Sustainability in Energy and Buildings: Research Advances ISSN 2054-3743
Vol. 6. No. 1 : pp.20-28 : seb17s-008

Testing and validation of 'building as power station technologies' in practice, to maximise energy efficiency and user comfort and minimise carbon emissions

Joanna Morgan
Building Integration Manager, SPECIFIC, Swansea University, Wales, UK
Professional Doctorate Research Student, Cardiff Metropolitan University, Cardiff School of Art and Design, Cardiff, Wales
Joanna.r.morgan@swansea.ac.uk and jomorgan@cardiffmet.ac.uk

Dr John Littlewood
Head of the Sustainable & Resilient Built Environment Group, Cardiff Metropolitan University, Cardiff School of Art and Design, Cardiff, Wales, UK, jlittlewood@cardiffmet.ac.uk

Paul Jones
Technology Director, SPECIFIC, Swansea University, Wales, UK, d.paul.jones@swansea.ac.uk

Paul Wilgeroth
Programme Director, Cardiff Metropolitan University, Cardiff School of Art and Design, Cardiff, Wales, UK, malam@cardiffmet.ac.uk

Abstract

This paper discusses a research project investigating whether the application of *'buildings as power stations'* (BPS) technologies actually work in practice to maximise energy efficiency and user comfort, while minimising energy costs and associated carbon emissions, which commenced in April 2017. The aim of the project is to determine whether the inclusion of BPS technologies therefore contributes to a more sustainable built environment and to evaluate the parameters needed to create energy positive buildings. The project will consider how 'buildings as power stations' can help address the challenges facing the construction industry in meeting Welsh and UK Government targets for reducing carbon emissions and improving the industry, as well as global targets for dealing with climate change.

The research methodology is also discussed and describes the inclusion of both quantitative and qualitative data gathered from literature reviews and case studies. Moreover, the expected outcomes of the research project are also discussed. This paper will be of interest to academics, architects, engineers and developers evaluating building fabric integrated energy generating technologies.

1. Introduction

This paper discusses the research being undertaken by the first author as part of a project associated with a role at the SPECIFIC Innovation and Knowledge Centre, UK, in the context to their 'buildings as power stations' (BPS) concept. The paper sets the scene for proving the value of the BPS concept in improving the built environment and energy use of buildings.

The aim of the research is to test and validate the BPS concept using real building demonstrator projects to determine how the buildings that incorporate the 'generate, store and release technologies' (GSRTs) under investigation at SPECIFIC behave in terms of energy usage, costs and associated carbon emissions and also user experience and comfort. SPECIFIC is an academic and industrial consortium led by Swansea University with three main industrial partners (Tata Steel, NSG and BASF) and many other academic and industrial partners. SPECIFIC aims to turn buildings into power stations by using a number of technologies embedded into building envelopes rather than mounted on the surface - to generate, store and release energy, which is deemed to be game changing in terms of enabling energy positive buildings [1]. The concept of energy positive buildings is that they generate more energy than they consume [2].

2. Background and Related Work

In the winter of 2016/17, the UK faced a margin of only 5.5% of available power supply from the National Grid, and this margin is getting worse each year [3]. It is estimated that energy use (regulated and unregulated) in buildings accounts for 36% of the UK's greenhouse gas emissions (GHG) [4]; and their energy consumption is responsible for 40% of total European Union (EU) energy consumption [5]. Thus, the potential opportunity to design and construct new buildings that embed systems and technology into their facades to generate and store energy for release and use in the building has significant environmental benefits [6]. This should lead to less impact on the UK electricity national grid, less carbon emissions from conventional power stations, reduced user energy costs, reduced reliance on the national grid for electricity and hence greater fuel security than conventional buildings for the UK. The widespread adoption of the BPS concept could save expensive and disruptive changes to the electricity grid that are likely to be necessary if the current increase in renewable energy generation continues without associated storage solutions.

In addition, there is a growing need and desire to change the UK energy market to incorporate more local energy systems, as highlighted in a recently published article by The Office of Gas and Electricity Markets (Ofgem) which discusses their work on assessing the changing world of energy, stating that *"Local energy projects can drive decarbonisation and energy efficiency, and have the potential to reduce the investment needed in our networks."* [6]. Ofgem also discusses the growing desire of consumers to control their own energy and gain more independence from the national grid [7]. The authors believe that the buildings as power stations (BPS) solution responds very well to Ofgem's findings, by creating buildings that generate their own energy, are energy positive, and act as local energy systems.

