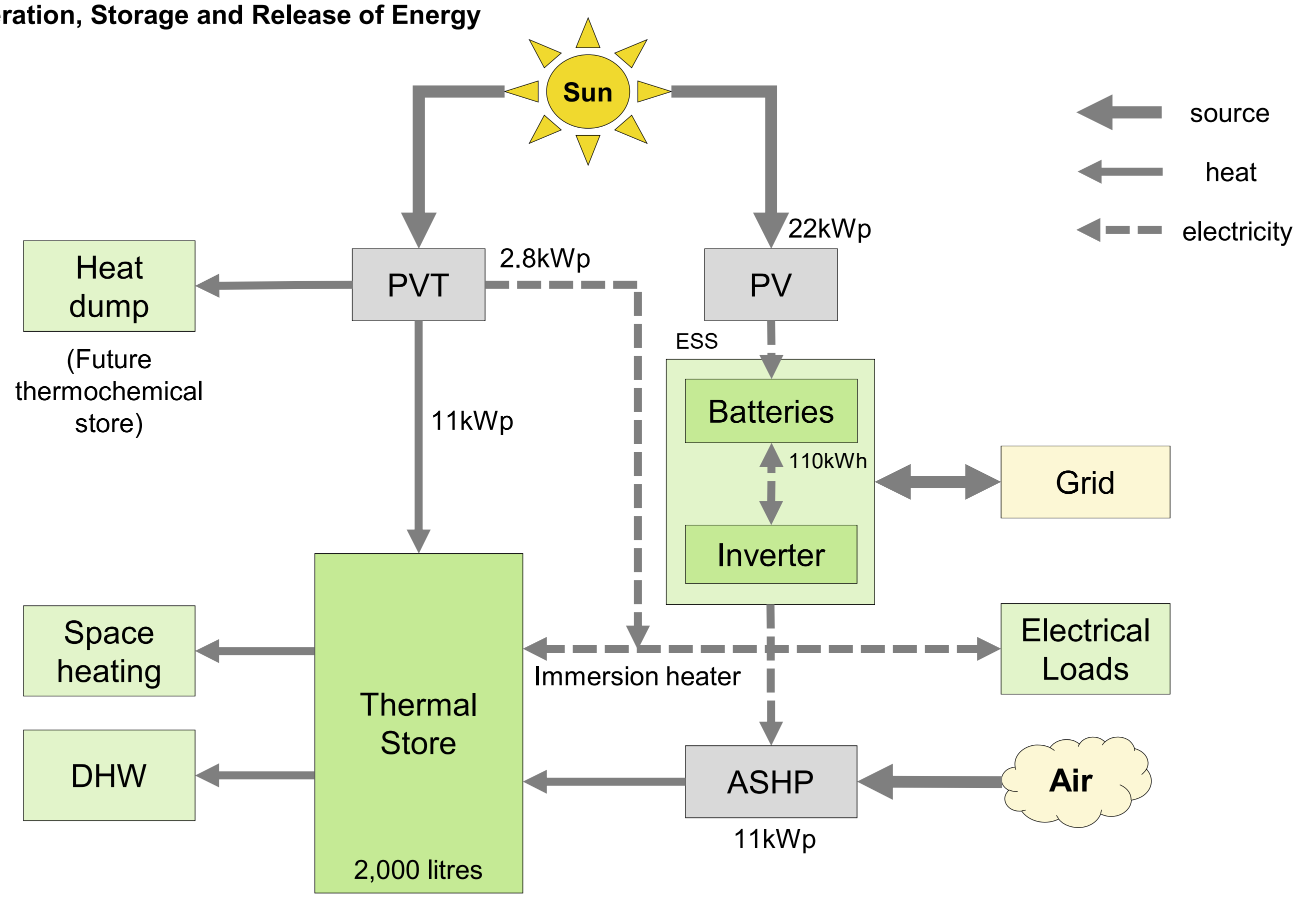


Figure 19: Illustration showing the comparative accuracy of a TM54 evaluation compared with a typical Part L model (source: CIBSE TM54 – Evaluating Operational Energy Performance of Buildings at the Design Stage)

4 Technical Design

4.1.2 Generation, Storage and Release of Energy



The **Energy Strategy** was designed with built-in resilience. There are 3 ways to charge the sensible thermal store (water tank) that supplies the heating system:

1. From the PVT system
2. From the Air Source Heat Pump (ASHP)
3. From a 6kW immersion heater within the store

All electrical power generated locally passes through the Energy Storage System (ESS) that dictates whether the power flowing is stored in the batteries, delivered to the grid or used to support the consumption within the building. Grid imported power can zero, increased above the consumption to be stored in the batteries, or be used directly by the building loads. This is driven by different strategies chosen by the building operators. Strategies include: reducing carbon impact on the grid; extending the lifetime of the batteries; operating in an off-grid manner; or a combination of each.

The two hydraulically separated heating loads are:

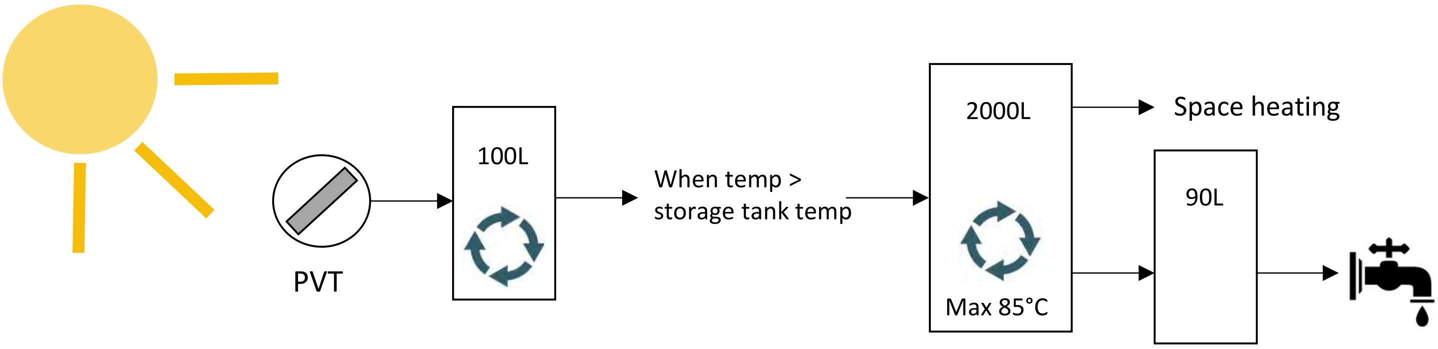
1. The Low Temperature Hot Water (LTHW) circuit – supplying water to air heat exchangers in two air handling units, which provide forced air space heating to the ground and first floors.
2. Domestic Hot Water (DHW) – Preheat coil heat exchanger in a 90 litre tank, suppling a shower and wash hand basins in the toilet facilities.

A 10kWp heat dump is incorporated into the system to deal with any excess thermal generation in the summer months. It is envisaged that once the thermochemical storage currently under development at SPECIFIC is sufficiently developed to be trialled in the building, this will be installed, replacing the heat dump. As described in the Active Building Technology Showcase, this will be capable of storing excess heat generated in the summer for use in the winter months, i.e. inter-seasonally. Further information can be found on the SPECIFIC website: https://www.specific.eu.com/thermal-storage/

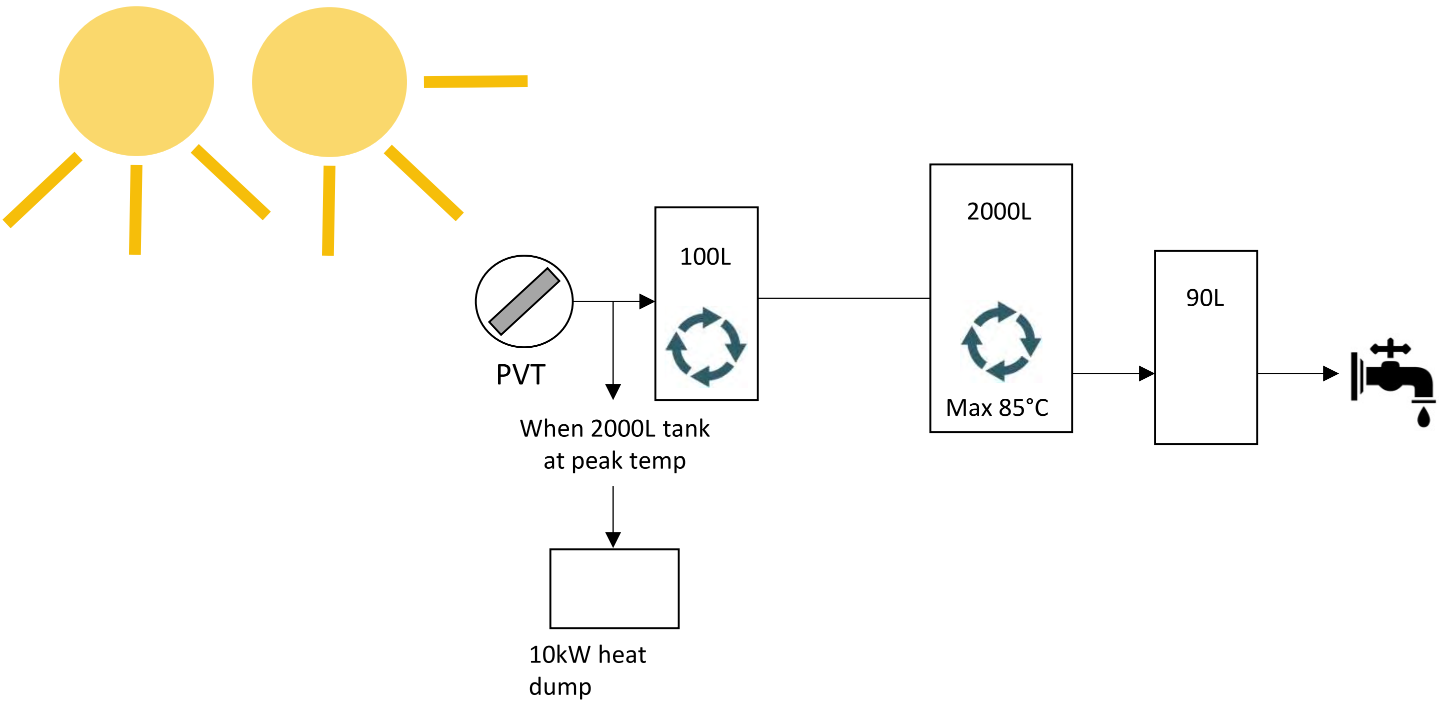
4.2 Examples of Energy Flow Scenarios

To optimise the building's performance and energy use, various heating operation modes are included, as follows:

Scenario 1 - Sunny day: PVT system charges the 2000L storage tank via a smaller 100L accumulator tank (when the temperature in the accumulator tank is greater than the temperature of the storage tank, it will charge the tank up to maximum attainable temperature < 85 °C). This then feeds the air handling units for space heating and a 90L tank for hot water

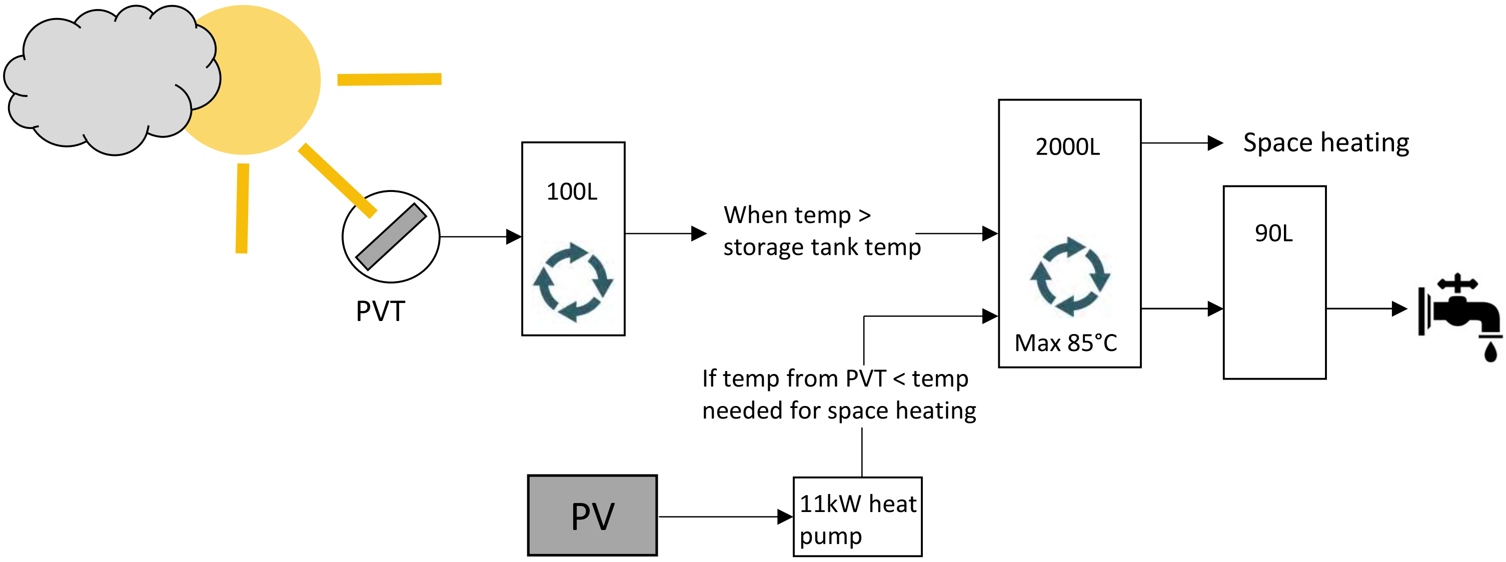


Scenario 2 – Hot, sunny day: If the storage tank has reached maximum temperature, excess heat will be dumped from the tubes before it reaches the accumulator tank. This has the added advantage of removing heat to improve the performance of the PV element. The charged 2000L tank will feed the 90L hot water tank as in the first scenario

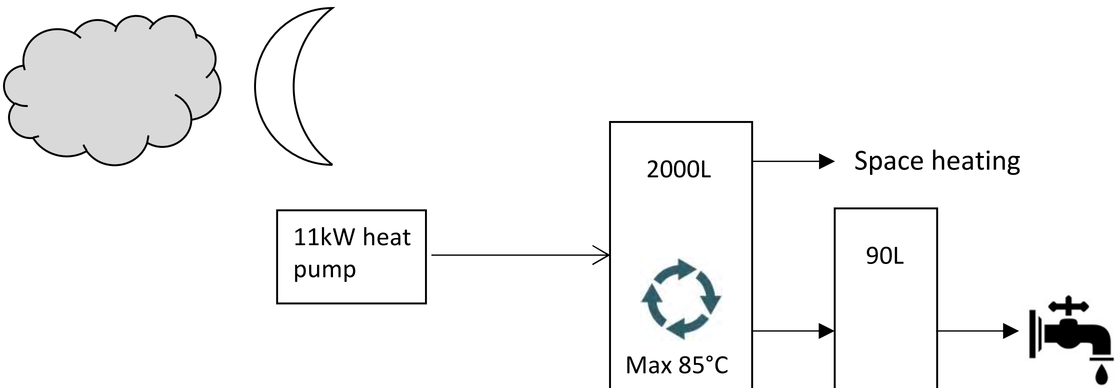


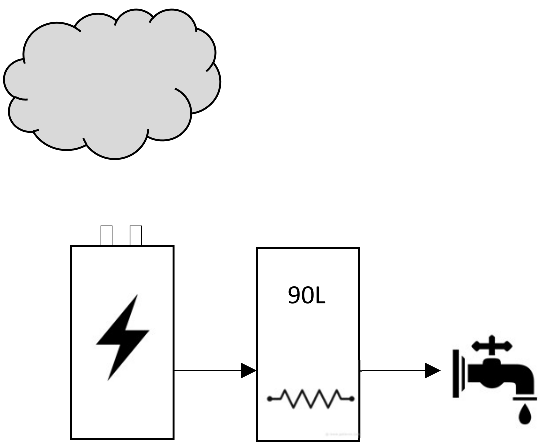
4 Technical Design

Scenario 3 – Cool, bright day (Spring/Autumn): On cooler bright days (Spring/Autumn), a mixed-mode will be used, where the PVT system heats the storage tank via the accumulator tank, but cannot provide sufficient heat for the heating system, then the heat pump is also used to boost the temperature in the storage tank sufficient to provide space heating and charge the hot water tank. If we've got excess PV capacity, this further increases the efficiency of the whole system.



