Institution: Swansea University		
Unit of Assessment: 12		
Title of case study: Buildings as power stations: the novel integration of new green technologies to transform buildings from energy consumers to power producers.		
Period when the underpinning research was undertaken: 2006 - 2018		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Eifion Jewell Dave Worsley	Associate Professor Professor	1993 – present 1992 – present
Period when the claimed impact occurred: 2015 – 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

"Buildings as power stations" (BAPS) is a revolutionary concept by which buildings go beyond self-sufficiency and integrate into local and national energy infrastructure to share energy loading and become net contributors to national energy demands. The underpinning research conducted at Swansea University (SU) resulted in the construction and operation of energy-positive buildings (the Active Classroom and Active Office), leading to the generation of 1MWh p.a. of green energy. Direct economic impact was achieved off the back of these buildings resulting in a GBP36,000,000 EPSRC investment into the national delivery of energy positive buildings which created the Active Building Centre (ABC), a new and independent Research and Technology Organisation (RTO). An additional economic impact was achieved with GBP5,000,000 of private sector investment into the commercial development of BAPS technology. The BAPS principles have also been applied to 12 social housing dwellings, removing 12 families from fuel poverty and invoking Welsh Government policy debate on the future of all new build homes in Wales being powered by clean energy. International social impact through technology transfer to India has also been achieved, improving the health and wellbeing of communities within this developing nation through improved energy security.

2. Underpinning research

The BAPS concept is a result of SU's extensive underpinning research in novel functional coatings. The concept is based on the premise that smart materials and integrated systems built into the fabric of the building are able to harvest, store and use zero carbon energy such that the building becomes a net contributor, as opposed to a net burden, to the national power grid. This vision has been championed by the EPSRC, Innovate UK and the Welsh Government, which enabled the creation of the Sustainable Product Engineering Centre for Innovative Functional Industrial Coatings (SPECIFIC) Innovation Knowledge Centre (IKC) at Swansea in 2011. SPECIFIC contains 10 academic staff and over 50 postdoctoral and postgraduate researchers, who undertake a wide breadth of research to enable the BAPS vision, ranging from fundamental photochemistry and large area photovoltaic (PV) design to thermal modelling and monitoring of buildings.

Pre-painted steel building facades can be subject to UV paint degradation and steel corrosion, limiting their life and suitability as solar energy harvesting surfaces. Our research on understanding the relationship between the paint spectral absorption characteristics **[R1]**, paint binder and pigment photochemical stability **[R2]** and cut edge corrosion of zinc-coated steel **[R3]** has resulted in functionalization of the building structure. Our research has enabled and demonstrated energy absorbing photo-stable full façade transpired solar collectors (TSC) which act as both a protective skin on a building and a source of 60°C hot air for building heating or thermal storage.

In order to address the temporal mismatch between the high supply of hot air from the TSC in the summer and the high demand in winter, thermal storage solutions were investigated by Swansea.

The hydration of salts was identified as a suitable thermochemical storage mechanism, appropriate to temperatures achievable directly from the building envelope. This research was critical for the implementation of the active buildings concept **[R4]**.

In parallel with thermal capture, our research has enabled innovation in electrical harvesting, storage and use. Based on our fundamental material and device research into scalable manufacturing of perovskite photovoltaics, we have developed a process for the production of the world's largest low-cost (<GBP0.05/KWh) printable PV modules **[R5]**, using low-energy manufacturing methods. Our research on binder / solvent formulation, carbon type and processing conditions of conductive carbon pastes has enabled thermal uplift through low voltage underfloor heating which is localised and controlled at individual tile "pixel" level **[R6]**, for highly localized workspace heating from any stored excess PV power. This marries well to heat release from thermochemical storage to provide individual workspace comfort.

In reference to everything above, SU's research was amalgamated into a functioning system. A variety of novel electrical and thermal energy harvesting, energy storage and consumption technologies were integrated into the building fabric and building management system for the first time. Each fully instrumented building delivers unique human-building interaction metrics to test the novel technologies. These buildings are functioning with normal occupancy rates and are providing net energy contributions to the grid. Our research was critical in enabling a substantial body of work that dictated the design and build of the Active Office and Active Classroom. These innovations were recognised by the Royal Institute of Chartered Surveyors Wales in shortlisting the buildings for multiple awards and winning two, the "Sustainable Building of the Year in 2017" award and subsequently a "Design through Innovation 2018" award.