Scenario 4 – overnight or cloudy, winter day: To heat the storage tank overnight, or if the temperature inside the tank has dropped below 45 °C, an air source heat pump is used. This charges the tank directly, which then feeds the air handling units and hot water tank. As data is gathered on the performance of the building, we will be able to predict and pre-charge the tank, based on occupancy and weather forecasting, enabling us to time-shift demand when there is less grid stress.





Scenario 5 – overcast, warm day: It will be inefficient to heat the thermal store just to satisfy the hot water demand, so an immersion heater in the smaller 90L water tank will be used, fed directly from the batteries.

4.3 Combined Solar Thermal and PV (PVT) System

The PVT system implemented on the Active Office is located on the south elevation. The system consists of a series of evacuated tubes, with individual PV cells within, the size of which determined the tube diameter. When locating this type of system on an elevation, the two main considerations are: risk of vandalism; likelihood of shading.

Figure 21 adjacent illustrates the 40 PVT tubes that were installed on the south elevation. Early modelling indicated that the bottom section of the array would experience some shading from the adjacent Active Classroom building in the winter months (see Figure 20 below). To accommodate this, the system was split into four sections with separate micro-inverters for each section – this enabled the unshaded sections to continue generating despite the shading of the lower modules. The resulting power of the 5 tubes in each section was within the technical criteria of the microinverters chosen.

The array was located in a relatively low-risk area within the university campus, so it was decided that the array could occupy the full height of the elevation, with minimal risk. In a public or urban area, it is not recommended to install tubes at low level.

At this stage in the process, we were in discussions with Naked Energy, the manufacturers of the system to determine predicted output from the tubes and timescales for when the tubes would be ready for installation. Initially, the company believed they could meet the June 2018 deadline, but subsequent issues with their supply chain meant this was not feasible. Therefore, during construction, the specially designed bracket system and other associated connections were installed, in readiness for the tubes when they were ready. During this time period, Naked Energy were able to identify a manufacturing partner and a manufacturing process that could be used. Previously, the devices had been made by hand to show proof of concept.

Figure 20: The modelled shading versus reality

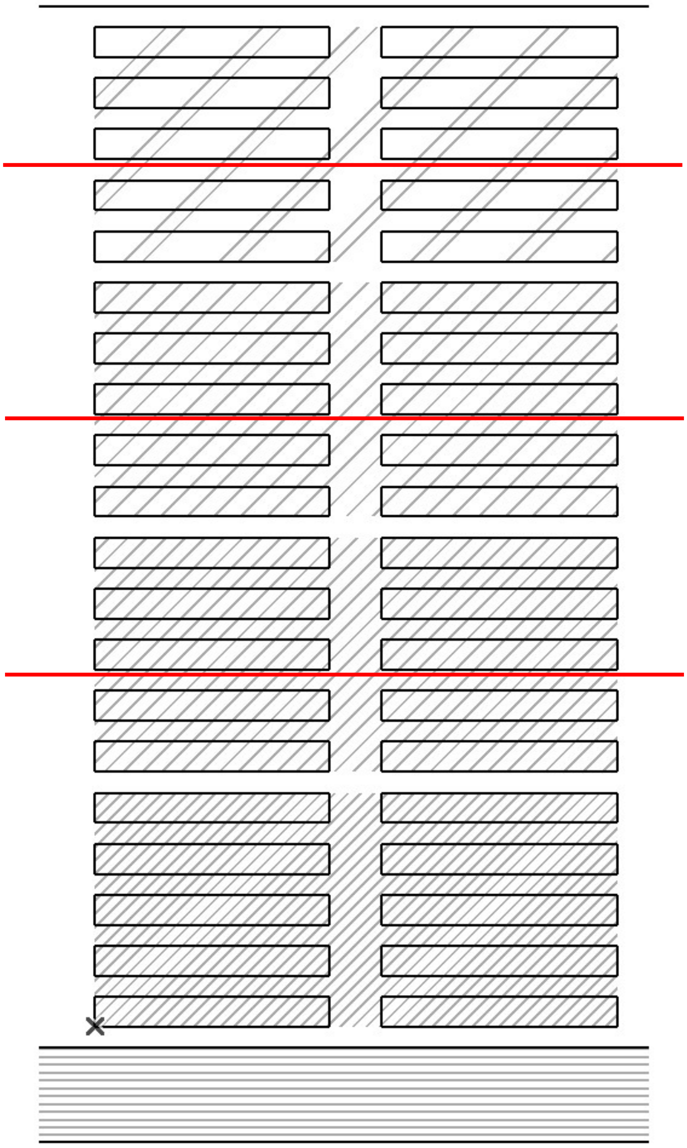


Figure 21: Zoning of the PVT array

In June 2020 this installation featured in an International Energy Agency Solar Heat and Cooling (IEA SHC) Task Report, "Existing PVT systems and solutions", p.107 https://www.solarthermalworld.org/sites/default/files/news/file/2020-07-01/iea-shc-task60-a1-existing-pvt-systems-and-solutions.pdf

4 Technical Design

Figure 22: The BIPVCo roof

Figure 23: A pyranometer

Figure 24: The battery system

4.4 Building Integrated Photovoltaic (BIPV) Roof

The PV system consists of 97no. 5.065m long, BIPVCo CIGS (Copper, Indium, Gallium, Selenide) flexible modules each generating 240W, generating a total of 23kWp electricity, which is supplied to eight compact 13.75kWh BYD Lithium Iron Phosphate ($LiFePO_4$) batteries, with a combined storage capacity of 110kWh.

Two pyranometers (devices to measure the amount of solar irradiance falling on the building at any time, as shown in Fig.23) are fixed in two positions on the roof on the east side of the building. These enable analysis of the PV effectiveness under different climatic conditions, and, in conjunction with the pyranometer on the Active Classroom roof (which is at a tangent to the curve of this roof), the 3 devices provide 3 points of incident radiation, at maximum, minimum, and median of the curved roof.

The PV modules are bonded to Tata Colorcoat Urban® roof sheeting in a factory environment. The roof panels were 12.5m long, which enabled us to incorporate 2 solar modules per roof pan. This dictated the need to locate the junction boxes on the back of the roof panels and create a cable void within the roof build-up. The Multi-Contact 4mm diameter (MC4) connectors (or junction boxes) were fixed to the underside of each roof panel, cables strung together within a roof void, run up the roof to the ridge, along the length of the ridge and are fed behind the cladding on the east elevation before connecting to the battery system, via an accessible storage cupboard on the first floor.

➢ **Key Design Considerations**:

- Number of modules per roof length
- Roof width designed to accommodate roof panel dimensions
- Curve profile and roof length determined by maximum length of Tata Colorocoat Urban® Roof Sheeting
- Position of junction box connections - accessibility and regulatory requirements
- Front of panel – would need to be covered by ridge flashing
- Back of panel – would need a roof void for cables

4.5 Electrical Storage: Lithium Iron Phosphate ($LiFePO_4$) batteries

The electrical storage system of BYD batteries are stacked on a bespoke racking within the plant room, each battery enclosed in its own fire rated metal cabinet.

The BYD Iron Phosphate battery differs chemically from the typical Lithium Cobalt Oxide ($LiCoO_2$) used in portable devices and cameras and has been thoroughly tested by BYD for safety.

BYD has subjected its Fe battery to multiple safety tests, from burning, to overheating, dropping, perforation, and crushing, so it is deemed safe for use in buildings. The system was specified jointly between SPECIFIC's Smart Systems Engineers and Dulas renewable energy installers.

4.6 Control System

The main technology elements are underpinned by the CISCO communications system, combined with control logic developed by SPECIFIC, which enables the individual elements to work together to optimise the operation of the building. The data inputted via the control logic enables decisions to be made on how the building should be running, based on all the factors considered, such as occupancy patterns from calendars, weather predictions from environmental sensors and data on past performance.

The primary concern was that the building operates and is functional. Secondly, we wanted to use interesting and innovative renewable technology elements and the individual elements needed to be weaved into a system that could operate as a single entity. The control logic would provide a platform to iterate the design and optimise the performance, such as learning around what energy the building needs, where it can get it from and how to optimise its use.

We could then build on this communications system to operate smart lighting, building utilisation monitoring and smart sensors and Internet of Things (IoT) devices, underpinned by the Cisco network infrastructure.

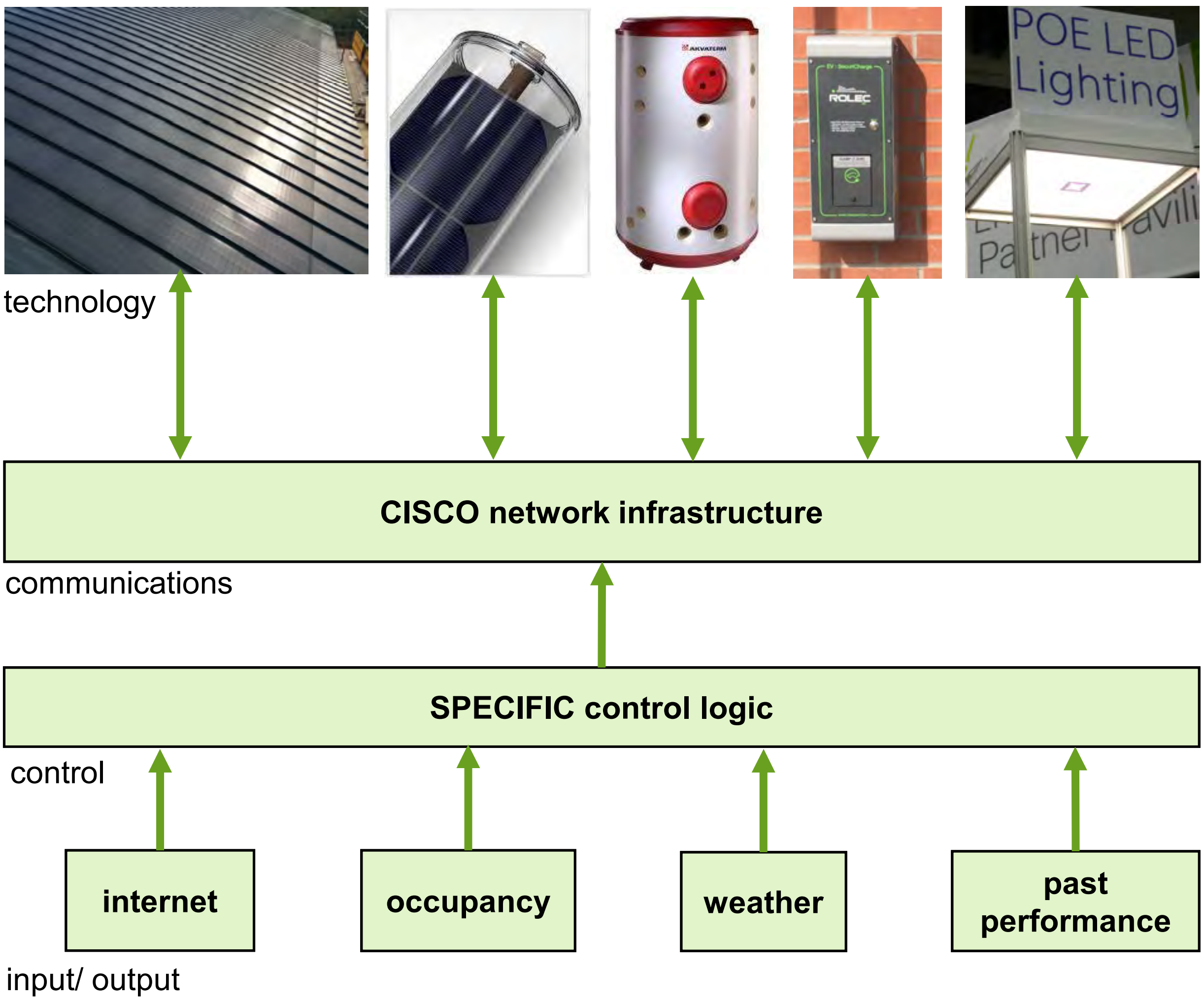


Figure 25: Schematic of the Control System

4 Technical Design

4.7 Heating System

The heating system utilises a sensible thermal store containing 2,000 litres of water as the primary source for heating and hot water within the building. As described above, three heat inputs are available to increase the temperature of the thermal store. In order of operational preference these are:

1. PVT tubes - Solar thermal (and electrical) generation
2. Hitachi Air Source Heat Pump (ASHP)
3. 6 kWp electrical immersion heater

The thermal store supplies two identical Mechanical Ventilation with Heat Recovery (MVHR) Air Handling Units (AHUs) located on the ground and first floors, to provide heating and fresh air to the offices and breakout area. In heating mode, the sole heat source for the AHUs is from the thermal store via the LTHW pipework, supplying water of the same temperature to both units. Remotely controlled three port valves control the volume of water that is allowed to pass into the 'wet heater battery', or heat exchanger in each AHU, thereby enabling independent supply air temperatures to be set for the ground and first floors. Thereafter the air supplying all areas on each floor level is at the same temperature. Control of individual room or zone temperatures is achieved on a volumetric basis using Variable Air Volume (VAV) automatic dampers. Temperature setpoint values can be altered via the central Building Management System (BMS). Algorithms programmed into the BMS then control the three-port valve and VAV positions to achieve and maintain the desired temperature in all areas.

4.8 Ventilation Strategy

A mixed-mode ventilation strategy was adopted for the building, combining natural ventilation through openable windows with mechanical ventilation through the air-handling system. The air handling units were designed to provide the required levels of ventilation in office spaces, of 10 litres/second.

Some mixed-mode ventilation systems manage natural ventilation through automatic opening and closing of windows. However, in the Active Office, windows are operated manually, allowing building occupants to choose when to open or close them depending on their level of comfort. Often automated opening systems are over-ridden in buildings as, even though sensors might suggest additional ventilation is needed, this can be perceived as draughts to occupants, and occupants tend to like to control their own environment. Therefore, the decision was made that, while room sensors measure the CO_2 levels in the spaces, they would not be used to control the natural ventilation.

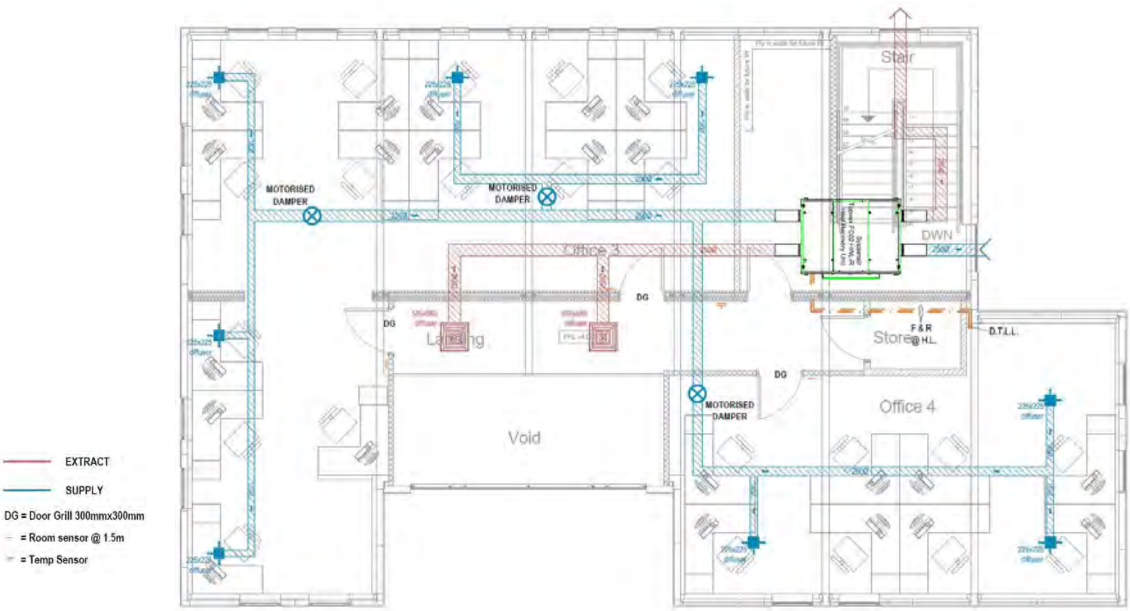


Figure 26: Air Handling System Layout

4.9 Water

Domestic Hot Water

Prioritisation of solar thermal generation requires the thermal store to be maintained at as low a temperature as reasonably practicable. Therefore, the heating system specification was designed to meet the modelled 10kWp heating load of the building, at a supply water temperature of 45℃. This target temperature was also intended to minimise the electrical power require by the ASHP to maintain the thermal store setpoint during periods when there was insufficient solar thermal generation. Ideally the 6kWp electrical immersion heater would only be used in exceptional circumstances, such as equipment failure or extremely low winter temperatures.

The control philosophy for the DHW system was to provide preheating from the thermal store, with top up from a 3kWp immersion heater in the 90 litre water tank, to achieve a safe operating temperature and enable periodic disinfection cycles.

DHW for the kitchen is heated via a direct water heater, as this is more efficient than running pipework from the hot water cylinder. The heat losses between the cylinder and the kitchen sink would be too great to meet the required supply temperature.

Low water use shower head

Kelda Technology are a UK company who have developed a new digital, air-powered shower system, which they claim delivers an invigorating shower at low flow rates of 4 – 6 litres per minute, using up to 50% less water than a standard shower. They supplied us with one of these, free of charge, for customer feedback and marketing purposes.

Figure 27: Kelda Shower Head

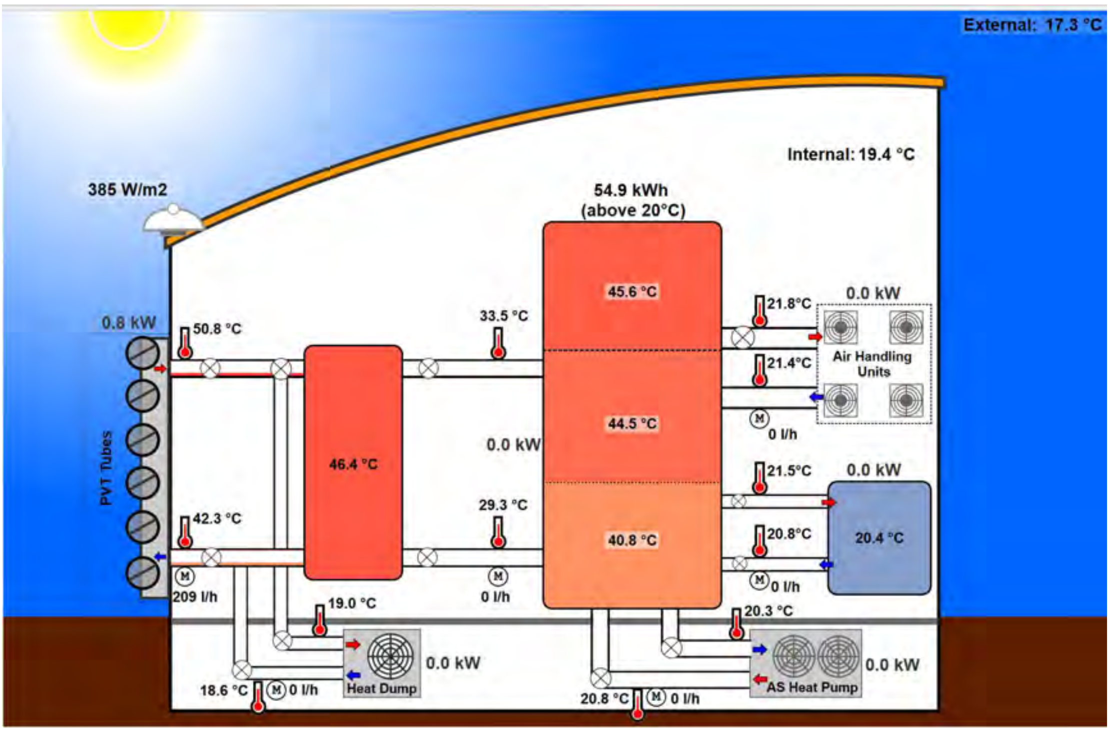


Figure 28: Visualisation of the Plant Room

4 Technical Design

4.10 Visualisation of Data

At this stage, we realised the importance of providing a clear display of all the energy flows in the building, mainly as an engagement and educational tool. This was an early diagram explaining what we hoped to achieve in terms of visualisation. We used this in discussions with Cisco to determine the best platform to use in the creation of the display.

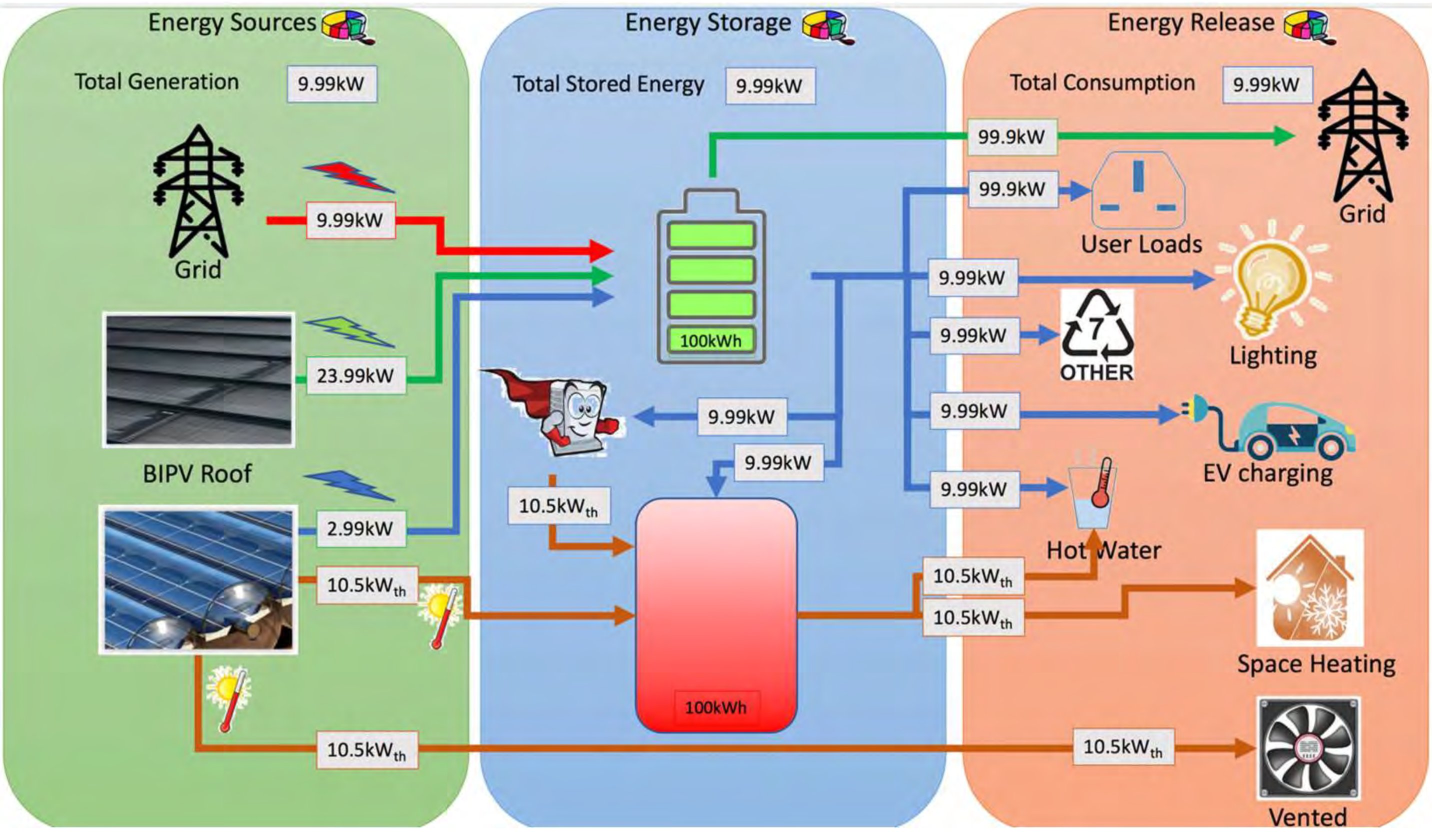


Figure 29: Early diagram to illustrate energy flows, courtesy of Dr Justin Searle

For processing the vast amount of data generated from the meters and sensors in the building, Cisco recommended their Kinetic Edge and Fog Processing Module (EFM) to add computing power to our distributed network. This would enable us to make fast decisions close to the point of action and reduce data before sending to higher levels in the network.

This was compatible with DG-Lux IoT platform which could bring all the data generated by the different building systems together in one unifying piece of software.

January –
June 2018

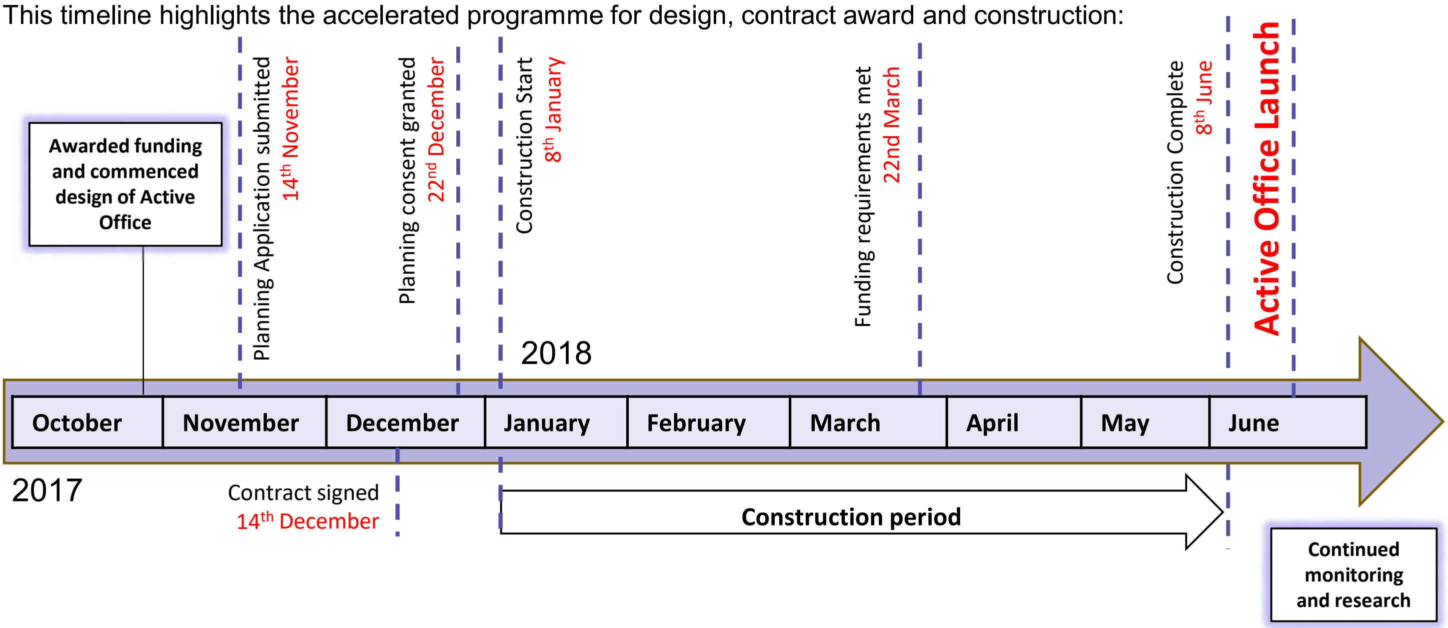
5 Manufacturing and Construction

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

5.1 Construction Programme

This timeline highlights the accelerated programme for design, contract award and construction:



Procurement of buildings is usually a lengthy process within public sector projects, which can mean projects take several years to come to fruition. This is due to the need to demonstrate due diligence and value for money in the procurement process to satisfy institution's and the funder's requirements. The Active office was funded by Innovate UK, who stipulated their satisfaction if the university's procurement rules were followed. The funding for the project was awarded in October 2017, but had to be spent by the end of March 2018. This presented a significant challenge to the project, as it would form part of the University's estate. As described earlier in this document, Wernick were procured through the Fusion 21 framework agreement (satisfying both the University's and the funders procurement rules) and appointed through a NEC Design and Build contract.