3. References to the research

The outputs below represent six peer-reviewed journal papers, five of which are published in Q1 journals with one in a Q2 journal (JCR). Three have industrial collaborations on the paper (Tata and Corus Colors). All papers were supported by funding from EPSRC and also one other source such as Welsh Government, Tata, or ESF. Eight competitively won grants support the body of work totalling GBP80,642,543. This research has made important contributions to the discipline internationally and contributes important knowledge to the field likely to have a lasting influence.

[R1] Mabbett, I., Elvins, J., Gowenlock, C., Glover, C., Jones, P., Williams, G., & **Worsley, D.** (2014). Addition of carbon black NIR absorber to galvanised steel primer systems: Influence on NIR cure of polyester melamine topcoats and corrosion protection characteristics. *Progress in Organic Coatings* 77 (2), 494-501. doi:10.1016/j.porgcoat.2013.11.015

[R2] James, S., Robinson, A., Arnold, J., & **Worsley, D.** (2013). The effects of humidity on photodegradation of poly(vinyl chloride) and polyethylene as measured by the CO_2 evolution rate. *Polymer Degradation and Stability*, 98 (2), 508-513. doi:10.1016/j.polymdegradstab.2012.12.007

[R3] Elvins, J., Spittle, J., Sullivan, J., & **Worsley, D.** (2008). The effect of magnesium additions on the microstructure and cut edge corrosion resistance of zinc aluminium alloy galvanised steel. *Corrosion Science*, 50 (6), 1650-1658. doi:10.1016/j.corsci.2008.02.005

[R4] Sutton, R., **Jewell, E**., Searle, J., & Elvins, J. (2018). Discharge performance of blended salt in matrix materials for low enthalpy thermochemical storage. *Applied Thermal Engineering*, 145, 483-493. doi:10.1016/j.applthermaleng.2018.09.052

[R5] De Rossi, F., Baker, J.A., Beynon, D., Hooper, K. E. A., Meroni, S. M. P., Williams, D., Wei, Z., Yasin, A., Charbonneau, C., **Jewell, E. H.,** & Watson, T. M. (2018). All printable perovskite solar modules with 198 cm^2 active area and over 6% efficiency. *Advanced Materials Technologies*, 1800156. doi:10.1002/admt.201800156

[R6] Philip, B., **Jewell, E**., Greenwood, P., & Weirman, C. (2016). Material and process optimization screen printing carbon graphite pastes for mass production of heating elements. *Journal of Manufacturing Processes*, 22, 185-191. doi:10.1016/j.jmapro.2016.03.001

Grants

[G1] Worsley, D. [Principal Investigator]. (Sept 2018- May 2020). The Active Building Centre (ABC). [EP/S016627/1]. EPSRC. GBP35,947,427.

[G2] Worsley, D. [Principal Investigator]. (2019 – 2020). FRED (Flexibly Responsive Energy Delivery). BEIS. GBP85,000.

[G3] Worsley, D. [Principal Investigator], & **Jewell, E.** [Co-Investigator]. (Apr 2016-Mar 2021). SPECIFIC IKC Phase 2. [EP/N020863/1]. EPSRC. GBP1,998,339.

[G4] Worsley, D. [Principal Investigator]. (Oct 2017–Dec 2021). SUNRISE. [EP/P032591/1]. EPSRC. GBP6,580,123.

[G5] Jewell, E. [Principal Investigator]. (Apr 2016–Jan 2019). Hi-Prospects. [EP/N509905/1]. EPSRC. GBP300,702.

[G6] Worsley, D. [Principal Investigator]. (May 2013–Jun 2016). SPECIFIC Tranche 2: Heat, Water, PV and Bio-inspiration. [EP/L010372/1]. EPSRC. GBP1,626,979.