This stage of the project was documented through a weekly blog, which proved an effective way of tracking progress of a project, especially one of this nature. The blog provided a useful tool to capture learnings from the project and consider potential improvements to the process for future projects, as well as keeping interested external parties informed of the progress and activities undertaken. It is also useful as an educational piece, to illustrate what can be achieved with collaborative working.

To realise the vastly accelerated 8-month delivery from design to launch, the project ran many design streams simultaneously. The ability to quickly translate traditional architectural designs into a modular format ready for offsite construction, while finalising details behind the building's M&E strategy to be installed later was invaluable. Working collaboratively with Wernick and their supply chain partners from the project outset helped ensure the building was delivered to time and within budget, while satisfying the innovative nature of the technical design, to meet SPECIFIC's goals. Achieving the right balance of innovation, reliability and repeatability. It also enabled efficient use of resources to resolve design challenges, avoided duplication of efforts and clashes between elements.

5 Manufacturing and Construction

The total construction programme was 23 weeks, each of which is described in this section. It should be noted that while we were successful in achieving all our design ambitions with the project and demonstrating that buildings within public sector bodies can be procured quickly and efficiently, the timescales were shorter than we would recommend. This did result in some technical compromises and some potentially useful technologies or processes being discounted. Therefore, it is important to understand we are not advocating these timescales for all projects, but identifying that when required and with a good plan and clear goals complex construction projects can be executed quickly.

Week 1 (8th – 12th January 2018)

<u>Mobilisation and Site Set up</u>

The first week was focused on mobilisation and site set up, with the site being secured and then diggers arriving to start work to remove the earth mounds covering the site. Prior to earth moving, the existing trees which lined the eastern border of the site were carefully removed and put to one side for the University's Grounds Team to re-plant. Some of these were successfully re-planted adjacent to the Active Classroom on new raised beds formed from some of the earthworks. The remainder of the earth was then transported to the other end of the University Campus, to be re-distributed, within the site, instead of transporting offsite. This work enabled groundworks to commence the following week.

Whilst this site work was ongoing, the factory were gearing up to start manufacture of the modules.

Figure 30: The site set up pre-construction

Week 2 (15th – 19th January)

<u>Site Preparation and Drainage</u>

Site clearance works were completed this week and existing drainage runs diverted to enable commencement of the substructure works - the concrete pad foundations.

Back in the factory, the module construction commenced, starting with the floor panels, which were completed before constructing the wall panels..

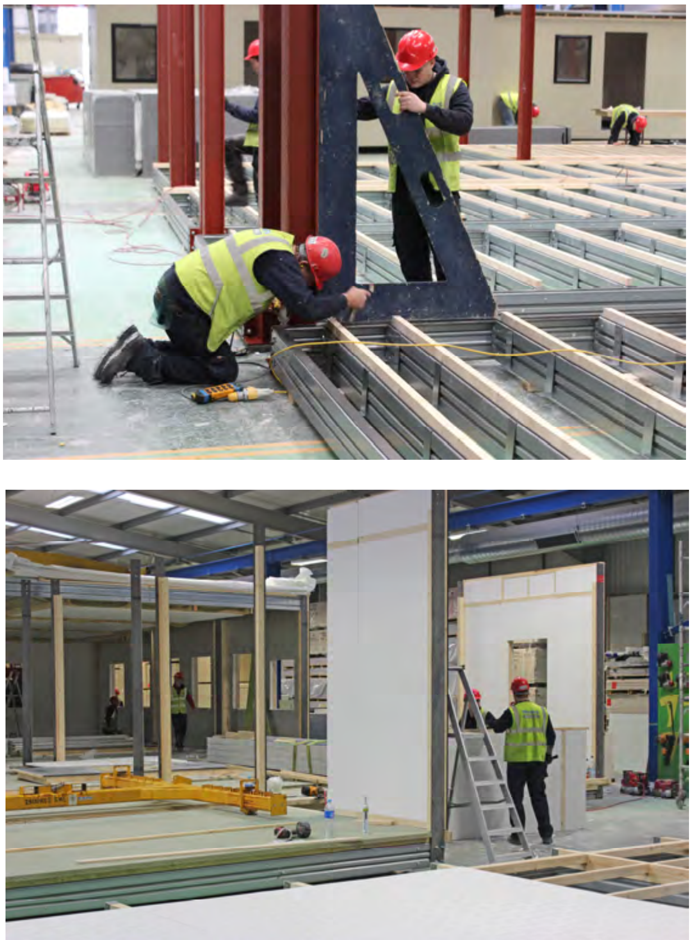


Figure 31: Module construction in the factory

During construction, the adjacent Active Classroom was being used almost daily for teaching and other important events. For example, during this week it was used by the Welsh Government Climate Change, Environment and Rural Affairs Committee, who were at the time carrying out an inquiry to inform policy developments of "Low Carbon Housing: The Challenge; Welsh Housing Policy Consultation", to the site. This sort of engagement is critical to SPECIFIC to gain momentum in the construction industry.

It was critical that the construction works did not impact on the use of the classroom. We worked closely with the contractor to ensure noise was kept to a minimum and access routes were not blocked.

5 Manufacturing and Construction

Week 3 (22nd – 26th January 2018)

As this photograph shows, the weather at this stage was typical of a January day in Swansea, very cold and damp – highlighting that this is not the optimum time of year to start a construction project in South Wales. It does, however, also highlight one of the benefits of using offsite construction. Whilst the site was waterlogged, work could continue in the dry factory, to manufacture the modules. After just two weeks of work in the factory, the modules were already nearing completion.

Figure 32: Site works commencing

Figure 33: Module construction in the factory

Week 4 (29th January – 2nd February 2018)

Substructure

The foundations were completed this week, along with the trenches for the incoming services, including a connection back to the Active Classroom, with the aim that in future the two buildings can share energy, optimising the amount of solar energy used and taking advantage of the combined storage capacity of 160kWh at the time (before June 2020, when this increased to 230kWh due to the installation of upgraded batteries in the Active Classroom).

During this week, Wernick hosted a group of architecture and built environment students from University of Wales Trinity St Davids, starting with a visit to the site, followed by a tour of the Active Classroom, and then a trip to Wernick's factory, giving them an insight into the benefits of both energy positive buildings and offsite construction. Education is an important part of the building demonstrators and should be integral to all construction projects. Visiting construction sites is hugely beneficial to engaging with the younger generation and encouraging them into a career in construction.

Representatives from Fusion 21 visited the site to discuss progress and determine whether the key performance indicators (KPIs) and social value aspects of the project were being met. This particular procurement framework is built around social values, community integration and job creation, all of which are embedded throughout the Active Office project, from the fact that the building will be energy positive, right through to the employment of local labour and involvement of local schools and colleges. As mentioned previously, the use of Fusion 21 also enabled the SPECIFIC team to engage early with Wernick, which was critical to the success of such an innovative project within a very tight timescale.

5 Manufacturing and Construction

Week 5 (5th – 9th February 2018)

The Active Office incorporates a curved building integrated photovoltaic roof, manufactured by Welsh company BIPVCo (generating a total of 23kWp). This consists of 96no. 5.065m long modules each capable of generating 240W, bonded to Tata Colorcoat® Urban roof panels. As the PV is attached to the steel roof sheeting in the factory, there are no additional works required on site to add the PV array, except for connecting up the modules and linking them back to the battery system. This has the added benefit of enabling the solar energy generating roof to be manufactured simultaneously with other site works, as another aspect of offsite construction.

Figure 34: Building integrated PV manufacture

Meanwhile, groundworks were ongoing, preparing the site ready for delivery of the building modules the following week – just 5 weeks into the programme.

Week 6 (12th – 16th February 2018)

Superstructure

Figure 35: The concrete pad foundations

During this week the ground-floor modules were delivered to site and carefully craned into position on the pre-prepared foundations, using a 300-tonne crane. High winds and torrential rain delayed the delivery of the first-floor modules and the roof trusses by a couple of days. The modules are manufactured with a pre-finished steel cladding, which can form the final outer skin of the building. However, in this case, an additional cladding layer was installed on site, for improved aesthetics, adding to on-site works.

Once the modules were in place, scaffold erection commenced ready for the next stage, which was to wrap the building in steel cladding, using the new contemporary colours available in the Colorcoat Prisma® range (as piloted on the Active Classroom) – Seren Copper and Seren Gold.

Figure 36: Modules arriving to site

The south elevation will also include the first commercial scale installation of Virtu, a patented hybrid photovoltaic and solar thermal (PVT) device, designed in the UK to provide both efficient electrical power and thermal energy to the building. These will be fixed directly to the modules in lieu of cladding, using a specially designed bracket system.

During this week, a visit to a local primary school in Neath took place to talk to the children about the project and invite them to take part in planting the living wall. As mentioned previously, this engagement with the younger generation in creating innovative buildings and increasing their awareness of renewable energy technologies, which will help secure their future, is a critical part of our work.

5 Manufacturing and Construction

Week 7 (19th – 23rd February 2018)

Scaffold

The scaffold erection was completed this week, and the modules were bolted together in preparation for the roof works to commence next week.

As part of our responsibilities under the Fusion 21 Framework, we will be capturing Key Performance Indicators (KPIs) developed at the Centre for Construction Innovation (CCI) by the Building Research Establishment (BRE) and the University of Salford to deliver innovation and improvement in the built environment, in the spirit of the framework agreement. The main KPIs we will focus on include:

- Construction Time
- Construction Cost
- Construction Quality
- Health and Safety
- Impact on the Environment

The use of a modular construction system, manufactured offsite in a factory environment, will help us achieve these KPIs, together with the fact that the building will be energy positive, generating more energy than it consumes over an annual period.

Figure 37: Scaffold erection

Week 8 (26th February – 2nd March 2018)

Superstructure

This week the 31 curved timber roof trusses, manufactured locally, were craned into position. These will then be covered with a layer of plywood before the photovoltaic roof covering is fitted in just a few weeks' time.

Figure 38: roof truss installation

At the same time, the brickwork plinth, forming a base to the steel cladding, was constructed; and the service trench for the connection to the mains services was dug in readiness for the grid connection to be installed. To enable the grid connection, the Engineering buildings on campus had to be shut down for a day, which required coordination with the College of Engineering and the University's Facility Management Team. To avoid too much disruption, this was undertaken on a weekend.

Figure 39: the brickwork plinth

5 Manufacturing and Construction

Week 9 (5th – 9th March 2018)

The copper and gold Tata Colorcoat® Urban cladding sheets were delivered to site this week ready for installation over the next four weeks. This would transform the appearance of the building from a series of dark grey boxes to a sleek looking building to match the adjacent buildings – the Active Classroom and the Energy Safety Research Institute (ESRI). Meanwhile the roof structure was prepared for the photovoltaic (PV) roof installation, using plywood sheeting to form the substrate for the roof sheets.

One of SPECIFIC's objectives is to trial new products being developed by our industry partners and during this week colleagues from AkzoNobel (one of main industry partners) visited to discuss opportunities to include some of their functional coatings within the building:

- Dulux Light + Space, which could reduce artificial lighting requirements;
- Coatings that absorb pollutants;
- Stain repellent coatings

These passive measures could help reduce energy demand in a building, improve indoor air quality (IAQ) and reduce maintenance.

The aluminium door and window frames - polyester powder coated in RAL 7016 Matt by Akzo Nobel – were installed during this week. The glass used in the windows and curtain walling is Pilkington energiKare™ Advantage, supplied by another of our industrial partners, NSG. To use glass from NSG necessitated an intervention into Wernick's supply chain, as their window supplier, ATB, usually use Saint Gobain glass in their units. There were several reasons we wanted to change the glass specification – firstly, to promote a product manufactured by one of our main industry partners; secondly, to introduce a thermally efficient glass product that could potentially save energy from heating and cooling demand in the building.

Figure 40: Roof construction – pre-cladding installation

Figure 41: Cladding panels pre-installation

Figure 42: Roof construction above the entrance foyer

Week 10 (12th – 16th March 2018)

External Engagement

During this week, as well as overseeing the construction works, we also took part in several external engagement events. One of these events was to support the Intellectual Property Office's celebrations of British Science Week, by giving a lunchtime talk at their Newport office.

Other events involved educating the next generation about the diverse nature of construction, through several school visits – one to take part in the BBC School Report with pupils of Ysgol Gyfun Gwyr, and others to plant seeds for our living wall at two local primary schools.

Watertight

Back on site, the double height glazed curtain walling forming the main entrance screen was installed this week, completing the watertight envelope of the building.

Internally, pipes and ductwork for the heating and hot water systems are being installed, ready for connection to the solar thermal system.

Figure 43: British Science Week talk at the Intellectual Property Office

Figure 44: Entrance screen curtain walling installation

Week 11 (19th – 23rd March 2018)

The Battery System

This week the first meeting took place with the renewable energy contractor, Dulas, who provided the grid attached energy storage system of 110kWh, using 8 BYD Lithium Iron Phosphate ($LiFePO_4$) batteries. These will be connected to the PV roof and the main electricity grid to provide power for the building.