[G7] Worsley, D. [Principal Investigator]. (Jul 2012 – Jun 2016), SPECIFIC. [80892]. WEFO. GBP26,300,000.

[G8] Worsley, D. [Principal Investigator]. (Jul 2012–Jun 2016). SPECIFIC Tranche 1: Buildings as Power Stations. [EP/K000292/1]. EPSRC. GBP2,791,868.

[G9] Worsley, D. [Principal Investigator]. (Apr 2011–Jul 2016). Sustainable Product Engineering Centre for Innovative Functional Industrial Coatings – SPECIFIC. [EP/I019278/1]. EPSRC. GBP5,012,105.

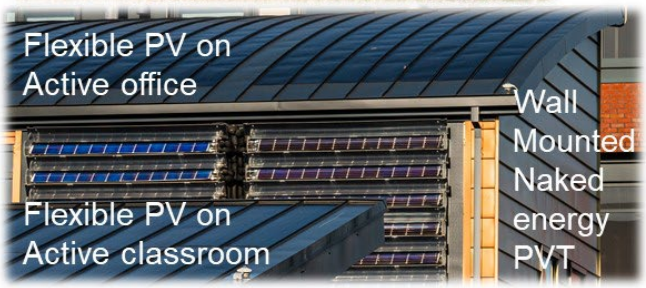
4. Details of the impact

Utilising the underpinning research strands outlined above, SPECIFIC IKC have taken these siloed green technologies and combined them into a fully integrated system for the first time. This culminated in the delivery of real buildings that address both the practical implementation and the technical challenges of BAPS.

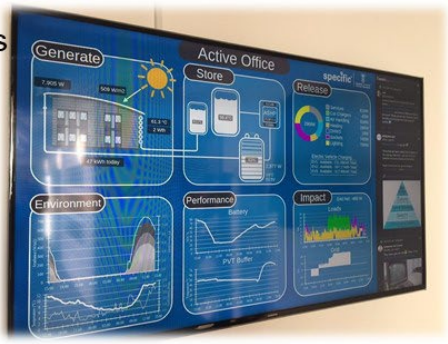
Ground-breaking scalable research on the system control, material properties and reactor design have enabled the first scale-up from laboratory reactor to a 5-tonne calcium chloride thermal storage reactor. The storage reactor was deployed in a factory-size building which was retrofitted with a TSC as a thermal source, and the building has operated for 3 years without fossil fuels achieving storage densities of 56kWh/m^3.

On the Swansea University Bay Campus over 4 annual cycles (between 2017 and 2020) under full occupancy, the Active Classroom (186m2) has delivered a net positive energy generation of 400kWh per annum. In addition, in its first year of operation (between July 2018 and 2019) the Active Office (376m2) reduced its net energy consumption by 99% (4 kWh/m^2 per annum), compared to an industry standard of 300 kWh/m^2 per annum for a conventional office. By the end of June 2020, optimization led to a net positive 600 kWh per annum energy production, **making it the UK's first energy-positive office space**. Six electric vehicle charging points on the buildings have also provided 29,000km of fossil fuel-free motoring. Since construction, these buildings had a direct positive **environmental impact** by removing reliance on fossil fuels, reducing carbon

emissions by an estimated 70 tonnes of CO_2 (compared to an office built to current national standards) as well as providing green energy back into the national grid at times of peak demand.



Continuous building data monitoring and dynamic grid support



Economic impact has been derived from the research. The buildings have been critical in creating the case for large national and international collaborations on BAPS. A GBP36,000,000 EPSRC investment was made into the new independent Active Building Centre (ABC) Research and Technology Organisation (RTO) **[C1]**. The creation of the ABC RTO was reliant upon Swansea's research, as affirmed by the CEO of ABC:

"…the demonstration buildings designed, specified and delivered on the University campus were a catalyst for change that inspired the investment to create the ABC." **[C1]**.

The technology used in the buildings has since been transferred to the industrial mass market through the new ABC RTO via best practice guidelines, and has invoked industrial support with collaboration across the building value chain, from 21 leading industry bodies who are committed to meet the governmental initiative to make all new buildings 100% zero carbon by 2030 **[C2]**.