External finishes

Cladding progressed during this week, starting with the Seren Copper on the East Elevation. Also, the main electrical cables were pulled through the service ducts ready for connecting the building to the main electricity grid, once approvals are in place.

5 Manufacturing and Construction

Week 12 (26th – 30th March 2018)

External finishes and M & E first fix

The BIPVCo roof arrived this week. The 49no. panels, with a total of 91no. 240W modules, were craned into position and installed on the curved roof in just a few days.

Meanwhile, the mechanical contractor, Pursey and Ball connected up the heating system infrastructure, which would eventually be supplied from the Naked Energy PVT panels once installed on the south elevation.

The swift progress of this project, with its many facets, was only possible due to the open and collaborative spirit of working, between SPECIFIC, Wernick and all the supply chain partners. The ability to engage with the contractor and supply chain early in the design process, through use of the Fusion 21 framework, saved both costs and time, and enabled the whole project team to work together to ensure the successful delivery of this unique building.

Figure 45: The BIPV roof installation

Figure 46: Heating system installation

5 Manufacturing and Construction

Week 13 (2nd – 6th April 2018)

Mechanical and Electricai (M & E) first fix

Most of the progress this week was internal, comprising the M & E first fix, which involved installing ductwork, pipes and cable runs. Preparations for internal decoration also took place this week. Ideally, these operations would not take place simultaneously, due to the logistics of trades people working around each other. With more time in the programme, some of the internal M & E installations and internal decoration could have taken place in the factory, before the modules were brought to site. However, this was not possible for this project, due to the accelerated programme.

Figure 47: Internal decoration and M & E first fix

One of the new technologies installed was a new digital shower system, which claims to use 50% less water than a typical shower system, while delivering an invigorating shower experience. This was provided to the project free of charge by Kelda Technology, for marketing and testing purposes.

At this stage in the project, we took time to revisit the Key Performance Indicators (KPIs) we are capturing to comply with requirements of the Fusion21 framework, as it was important to ensure we were meeting all the requirements.

Construction Time	This has been significantly reduced through the use of offsite construction, which enabled the main building elements to be constructed in factory conditions, with no site hindrances such as inclement weather. Also helped by the whole project team working together collaboratively.
Construction Cost	This has been significantly reduced through the use of offsite construction, which enabled the main building elements to be constructed in factory conditions, with no site hindrances such as inclement weather. Also helped by the whole project team working together collaboratively.
Construction Quality	Offsite construction enables a better quality of construction, with the main elements being constructed within a controlled environment. Having strong relationships with local contractors and their supply chain has also helped Wernick ensure a good quality build. From the brickwork, to the cladding, electrical and mechanical installations, the quality so far has exceeded our expectations.
Health and Safety	The factory environment provides safer working conditions than a construction site, reducing the amount of work that needs to be undertaken at height and during poor weather conditions, for example.
Impact on the Environment	There are less environmental impacts associated with offsite construction, including less waste generated. And of course, the use of renewable technologies, to enable an energy positive building, significantly reduces the impact of the building on the environment.

5 Manufacturing and Construction

Week 14 (9th – 13h April 2018)

<u>External Finishes</u>

The curved BIPVCo photovoltaic roof installation was completed this week, with the cables connected by Dulas, in readiness for linking to the battery system.

External wall cladding also progressed, including the living wall troughs which would be planted with approximately 450 seedlings.

Figure 48: External cladding installation

Figure 49: PV connection panel

Figure 50: Seedlings for living wall

Week 15 (16th – 20th April 2018)

Works this week included connecting the building up to the mains water supply, finishing the termination of the PV cables, first fix electrical works, internal painting and a continuation of mechanical systems installations. To meet the programme, the different trades needed to work around each other, which was not ideal, but ensured the programme could be adhered to.

Figure 51: Cladding and living wall trough installation on east elevation

In addition to the innovative technologies installed to generate onsite renewable heat and power, extensive energy monitoring is installed in this building to enable post-occupancy evaluation (POE), comparison with design goals and system optimisation. Ongoing data capture enables analytics and insight to feedback into the Active Building design process, development of planned maintenance regimes, and optimisation and refinement of predictive control strategies, for both cost, energy and carbon reductions. During this week, a meeting took place with the specialist building management systems (BMS) engineers, Demma, to discuss the control systems and the level of control we hope to achieve with the building (Stage 4: Technical Design work).

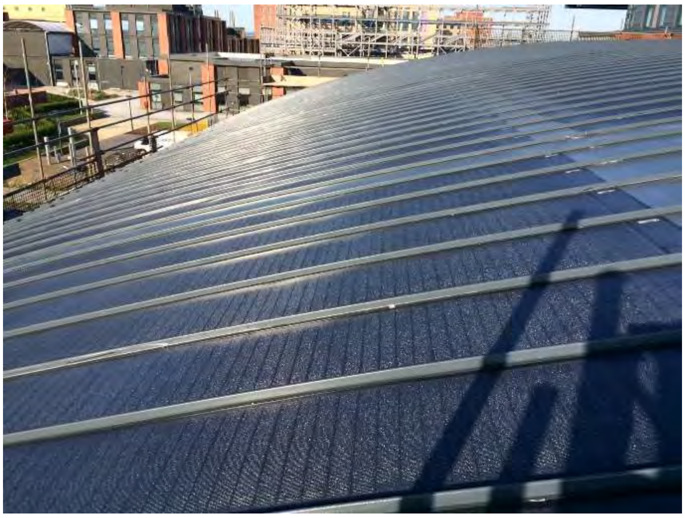


Figure 52: Completed curved BIPV roof

Week 16 (23rd – 27th April 2018)

At this stage, the programme was still on target to complete the build by the end of May. Several factors contributed to this:

- The use of offsite construction
- Wernick's strong and trusted relationships with their supply chain partners, who worked collaboratively to enable the project to progress at the pace required
- The close relationship between SPECIFIC and Wernick, and the desire from both client and contractor sides to ensure the project would be completed on time
- The enthusiasm of the subcontractors in embracing the new technologies, working with us to integrate them with the more traditional systems they were used to working with.

This week we also took time out with Wernick to help deliver an RIBA Core CPD Seminar entitled *"Is offsite the future of construction"*, to a group of Architects in Crawley, which provided a platform to introduce the Active Building concept and talk about our Active Office project to a large group of Architects.

We also presented progress to the funders of the project at the Quarterly Review Meeting with Innovate UK. Maintaining excellent communication between all parties in a construction project, particularly those funding it, is crucial to the success of the project.

Figure 53: Offsite construction Seminar, Crawley

Week 17 (30th April – 4th May 2018)

Internal finishes and M & E second fix

This week, environmental sensors were fitted to the roof by members of the SPECIFIC technical team. These will enable us to capture data which will help to assess the true energy performance of the building. PV panel performance varies under differing climatic conditions. The intensity of sunlight will be measured using pyranometers installed on the roof and compared to power meter readings to calculate how efficient the building integrated PV is at converting solar energy into electricity. Ambient and surface temperature sensors will be used to monitor any changes in PV efficiency with temperature, while the installed wind sensor will enable the effect of windspeed and direction on solar thermal generation to be calculated.


Figure 54: Installation of environmental sensors

Internal decoration of the office spaces was still ongoing and the second fix electrical installation underway. The high ceilings and exposed ductwork provide a spacious feel to the offices.

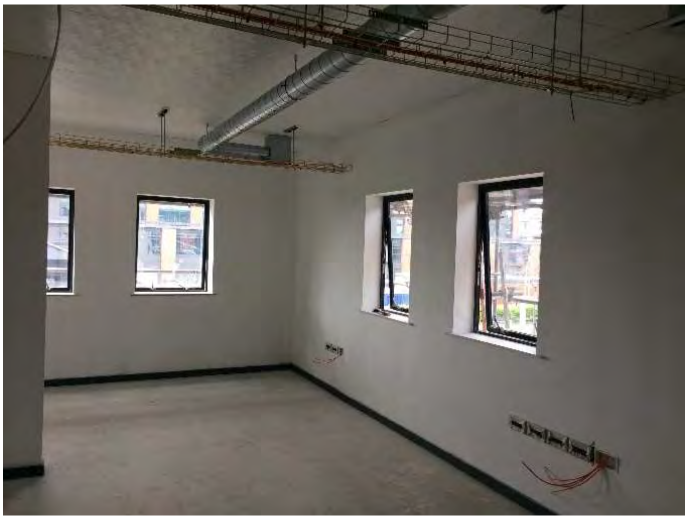


Figure 55: Internal view of first floor office

5 Manufacturing and Construction

Week 18 (7th – 11th May 2018)

The living wall on the east elevation was filled with a soil and sand mix, and planted with a variety of native plants grown from seed, suited to the site's coastal location and proximity to the SSSI.

Figure 56: Seren Gold cladding on east elevation and living wall filling

As part of our role to demonstrate new products produced by our industry partners, we agreed to trial a paint developed by AkzoNobel, to improve indoor air quality (IAQ) in buildings in one of the rooms. This is a sustainable indoor paint with an anti-formaldehyde formulation, called "Forest Breath" introduced in China in 2016 to address the country's focus on improving air quality. Air sampling in identically sized spaces with and without the paint will take place to test for formaldehyde and a range of other VOC's, using adsorption tubes to capture formaldehyde and other organic species. One office will be painted using Forest Breath and a corresponding office in normal emulsion, allowing us to test the air in both spaces, as well as outside, and to see the difference made to the air quality through use of the specially formulated paint.

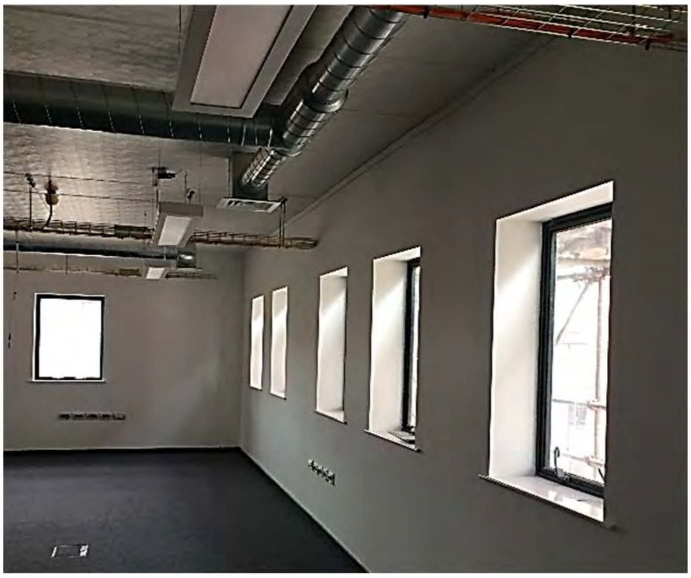


Figure 57: Internal view of first floor office

This week, we procured the furniture from a UK company called Rype Office who provide sustainable furniture, that combines ethically sourced pieces with high quality remanufactured pieces, which have an 80% smaller environmental footprint than those made from virgin resources. Some of the furniture will be manufactured by the Merthyr Tydfil Institute for the Blind. Sustainability benefits include: reduced waste and landfill; lower greenhouse gas emissions; and creation of UK jobs.

Week 19 (14th – 18th May 2018)

Internally, we will be showcasing Tata Steel's Coretinium®, installed by Reform Systems Ltd who have been working closely with Tata to combine Coretinium® with their novel flexible fixing system. Three 'idea' walls in offices and meeting spaces will be installed, enabling the capture of creative thinking on a robust and wipe-clean surface.

As the project was nearing completion, we also met up with Welsh design agency, ICON Creative, to discuss ways to bring the interior spaces to life with wall designs and splashes of brand colour.

The scaffold strike commenced this week to enable external works to proceed, and the three electric vehicle charging points were installed on the east elevation.

Figure 58: Wall mounted Electric vehicle charge points

5 Manufacturing and Construction

Week 20 (21st – 25th May 2018)

Surplus bricks from the build were donated to and collected by Swansea Care and Repair, as part of the Recipro Wales scheme, which is a collaborative project between Recipro UK, Constructing Excellence in Wales and Swansea Care and Repair, linking the construction industry with not-for-profit organisations to enable the reuse of surplus building materials donated by the construction industry. Benefits of taking part in this scheme include:

- reducing levels of waste at landfill;
- giving surplus materials a second chance;
- benefitting charitable organisations and community projects

External landscaping also commenced this week. This was slightly behind programme as the cladding installation over-ran, due to supply issues, which consequently delayed the scaffold strike.

The brackets for the Naked Energy PVT tubes arrived to site and were installed on the south elevation ready to receive the evacuated tubes which are expected to supply 9kWh peak thermal energy (via water) to the thermal store, and some additional electricity to compliment the BIPV Roof. These brackets were specially designed and manufactured for this building, as the tubes had not been used vertically before. The tubes are not expected to arrive before the end of the project, due to issues with the supply chain and manufacture.

Through collaboration with Cisco the office will utilise a smart network infrastructure and Internet of Things (IoT) communication system. This will include the ability to create a heatmap of the building indicating locations of people within the offices and monitoring occupancy rates. Smart lighting will be controlled by occupancy detectors via the infrastructure. In the future, electric vehicle charging points will be linked to the system, adding the ability to locate vehicles, determine their state-of-charge, and ascertain whether any charging points are available.

Figure 59: Surplus bricks for collection

Figure 60: Brackets for PVT system

5 Manufacturing and Construction

Week 21 (28th May – 1st June 2018)

By this week construction was nearing completion. This week saw the cladding completed; the scaffold strike completed and the external finishes, including the fire escape staircase and the paving to the building entrance, undertaken; enabling the building to be viewed properly for the first time in relation to its setting. The unimpeded view enabled onlookers to see how the building profile tied in with the Active Classroom and adjacent ESRI building, with the curve being on a tangent with the line of the Active Classroom roof. The window detail to match the curtain walling on ESRI could also be appreciated for the first time.

The batteries arrived this week and installation of the supporting infrastructure commenced, to be completed the following week, along with commissioning of the mechanical and electrical installations. It soon became clear that the plant room we had originally thought to be plenty big enough, if not oversized, was going to become quite crowded. Half of the plant room has been allocated to the heating system and the other half for the batteries and associated electrical systems.

Internally, the glass balustrading to the first floor balcony was installed.

Snagging of the interior was carried out at the end of the week, to enable completion next week in time for building handover..

Figure 61: Elevation synergy with adjacent ESRI building

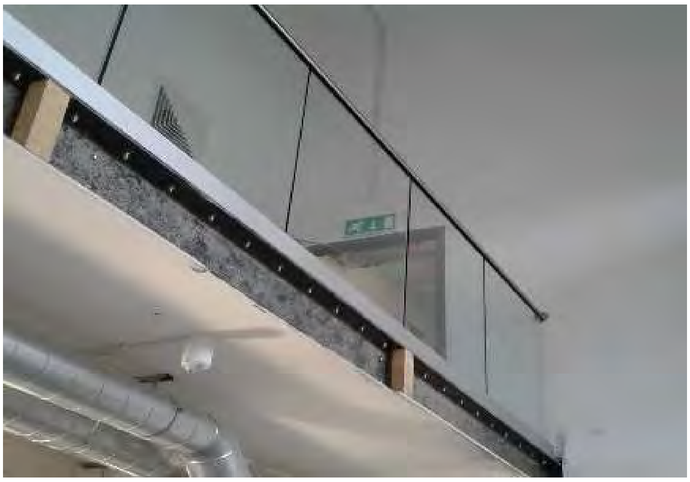


Figure 62: Balustrading installation on first floor balcony

Figure 63: Battery delivery

5 Manufacturing and Construction

Week 22 (4th – 8th June 2018)

Demma Controls commissioned the building this week, while Wernick attended to the finishing touches, ready for building handover on Friday. The battery and solar thermal installations were still to be completed, but underway by renewable energy installers, Dulas.

SPECIFIC's Smart Systems Engineers connected up the roof mounted environmental sensors to the control panel - the intensity of sunlight will be measured using pyranometers; ambient and surface temperature sensors will be used to monitor any changes in PV efficiency with temperature; and a wind sensor will calculate the effect of windspeed and direction on solar thermal generation.

The earth mound outside the Active Classroom has been redistributed around the office, improving the landscape areas around both buildings. This will eventually be seeded with a native Coastal Areas wildflower mix.

We also hosted a group of Year 5 pupils from a local primary school as part of their STEM week, teaching them all about solar energy and the future of the built environment. Their visit included a tour of Swansea University's Bay Campus and various activities, such as making solar powered windmills and completing solar puzzles – all part of the education of the next generation, encouraging them to think about construction careers even from a young age.

Figure 64: The completed building in context

Figure 65: Smart Systems Engineers, Dr Richard Lewis and Tom Griffiths in the Plant Room

Figure 66: Photos of the STEM week visit

5 Manufacturing and Construction

Week 23 (11th – 15th June 2018)

The furniture installation took place this week, including height adjustable, A-frame tables, which had a previous life in an office in London. The original vitra chairs in the meeting room were saved and restored by Rype Office, allowing us to purchase them at a fraction of their original price.

The installation of the Tata Coretinium® idea walls also took place this week.

During this week, we took part in 4theRegion's conference - *'Empowering Future Generations'*, which explored the challenges and opportunities of implementing the principles of the Circular Economy in line with The Well-being of Future Generations Act (Wales) 2015. The sentiment of the conference echoed the main aim of our building demonstration work and was summed up nicely by the conference organisers as:

"A new way of living, working and collaborating is emerging in Wales to better manage resources in a sustainable manner to enable businesses and organisations of all types and sizes to thrive and grow, while protecting and maintaining our natural environment for the benefit of current and future generations."

The primary connection of both the Active Classroom and the Active Office took place after a long process of gaining permissions. This will enable both buildings to feed surplus power into the grid, through a novel export limiter – even on an overcast day, in the first hour we exported 10.5kWh to the grid.

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Figure 67: Formal and informal meeting furniture

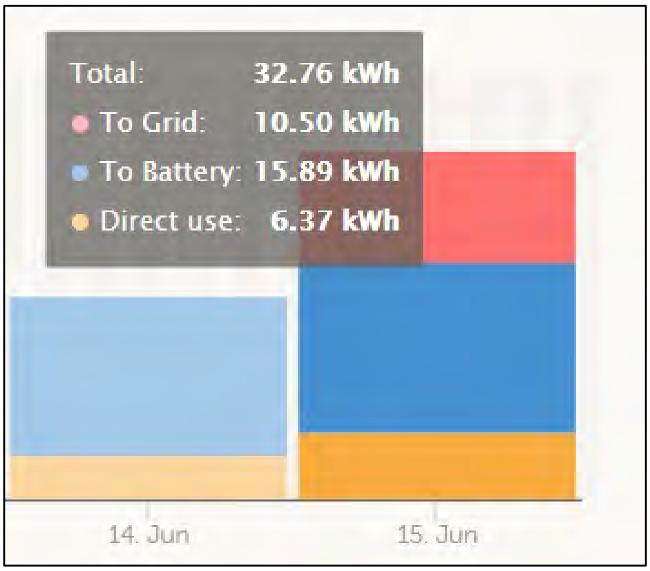

Figure 68: An image from the Victron inverter display

Figure 69: Coretinium® idea wall installation

5.2 The Combined Solar Thermal (PVT) System

As discussed in Stage 4, a novel PVT system was used on the south elevation. This technology highlights one of the purposes of our demonstrator buildings. This UK company had developed a new product and, prior to the Active Office, had installed just one small array of tubes on a flat roof. As with many newly launched products, the company found it is difficult to launch new products into the construction industry, due to the risks involved if the new product cannot be delivered within the construction programme, or if it suffers any failures once installed.

As an Innovation Centre, we were able to take the risk of enabling the company to showcase their product on our building. We discussed the programme with Naked Energy who agreed to target manufacture and delivery of the tubes in line with our programme. However, we were always aware that they may suffer setbacks.

The key again here was good communication. We maintained regular contact with Naked Energy, who provided updates on their changing situations. Being the first time manufacture of a new product at this scale and being reliant upon other supply chain partners to do this, meant Naked Energy were unable to supply the tubes by the end of the construction period in June 2018.

We had built resilience into our heating system to account for this possibility and also to allow for any teething problems once the tubes were installed, so it did not cause any significant issues to the project.

The tubes were actually installed in December 2018 and we have provided data on the performance of their system since installation, which has been invaluable to Naked Energy to aid funding applications and their marketing strategy.

This collaboration was a true success, as Naked Energy have since secured significant additional funding, as well as exposure within the industry and consequently much interest in their product.

For us, not only does the technology look great, but it has been performing as expected – see Stage 7 for some performance data. It also highlights perfectly the challenges of introducing innovation into construction and why our demonstration programme is critical.

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naked energy™

Figure 70: Close up image of a PVT tube

Figure 71: The PVT array in situ on the south elevation

5 Manufacturing and Construction

5.3 Summary of Sustainable Construction Activities


Trees re-planted around campus


Excavated spoil redistributed on site


Construction waste re-utilised


Surplus materials donated to Recipro Wales scheme

Sustainable furniture


Biodiversity – living wall

Student visit from local college


Seed planting with local primary school


BBC School Report with Yr9 pupils


Supply Chain Sustainability School (SCSS) “Introduction to Sustainable Construction” workshop


Talk for International Patent Office during British Science Week


RIBA Core CPD Seminar: “Is offsite the future of construction?”

5.4 Lessons learnt

- The amount of on-site work required with an offsite construction system should not be underestimated.

- Wernick provided us with a turnkey system and we worked closely with them and their subcontractors to resolve cladding details and integration of technologies. However, there was little opportunity to fully scrutinise all details and, due to the fast programme, there were a few minor quality issues apparent post-construction – window details, junctions between modules, gaps in insulation, etc. Although the modules were made in a factory, they were assembled by hand, not machine, so can suffer the same inconsistencies as buildings constructed traditionally on site.

- For complete cross-discipline co-ordination, all buildings should be fully modelled, including ductwork and pipe runs, before construction, adopting BIM Level 2-3 for a truly coordinated approach. This should be mandatory for all buildings, particularly Active Buildings.

- The Energy Strategy for the Active Office is far more complicated than needed, purely because we wanted to test different technologies and systems working together. For an Active Building, it would make more sense to use one provider for each system; for example, the installer of the PV panels, should also be responsible for connecting these up to a suitable energy storage and control system, whereas we had separate installers for the PV and battery installations. We had an electrical contractor providing the cabling for the BMS installer, for e.g., which caused issues, such as waiting for one contractor to return to site, before the other could complete their work. It also muddies water, where contractors can blame each other for things not working, or for incomplete work.

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

6.1 Introduction

On most buildings, at handover, the client (or building owner) is handed an Operations and Maintenance (O & M) Manual, which should contain all the relevant information needed to operate and maintain the building. In reality 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. However, the building had to comply with the standards set by the University's Estates Department, who would ultimately be responsible for ensuring the building operated safely. They were not so concerned with the performance of the systems within the building from an energy demand point of view, which was of most concern to SPECIFIC.

Working collaboratively with Wernick and their supply chain partners from the project outset helped ensure the building was delivered to time and within budget, while satisfying the innovative nature of the technical design, to meet SPECIFIC's goals. Achieving the right balance of innovation, reliability and repeatability. It also enabled efficient use of resources to resolve design challenges, avoided duplication of efforts and clashes between elements.

In addition to the innovative technologies installed to generate onsite renewable heat and power, extensive energy monitoring was installed to enable post-occupancy evaluation, comparison with design goals and system optimisation. Ongoing data capture enables analytics and insight to feedback into the Active Building design process, development of planned maintenance regimes, and optimisation and refinement of predictive control strategies, for both cost, energy and carbon reductions.

6.2 Lessons Learnt

- Even though we worked closely with all contractors including the BMS installer, this did not guarantee the level of access we had anticipated we would have. It also did not guarantee that all the features we agreed to include at meetings throughout the project were translated into reality.

- Not all of the systems we trialled were effective at all times of year, e.g. the method of cooling the Comms Room, which is discussed in the next section.

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 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 Introduction

The Active Office provides a flexible platform to test and evaluate control methodologies and strategies that enable buildings to operate using lower carbon electricity for operation and EV charging. It has also enabled SPECIFIC to take part in collaborative projects examining domestic demand side response (DSR), Smart EV charging and building sensors and control systems.

The design ensures that all significant electrical loads for heating, hot water and building operation can be offset to times of lower cost, carbon intensity or demand. This can be controlled in 3 ways:

- remotely (as part of a virtual power plant);
- locally, based on a local strategy; or
- automatically, receiving control signals from an aggregator.

Each control strategy demonstrates possible routes to low carbon electrification of buildings in the future. The low carbon future will include electrification of heating and transport and as yet there is no single solution to achieving this without significant infrastructure upgrades. The Active Office provides a platform, using available technologies and with monitoring and control capabilities in place to enable future solutions to be investigated, demonstrated and proven. As a flexible energy resource the building is able to operate with the University campus infrastructure, time-shifting significant demand, charging the EV fleet and importing or exporting electricity based on targeting lowest cost or lowest carbon intensity.

In addition to demonstrating a novel Energy Strategy, this building has demonstrated benefits of collaborative working and how different procurement methods can be used for a more holistic approach to building design. The extensive data monitoring enabled a >10% energy reduction in the first year of operation via system optimization.

The Active Office aimed to demonstrate solutions to achieve Net Zero carbon emissions from buildings. A Life Cycle Cost Comparison Report commissioned in 2019 demonstrated that the Active Office emits 33% of the carbon in use of a similar sized standard office building during its 60-year lifetime. Furthermore, the building's EPC rating was A+ and -9 for carbon emissions during operation – demonstrating the building's low carbon design.

By integrating generate, store and release technologies into one integrated system, the Active Office is a live example of how a building can operate without negatively impacting on the mains grid networks, instead showing how new building assets could coordinate to support the energy infrastructure. If every new building interacted with the energy system in the way that the Active Office is able, there would be a significant reduction in stress on the existing grid.

The building also provides a platform for collaborating with businesses and showcasing emerging technologies. Naked Energy have used the Office in their promotional material showing clients the installed Virtu tubes, helping to secure orders and £5M growth funding. Project sponsors, TATA Steel and Cisco, can demonstrate that their products (TATA's roof and wall cladding, Cicso's smart network infrastructure) can add real value to low-carbon buildings.

7.2 Building Performance Evaluation (BPE)

In addition to the innovative technologies installed to generate onsite renewable heat and power, extensive energy monitoring was installed to enable building performance evaluation (BPE), comparison with design goals and system optimisation. Ongoing data capture enables analytics and insight to feedback into the Active Building design process, development of planned maintenance regimes, and optimisation and refinement of predictive control strategies, for both cost, energy and carbon reductions. It also enables the building to act a flexible platform for demonstration, testing of integration and operation of new technologies or products and services, such as the virtual power plant being developed by the FRED project

In its first year (2019), the Active Office generated 22.6MWh of solar heat and electricity and consumed 26.2MWh, equating to 70kWh per m^2, approximately a third of what you'd expect from a similar standard office. Performance was optimised over the next 6 months and in 2020 the building operated at approximately 23MWh per annum (approx. 61kWh/m^2), equating to a 12% improvement. Further optimisation work has been identified to further reduce the energy consumption. Due to the impact of COVID-19 on the building occupancy these numbers are based on a rolling 12 months prior to lockdown so represent 'normal' building operation.

The extensive data collection identifies where the required energy is being sourced (PV, Battery or Grid) and where it is being utilised. The control systems also enable us to control when the batteries are charged and discharged. When combined with other inputs such as price or carbon intensity (CI) data we can calculate the battery CI, or price equivalent, compare this to the grid values, and select which energy source to utilise. This process requires careful management of the battery state of charge and helps with targeting appropriate times to import energy from the grid during periods of low solar insolation. This approach can be improved by more intelligent prediction of renewable generation and energy consumption profiles to identify potential future shortfalls or excess and import or export at the most beneficial times.

Impact of EV Charging

During the first year of operation, 4.5 MWh of electricity (20% of total building consumption) was used to charge EVs using standard EV chargers.

The 'dumb' chargers have since been replaced with 'smart' chargers, which allow charging regimes that enable control to ensure the best use of the available renewable generation while minimising the peak demand on the grid.

Currently EV charging has a big impact on overall performance. It also highlights the future impact of electrification of transport and helps to identify future strategies for managing this increased demand, using Vehicle-to-Building (V2B) chargers, for example.

All EVs used by SPECIFIC are fitted with tracking devices, which will enable the smart charging regime to be implemented more effectively in future.

Continuity of Insulation and Thermal Bridging

This will be discussed in a Thermography Report to follow.