Companies such as Wernick Buildings within the construction sector and Naked Energy, a Small to Medium Enterprise (SME) that develops photovoltaic thermal (PVT) collectors, have both directly benefited from Swansea's active building projects. Build partner Wernick states:
"The process of developing the Active Office was a significant technical advance for the company, opening new commercial possibilities in architecturally inspired buildings." Deputy Managing Director, Wernick Buildings Ltd **[C3]**.

In addition, Naked Energy's ground-breaking PVT installation on the vertical facia of the Active Office allowed the company's first quantifiable demonstration, which resulted in them securing a GBP5,000,000 private investment into scaling manufacture of their PVT products for the construction industry **[C4]**.

Direct **social impact** has also been affected through the design and construction of energy-positive social housing in the Active Homes 12-dwelling estate in Neath, South Wales, which represents a multi-partner collaboration with social housing provider. The CEO of The Active Building Centre emphasises the **health and wellbeing benefit** of these homes:

"We are particularly pleased that the 12 Active Homes in Neath will be occupied in the late summer of 2020 and that these 12 novel homes will provide heat and power to occupants who would otherwise be in fuel poverty." **[C1]**.

The benefits derived from this concept have also influenced **Welsh Government Policy** debate, invoking a consultation (as a preliminary to legislative policy) that all Welsh new-build homes must be powered from clean energy sources by 2025 **[C5 & C6]**.

Beyond the UK, Swansea's active building research is having impact within developing nations such as India, where energy security is one of many significant societal issues due to limited and unreliable supply. The SUNRISE project (2020 winner of the Times Higher Education Award for International Collaboration), which aims to address global energy poverty by implementing next generation TSCs and large area low cost PV technologies, has used sustainable building principles generated from our research to provide secure energy supplies to community schools and health centres in rural India. Through our delivery partner The Indian Institute of Science, Bangalore, **impacts on learning and participation** have been derived from the 1.92kW microgrid and battery installation at Panchaya Union School in Tirupur, Tamilnadu, which has benefitted the school and its pupils by providing lighting for an additional 3 hours of learning time per day. In addition, a 5.12kW microgrid was installed in the Primary Health Centre in Dharwad, Karnataka, **benefiting the wellbeing and health** of the local community through a new stable, green electrical supply **[C7]**. This energy security intervention allowed the health centre to maintain its services and function effectively without the risk of power loss. Impact on **energy poverty** in Africa is evidenced by Solar Powered classroom/play area in Mutende Orphange, Chingola, Zambia (installed 2016) and an independent school power supply in Siavonga, Zambia (installed 2019).

Our research has also formed the basis for Continued Professional Development (CPD) training, where our technology advances and best practices in BAPS have been widely disseminated throughout industry. National recognition of SPECIFIC's leadership in this area resulted in our CPD content being used to formulate a national framework to influence building standards, new design guidelines and codes of practice. The Royal Institute of British Architects CPD programme, which was begun in 2019, now includes the SPECIFIC Active Building workshops which have educated and inspired 271 professionals (to end of Jan 2020) from a wide range of industries including the MoD and the NHS and is a continuous ongoing activity **[C8]**.

5. Sources to corroborate the impact

Where organisations provide testimonials below, in what capacity they are involved with the impact follows in brackets:

[C1] Letter of Support: CEO, Active Building Centre. (Reporter)

[C2] ABC – Transforming Construction section https://www.activebuildingcentre.com/about-us/

[C3] Letter of Support: Deputy Managing Director, Wernick Buildings. (Reporter)

[C4] CEO, Naked Energy Ltd - Signed Private Investment Enterprise Declaration Form.

[C5] Welsh Government Press Release 27th January 2020: Green Energy Homes.

[C6] Welsh Government Consultation Document, Tackling Fuel Poverty 2020-2035.

[C7] Letter of Support: Professor, The Indian Institute of Science, Bangalore. (Reporter)

[C8] Letter of Support: Director, RSWA - Royal Institute of British Architects. (Reporter)