Figure 72: Smart EV chargers outside the Active Buildings

7.3 Initial Capital Cost Review (June 2018)

An initial cost review was undertaken just after completion in June 2018 to determine how the capital cost to construct the Active Office compared to the cost expected for a standard building of this size, type and nature.

Information on typical construction costs was obtained from: http://www.costmodelling.com/building-costs, released 1st April 2018. Costmodelling have produced a guide to typical construction costs of different building types per m^2 of gross internal floor area. They advise that costs can vary from -15% to +10% from the guide costs depending on the specification of the building. The costs are for the building only, inclusive of contractor's preliminaries, overheads and profit, but excluding furnishings, external works, allowance for risk, fees and VAT. They recommend adding a further 20% of the guide costs to cover external works and then a further 15% to cover risk. Professional fees can be anything from 5% to 10% depending on the size and nature of the project (generally larger for smaller projects).

Typical Construction Costs for a non-air-conditioned office building up to 3,000m^2, according to Costmodelling are £1,530 per sqm of Gross Internal Floor Area (GIFA).

The GIFA of the Active Office is 372m^2, giving a total guide cost of:

£569,160.00	+ 20% external works (hard and soft landscaping, drainage and services)
£682,992.00	+ 15% contingency
£785,440.80	+ 10% professional fees
£863,984.88	**ex VAT = £1,036,781.86 incl VAT**

The actual cost was **£832,572.00** ex VAT, **£999,086.40 incl VAT**
+ batteries (£93,045.14 incl VAT) = **£1,092,131.54** = 5% over the guide cost.

Adding 10% for professional fees (which were not needed in this project) gives a total of: **£1,201,344.69** = 15% more than the guide cost of an office building of this size, built to a typical or mid-range specification. Furthermore, in normal circumstances, costs are expected to range from -15% to +10% of this guide, depending on specification and quality of finished building.

For an innovative building such as this, with the complexity of building services to enable experimentation, and excessive metering, the cost over and above that of a standard office building could be expected to be higher. Some of the factors that enabled us to reduce costs included:

- Early engagement of the Main Contractor, Wernick;
- Close collaboration with Wernick;
- The fact that Wernick have a well-established supply chain;
- Wernick were keen to demonstrate the flexibility of modular construction and that modular can be used to produce unique buildings, so negotiated lower prices with their supply chain;
- Due to the timescales, everyone was forced to make quick decisions and avoid duplication of work, as often happens in construction projects, e.g. MEP design was undertaken by the MEP subcontractors in conjunction with the SPECIFIC team, rather than by separate appointment of MEP consultants.
- Reduced timescales also reduced site costs – overheads; hire of site cabins, fencing, labour, etc;
- Although compromises were necessary to keep costs within budget, the designer and contractor were able to work closely together to make considered decisions on where to make savings, e.g. use of pre-finished ceilings, to save decorating costs and time on site; the original fenestration detail of curtain walling to match ESRI, was replaced with Wernick's standard windows and the detail mimicked through cladding design;
- External works were minimised;
- Any variations were scrutinised to ensure there were minimal additional costs.

7 Use

7.4 Life Cycle Cost Comparison Report

Introduction

Active Buildings are currently (2020) expected to cost in the region of 10 – 20% more than traditional buildings of the same type and size, due to their innovative nature. However, they are expected to cost less than a standard building over their life, due to their energy efficient design and the inclusion of renewable energy technologies, aligning with Construction 2025 targets to reduce the whole life cost (WLC) of buildings by 33% by 2025.

To understand whether this is achievable yet, we commissioned a Life Cycle Cost (LCC) Comparison Report for the Active Office in June 2019. This would compare the Active Office to a standard office building and would provide a baseline from which to understand the challenges and identify further research work needed to help reduce the lifetime costs.

The LCC of a building relates to costs associated directly with construction and operation, while the whole life cost (WLC) includes additional costs such as land, income generated from a building and support costs associated with the activity within a building. WLCs are usually calculated by clients, using LCCs prepared by construction industry professionals. Therefore, this LCC report did not take into consideration business models for generating income from energy trading. Instead, it provided a base document for use to determine the WLC.

The project was undertaken over a 3-month period and involved a team of 6 from Faithful & Gould (F & G): a Life Cycle Champion, two Quantity Surveyors, a Maintenance expert, a Building Physicist and a Graduate Quantity Surveyor.

Over this time period, they analysed data provided from the Active Office database.

Unsurprisingly, operational energy costs and operational carbon were lower than the standard comparison building. However, no incentives or value generated from energy were included – whereas they would be considered in a WLC analysis.

Also, BEIS predicted prices for energy were used – different prices at different times of day were not factored in. Additionally, BEIS have no predictions beyond 2032, showing stable costs after this date, when they are likely to change.

Assumptions and Caveats

- Costs presented in the report were based on Q3 2018 for construction and Q3 2019 for other LCCs.
- LCCs are baselined with no sensitivity analysis.
- For technologies where existing reliability or residual value data is either not available or not sufficiently robust the assumption was that the product would be renewed at the initial cost at the point of the warranty period ending. So, the batteries would be valued at approx. £90k at 9 years 11 months and have zero value or storage capacity at 10 years 1 month.
- The report was based on the first year of occupation of the building, while commissioning and fine tuning of systems was still underway. During the exercise timescale, several faults in the heating system were detected, which have subsequently been fixed (refer to Appendix 2. Therefore, it is envisaged that if the exercise was repeated next year, the results would be different. This understanding of where the data comes from and how it is impacted by changes to building operation and systems is necessary in undertaking LCC reporting.
- While it is not realistic to assume energy consumption from the first year of operation of a building is representative of a 60 year lifespan, this was the only data available to F & G and for the new technologies there was no historic data that could have been used.
- Where systems had not been in place for the full 12 months then pro-rata data was used, taking into account changes in operation. In the case of the PVT tubes, the outputs were scaled, but the anticipated impact on the reduction of the heat pump usage was not factored in.
- As a consultant, they could only use real cost data. Part of the research underway at SPECIFIC is to apply a sensitivity analysis to the costs, for example, applying predicted cost reductions in batteries over the coming years.

Maintenance Costs

One of the possible misunderstandings of the new technologies incorporated into the building was that they would require additional maintenance.

However, much of the equipment used in the heating and ventilation system, for example, are not new technologies and would be present in a traditional office building. The batteries are self-maintaining, the BIPV roof does not need any maintenance and the PVT tubes have no moving parts, so additional maintenance is not anticipated for these. The "new" technology assets assumed to require additional maintenance over and above maintenance cost benchmarks for the Standard Office Building were listed as:

- ASHP – No more than a gas boiler
- Roof – No maintenance required
- Tubes – No maintenance anticipated
- Thermal Store – No maintenance required
- Batteries – Self maintaining – may be small additional costs for electrical certification
- Inverters and monitoring – No maintenance required.
- AHUs – Filter changes, which would also be associated with the standard office building proposed

Renewals

Renewal costs for the Active Office were higher than the standard office mainly due to the mechanical and electrical equipment. The Report assumed that technologies will be replaced as soon as their warranty comes to an end – for the batteries, it is assumed they will be renewed three times within the 60-year period at the same price paid for them in 2018.

A 25-year lifespan was used for the BIPVCo roof, which was renewed twice over the 60-years, at the original price paid for them.

A 10-year lifespan for the electric vehicle (EV) chargers was used. The renewal cost of the EV chargers used seemed high (£5,000/charger, when they cost closer to £500/charger).

It was unclear how the warranty lifetime of the equipment compared to that of a gas-fired boiler and whether a new boiler is factored in once the warranty has expired in a similar way to the equipment used in the Active Office. This is one area where the available reliable data extends beyond the warranty period and so the anticipated lifetime was used instead.

While F & G factored in the replacement of the gas boiler with an ASHP in the Standard Office in 2032, the added disruption costs of doing so were not captured. These costs could potentially be quite significant when issues such as staff relocation costs, loss of earnings, etc, are added for the replacement works period.

The cost of batteries, even after 1 year, are likely to reduced, but this was not factored in.

7 Use

Energy Consumption

Fans and pumps made up a significant proportion of the demand. Subsequent data analysis and reference to changes in operation have shown a significant drop in energy consumption associated with the AHUs and the water pumps used for space heating and domestic hot water. This is primarily due to initial poor setup of the system, including air leaks in the ductwork so the units ran at constant rates rather than backing off as dampers closed. There was also limited capability for operating a calendar, so the units were running 24/7 for extended periods. This is particularly visible in the trend data during May, as shown in Figure 73 below, when commissioning and changes to the BMS resulted in significant extra energy consumption - this lasted for a period of 3 weeks.

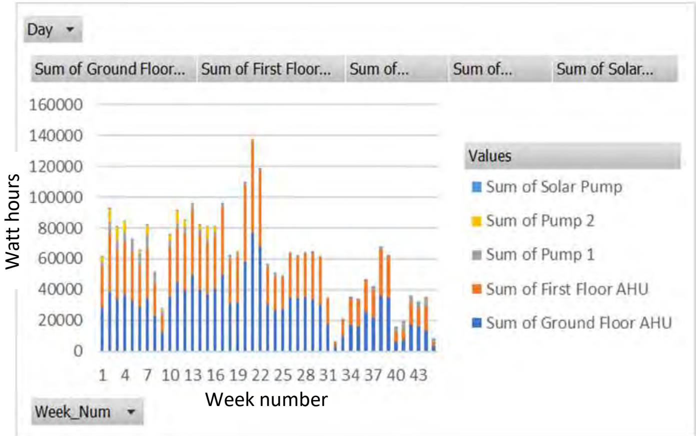

Figure 73: Annual energy consumption of pumps and fans in Active Office, 2019

Energy Generation

- A full year of the roof output data was available.
- Only 5 months data from the PVT tubes were available. Changes to the operation have shown an increase in thermal generation since this time.

Summary

- Renewal, maintenance and construction costs are higher for the Active Office, but operational cost is lower.
- There is a significant carbon reduction in operation for the lifetime of the building and the future costs (if any) of carbon have not been taken into account.
- Costs are accentuated due to the size of the building, i.e. they would be less on a larger building. If a sensitivity analysis was applied to a typical sized office building with 'Active' applied, the cost would be closer to that of a standard office building without 'Active'.
- Due to the trial nature of the building and systems – there is an element of redundancy of systems, and the requirement to be flexible has also resulted in some additional complexity that would not be needed should this concept be used again.
- Considering an intelligent approach to trading energy would help the business case and WLC.
- Assuming zero value at end of battery life is probably unrealistic, but the value is unknown yet.
- Renewal costs for the key technologies, such as the PV roof, the batteries and the PVT tubes are unlikely to remain the same for 60 years given they are technology based and the costs of technology would typically reduce as manufacturing costs reduce, process efficiencies improve and demand increases.
- The Active Building approach may be more beneficial at energy system scale (i.e. with lots of Active Buildings), but not necessarily at individual building scale.
- Another benefit of Active Buildings is avoiding infrastructure costs.
- Missing data identified:
    - The predicted costs of new technologies
    - Expected lifespan of technologies used.

Future Work Identified for full LCC Analysis

This LCC Report provides a baseline for many other research projects, some of which are listed below:

- Optimising EV charging regimes – currently the batteries are charged overnight, but a significant amount of power is then discharged into EVs first thing in the morning. We have identified potential solutions to this, which we are working on as part of the next phase.
  - The operation of the building and batteries in a more strategic and controlled way should be able to drive the carbon or the financial cost down further.

- Batteries still have 80% life left in them when the warranty comes to an end. In the future, EV batteries can be used in buildings, instead of renewing. Bloomberg have done some modelling on battery prices reducing, which can be used in further research.

- Research into recycling costs that can be recuperated – circular economy thinking.

- Undertake a Sensitivity Analysis to ascertain the expected cost reductions in some of the technologies, the timescales for both the building lifetime and technology lifetime assessments. For example, there is almost £100K in the last year over and above the Standard Office, so the details around what this entails will help us target information to support or identify alternatives. Reproduce the report using experience curves for batteries and other technologies. What price would batteries need to come down to, to make the LCC reasonable?
  - An approximately £100k saving could be realised if the warranty for the batteries was just 1 month longer (resulting in 5 renewals rather than 6 – this sensitivity to the time of the study and the lifetime of the products is essential to understand as it is a significant impact).

- The AHUs seem to have a significant associated maintenance cost – an alternative that would work better and was considered, but ruled out due to time constraints, was to use a wet underfloor heating system. This would work well with the low temperature thermal store and would have next to no maintenance cost – and the AHU's could be replaced with lower cost ventilation units as used in the Standard Office. A breakdown of why the existing systems maintenance costs are high and how these numbers were identified will be useful. Pumps and valves don't need much in the way of routine maintenance and filter changes would be the same across AHU's and ventilation type systems.

- It would be interesting to do a comparison of the Active Office against a Standard Office built to Part L compliance, and against offices built to the London Plan for example (where gas boilers are not permitted).

- We could re-run the exercise with some design changes to the Active Office – with less technology flexibility built in. Substitution of BIPV roof and PVT system, with more conventional PV and solar thermal technologies could drastically reduce the cost differential without significantly affecting CO_2 reduction potential.

- Carbon impact (embodied + operational), e.g. embodied carbon of batteries can be partially recuperated by recycling the batteries. Research into the embodied carbon of the Active Office is already underway through a PhD project, being undertaken by a student at the University of Bath.

- Value creation (WLC considerations):
  - Business models – variable tariffs
    - We have sufficient data at the required granularity to run simulated scenarios using available ½ hourly tariff rates, or more simple EV specific tariffs.
  - Income generation
  - Reduced infrastructure costs
  - Reduced climate change impact

➢ ***The main learning point from this exercise is that it is incredibly difficult to accurately assess the WLC of a building. There are many nuances to be considered, assumptions to be made and a certain amount of estimation. This report was not conclusive in proving the WLC of an Active Building, but there were too many unknowns to make a completely accurate assessment.***

7 Use

7.5 Maintenance

Regular monitoring of systems is critical to ensure they continue to work effectively. For example, monitoring of MVHR and ASHP systems will ensure their performance can be optimised, highlighting when filters need to be changed, for example, to ensure a good standard of Indoor Air Quality (IAQ) is maintained. The time period for changing filters will depend on external and internal environments. Our living wall installation provides an example of how maintenance considerations should form part of any design decision.

The Living Wall

The living wall presents a challenge for maintenance, as even the lowest troughs are over 1m from ground level, with the highest troughs at over 4m. This has already caused some issues – the living wall was filled with soil and plants whilst the scaffold was in place. The plant species used are all hardy plants that grow naturally in the surrounding area, and there is an in-built irrigation system for the wall.

However, when the scaffold was taken down, the troughs were no longer accessible, but the plants appeared to be growing well at first. It was a few months later, when the plants started to deteriorate that it became apparent the irrigation system was not working properly. Hence many of the plants perished.

An additional problem for accessing the wall is that the ASHP and its enclosure are sited in front of the living wall. The enclosure is bigger than anticipated at design stage and at design stage the exact position of the ASHP had not been determined.

The outcome is that a cherry picker will be needed to access the wall and replant it. In the meantime, some of the plants have survived and we have dispersed some additional seeds into it, which will help provide some greenery and colour.

Figure 74: Living wall just after project completion

- ***Key learning points:*** ***If including living wall features, ensure they are fully accessible for maintenance***
  Always consider maintenance of systems at design stage.

Additional cooling requirements

Rather than installing air-conditioning in the Comms Room, which could reach temperatures of more than 30 degrees, we extended the ventilation ductwork into the Comms Room to extract the heat, drawing cooler air in through a vent in the door. This would serve a dual purpose of cooling down the Comms Room, whilst using the 'free' heat in other heated spaces.

This works well in the cold season. However, in the summer, when the ambient air temperature is high and heating is not required in the building, another method to cool the Comms Room is required.

7.6 Chronology of Improvement Opportunities Identified from Monitoring Equipment

Heating and Ventilation Systems

Contributing factors to issues experienced with the heating and ventilation systems:

- Mechanical and Electrical Design
- Commissioning Errors
- Equipment Failure
- Lack of rigour in checking equipment supplied against specifications
- Use of different subcontractors for a holistic building services strategy, e.g. solar panel installer, battery installer, BMS installer, AHU installer, ductwork installer, electrician, plumber

During the first heating season, it was clear that the installed heating system was not capable of delivering the 10kW of heat into the building from a 45ºC temperature source, as per the design specification. There were a number of reasons for this, identified through the extensive monitoring system:

1. Visibility of temperatures and flow rates were not available from the BMS immediately
2. Signals on the Variable Air Volume (VAV) dampers were reversed, so when signalled to open they closed and when signalled to close they opened – commissioning error
3. Equipment failure – both remote-controlled 3-port valves failed on the AHUs, resulting in no heat transfer from the low temperature hot water (LTHW) circuit to the ducted air, despite raising the temperature of the thermal store to 80ºC (consequently using more energy)
4. The 22mm diameter pipework connected to each AHU stepped down to 15mm to match the pipework of the wet heater batteries – a larger capacity water pump was fitted to the LTHW circuit in an attempt to remedy this, but this resulted in a limited increase in the flow rate. The 15mm pipe was replaced with 22mm pipework, removing the flow constriction, resulting in more than double the volume of water through the LTHW circuit and a reduction in speed of the LTHW pump to compensate.
5. The AHU equipment supplier had overlooked the need to supply units from a 45ºC source temperature and supplied units capable of achieving a 10kW heat output at a temperature of 80ºC source. Larger capacity wet heater batteries were then designed and custom manufactured to fit within the existing AHUs.

➢ ***Note: The process of identifying and remedying these issues took several months, but might never have been resolved without the high level of monitoring in place; and the result would have been to continue operating at the higher temperature, further reducing efficiency through increased energy use.***

6. The BMS control logic did not provide a facility to enter a lower, setback temperature for overnight operation, which meant the setpoint for all heated spaces was 21 degrees, 24 hours a day. This resulted in a higher energy use than anticipated at design stage.
7. Due to the lack of manual dampers at each supply grill, the dampers fitted were not able to equalise the air delivery from individual supply grills, leading to preferential heating to some spaces, preventing a uniform temperature to be achieved. Once this issue was identified, manual dampers were retrofitted. The airflows were then balanced by a different subcontractor.
8. The solution to increase the flowrate based on maximum designed occupancy of the building (in compliance with building regulations) resulted in a nearly doubling of the supply air flow, which resulted in unacceptable noise levels within the working environment. The reason for this was that the increase in supply air flow was not coupled with a similar increase in extract air flow rate, resulting in positive pressure within the building. This also caused a significant increase in electrical power demand, to almost triple the power. To combat this issue, the ventilation rate was gradually reduced over a few months, whilst monitoring CO_2 levels to ensure adequate ventilation was maintained. These changes did enable more uniform heating of all areas within the building.

The noise level from the air handling system has been a cause of concern throughout. A number of air leaks around joints in the ductwork have now been rectified, which has helped alleviating the problem.

7 Use

BMS Heating Control Logic and Communication

Some of the problems encountered with the BMS heating and control logic over the first 18 months of building operation included:

1. The AHUs did not initially adhere to the setpoints and calendar events entered into the BMS logic. On further investigation it transpired that communication between the BMS and AHUs had not been correctly assigned, leading to the inbuilt control on the AHUs overriding the signal being sent from the BMS. Altering the settings on the AHU to make it a slave to the BMS control resolved the issue.

2. The temperature setpoint for the 6kW immersion heater in the thermal store was initially set higher than the designed system operating temperature, meaning that it operated continuously. As there was no indication of when the immersion was on, this resulted in very high electrical energy consumption for several weeks after handover, until it was eventually identified when individual circuit metering was enabled. The trigger temperature was subsequently reduced.

3. A -2℃ offset was applied to the thermostat readings in all rooms, meaning that a programmed setpoint of 21℃ would equate to an air temperature of 23℃. Having checked the accuracy of the room thermostat readings against independent temperature loggers, the offset was removed.

4. The logic control for the heating system included areas of the building which had thermostatic wall sensors, but were not directly heated, therefore the AHUs would run continuously as they tried to heat uncontrolled areas, long after the heated spaces had reached temperature. These areas were subsequently removed from the control logic.

5. There was no logic to check that hot water was being supplied to the AHU before enabling the heating cycle. On several occasions, when there was a problem with delivery from the LTHW circuit, this resulted in substantial cooling of the building as cold external air was circulated for several hours prior to the first occupants arriving in the building. The BMS supplier provided an additional logic block to prevent AHU operation if the LTHW circuit was cold. However, this would not work if there were a repeat of the three-port valve failure.

6. As the external temperatures began to increase with the onset of spring, the ability of the heating and ventilation system to switch between heating and cooling was tested for the first time. When in ventilation / cooling mode the AHUs should have automatically bypassed the heat exchanger to bring cool fresh air into the building. Unfortunately, this was not the case as the controls on the AHU had not been set up correctly. This was rectified during a site visit by an air handling unit specialist, in May 2019.

7. An unrelated issue, identified around the same time, caused the flow to stop on three of the main water circuits; the LTHW, DHW and ASHP. The problem was traced to a faulty pressure sensor. A software workaround was implemented remotely by the BMS installer, until a technician could attend site to replace the defective sensor. While on site the BMS technician added some logic blocks, which had been missed from the specification document. These provided an interface with recent changes to the AHUs to enable free cooling of the building using fresh outside air, when possible. This was not entirely successful as it caused the AHU fans to operate continuously, 24 hours a day for two weeks, before the situation was resolved.

8. The return pipework from the DHW tank to the thermal store was altered through the addition of an automatic three port valve during October 2019. This enabled two control modes for the thermal store, depending on the thermal strategy under investigation:

    a) Increased stratification - to increase the potential for thermal transfer from the PVT system.
    b) Destratification – to provide maximum thermal storage capacity.

Since building handover, the temperature setpoint of the thermal store has been manually adjusted in response to the changing heating demand. In future it is envisaged that the temperature setpoint will be altered automatically based on the predicted external temperature. The ASHP was effectively disabled from the end of August 2019 until the beginning of November 2019, allowing the temperature in the thermal store to be governed by generation from the PVT tubes alone, which maintained a temperature of between 23℃ and 47℃ at the mid-point of the tank.

None of the issues identified could be attributed to any one factor. Despite close collaboration between the client and project delivery team, the combination of design anomalies, installation errors, poor commissioning and the difficulties in co-ordinating disparate subcontractors all played their part, as observed in many construction projects. The flexibility we built in also played a part, in that the operation is inherently more complex and non standard - a more detailed control specification would have helped avoid misinterpretation.

it may be that test scenarios would aid in identifying and testing control logic. Test scenarios outline key operating processes and then feed data into the system that should evoke that control methodology. By determining short targeted test performance scripts commissioning could be sped up and targeted based on expected behaviour based on design and operational methodology.

7.7 Retrofit of technologies

Thermochemical Store

At the time of constructing the Active Office, it was anticipated that excess heat would be generated by the PVT system during summer months. This would provide an ideal source of heating to trigger the thermochemical heating technology under development at SPECIFIC. As this technology was not yet available at the time of construction, a 10kW heat dump was installed to dispel excess heat should it occur.

The system was designed to enable a thermochemical storage device to be retrofitted once a suitable building-scale prototype has been developed. This is anticipated in 2021.

Further information on the technology can be accessed here.

Figure 75: Thermochemical storage material

7.8 Life Cycle Assessment (LCA)

The UK is on a pathway to achieving Net Zero carbon emissions by 2050. While we are able to prove significant operational carbon savings, we do not have in-house expertise to assess embodied carbon. Embodied carbon is more complex and time consuming to assess, so would not have been possible within the scope of the project given the programme and cost constraints we faced. However, embodied carbon becomes ever more important as the electricity, heating and transport decarbonise.

A student at the University of Bath is currently undertaking a PhD focused on developing an LCA of both the Active Classroom and the Active Office. This 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, which will help bring the issues surrounding LCA to the forefront.

Summary Checklist

Active Building Principle	Actions	Issues identified
Principle 1	• South orientation with unshaded roof • Simple building form • Use of natural and mechanical ventilation • Plenty of good quality, natural light • Air-tight building envelope • Thermally efficient envelope • Thermally efficient windows – Pilkington energikare advantage glass • Living wall for biodiversity and reduced run-off • Construction method: offsite, modular • Materials: • Steel cladding • Welsh or UK suppliers used where possible	• South elevation partially shading during winter months – this was taken into consideration when modelling the PVT system • Thermography indicates thermal bridging around module joints, junctions and window frames • The windows used are aluminium, so not as thermally efficient as timber. They are also positioned close to the external building line, not in the insulation zone – this was due to the need to use Wernick's existing supply chain and detailing. • Steel screw piles would have been a suitable foundation choice, but we had to use Wernick's concrete solution to avoid time delays.
Principle 2	• MVHR and ASHP combined with solar thermal system • Low energy lighting with daylight dimming and proximity sensors • Sensors and other monitoring devices installed to allow data collection	• Some issues with sensitivity and operation of daylight dimming and timing control – to be targeted during 2021 to improve occupancy comfort and energy efficiency
Principle 3	• Building integrated PV (BIPV) roof • Combined solar thermal and PV (PVT) system for generating heat and electricity	
Principle 4	• Electrical storage – 110kWh lithium-ion phosphate batteries • 2,000 litre thermal store, with capacity to install thermochemical store when available	
Principle 5	• Initially 3 wall mounted EV chargers incorporated. These were later replaced by 5 free-standing smart chargers.	• The impact of EV charging on overall building consumption, if not metered separately.
Principle 6	• Advanced control systems to enable the building to interact with the local grid in different ways, and to display a flat load profile to the grid.	• SPECIFIC is a member of the FRED consortium examining demand side response (DSR) and virtual powerplant (VPP) operation

Awards and Recognition

Awards

- Education Buildings Wales Awards 2019 – "Innovation in Delivering a Sustainable Education Facility"
- British Construction Industry Awards 2020 – Highly Commended in "Climate Resilience Project of the Year" category

Articles

- SPECIFIC. 2019. *The Active Office: One Year On...* https://www.specific.eu.com/the-active-office-one-year-on/
- Swansea University. 2019. Active Office scoops top honour at building awards. Wales 247. https://wales247.co.uk/active-office-scoops-top-honour-at-building-awards/
- Colley, D. 2019. *Factory-made buildings and the planet*. New Statesman. https://www.newstatesman.com/spotlight/manufacturing/2019/09/factory-made-buildings-and-planet
- McWhirter, S. 2019. *An Active Solution: Putting Energy into Architecture. Building Construction Design.* https://www.buildingconstructiondesign.co.uk/news/an-active-solution-putting-energy-into-architecture/.
- Clarke, J. 2019. *From little acorns Active Buildings grow.* Building Construction Design. https://www.buildingconstructiondesign.co.uk/news/from-little-acorns-active-buildings-grow/
- The Engineer. 2020. *Built environment driven by sustainability and technology*. The Engineer. https://www.theengineer.co.uk/sustainability-building-engineering/
- Clarke, J. 2020. *The six degrees of Active Buildings*. Building Construction Design. https://www.buildingconstructiondesign.co.uk/news/the-six-degrees-of-active-buildings
- Clarke, J. 2020. *Active Buildings – even better than passive*. RIBA Journal. https://www.ribaj.com/intelligence/what-are-active-buildings-using-the-energy-grid-better-active-building-centre
- UKGBC. 2020. *CASE STUDY: Active Office and Active Classroom*. https://www.ukgbc.org/ukgbc-work/case-study-active-office-and-active-classroom/

List of companies involved

Company Name	Responsibility
Arup	CIBSE TM54 calculations
ATB Systems Ltd	External door and window supplier and installer
AkzoNobel	Specialist paint supplier
Biotecture	Living wall supplier
BIPVCo Ltd	PV panel supplier
Cisco	Sponsor and internet access points supplier
Demma	BMS installer
Dulas	Battery System Supplier and installer
Evabuild Ltd	Groundworks and Substructure
Evabuild Interiors Ltd	Flooring and Ceilings
Faithful & Gould	Life Cycle Cost Consultants
Kelda Technology	Water saving shower head supplier
Naked Energy	Manufacturers and suppliers of the PVT system
NSG	Glass supplier for external doors, windows and curtain walling
Paramount Office Interiors Ltd	Electrical Subcontractor
Pursey and Ball Ltd	Mechanical and Plumbing Subcontractor, also responsible for installation of Building Management System (BMS) and controls
Rainbow Blinds	Internal blind supplier and installer
Rype Office	Internal furniture supplier
SRS Roofing ad Cladding	External cladding supplier and installer
Tata Steel	External Cladding manufacturer Internal Coretinium “Idea Wall” supplier
Total Building Control	Building Control Officers
Wernick Buildings Ltd	Main Contractor and provider of turnkey building solution. Responsibilities included Principle Designer, Principle Contractor, responsibility for gaining planning consent and building regulations approval