Way [8] in the 'Soft Landings Framework' [8] states that there is an increasing awareness of the need to reduce energy use and carbon emissions in buildings, and for more emphasis on post-occupancy evaluation. The BPS solution combines the integration of technologies to reduce overall energy consumption and carbon dioxide (CO_2) emissions with appropriate control systems, which enable the building to continue to operate efficiently as designed and learn from the occupancy of the building, so addressing post-occupancy performance.

The Zero Carbon Hub in 2014 [9] alluded to the need to change culture and mindsets to place greater emphasis on energy performance in buildings in the UK, from design stage to completion and beyond to buildings in use, suggesting the appointment of 'Energy Champions' responsible for ensuring the energy principles for the building are clear, achievable and implemented. As an Architect, one of the roles of the first author as Buildings Integration Manager at SPECIFIC is to adopt an advisory role for her colleagues, clients and their design teams on how to integrate technologies into the building fabric. It is anticipated that embedding energy generating technologies into the building fabric will by default encourage clear energy principles from the outset of a building project, as the facades themselves will be designed to provide the main source of energy for the building. The BPS concept requires all stakeholders to think differently about the buildings they are designing, constructing or using; not only focusing on reducing energy consumption and waste as part of the overall design but also considering how the building fits into the local energy system [6]. BPS buildings link the construction industry and energy industry together by addressing problems both industries face in terms of reducing energy use in buildings and alleviating pressure on the electricity grid, as well as the plans to de-carbonise the heat in the UK, with buildings that are now local energy generators/providers, in addition to their usual functions [7]. The BPS concept combines electricity generation and storage with heat generation and storage. The authors believe that the BPS approach is a brand-new concept and requires new ways of thinking about buildings, which is one of the challenges that will be explored and addressed in this research project.

To date (April 2017) there are a limited number of building examples incorporating the generate, store and release technologies (GSRTs), enabling buildings to act as power stations (BPSs). The GSRT concept is unique in that it includes building integrated generation technologies for both electricity and heat, using solar energy; the storage of that energy locally; and the release, or use, of that energy as light, power and heat within the building. In addition to utilizing existing technologies, these buildings incorporate new technologies that have been developed either at SPECIFIC or by other partnering organisations, which is believed by the authors to be unique in the construction industry. The experience of the first author as an Architect and now as Building Integration Manager at SPECIFIC provides a good knowledge base to enable the research, innovative technologies, building designs and user experiences to be pulled together to develop solutions and assess the performance of these buildings.

In addition to influencing the UK construction industry to change, the first author will be able to influence SPECIFIC as an organisation to change and adapt. This includes advising on factors such as aesthetics and feedback from the construction industry, to help in improved technology developments and better building integration and also building user experiences. The research project will explore whether the assumptions around BPS upon which current practice within SPECIFIC is based are well founded. Do these buildings perform as designed and enable occupants to have lower energy use, costs and carbon emissions.

In undertaking this research project and understanding whether these buildings actually work in practice as-designed, the first author's practice as an architect will change particularly in respect to the ways in which she designs and monitors buildings and their users with BPS technologies integrated into their building facades. In addition, if these buildings prove successful in reducing carbon emissions, energy use and costs then this work will be of benefit to the wider architectural profession within the UK and in particular the work of SPECIFIC.

3. Assessing Buildings as Power Stations in practice

A mixed methods approach will be adopted, using case studies of BPS buildings that have been designed and built, and are currently being monitored. This will include assessing the quantitative data from the sensors (temperature, relative humidity, carbon dioxide, volatile organic compounds, power generation, power usage), in conjunction with qualitative data gathered from building users. Heat flux sensors for short term monitoring to establish the U-value of façade elements will also be deployed.

3.1 Case studies

The first case study will be the SPECIFIC Pod, which is a small building designed to demonstrate GSRTs on a structure which the general public, construction industry professionals and contractors can experience and helped to visualise the BPS concept on a real building [8]. When built, the pod also served the purpose of bringing the different SPECIFIC research groups together to showcase their technologies integrated into an actual building as opposed to a laboratory [ibid].

The second case study is the SPECIFIC Active Classroom, which uses the same principles as the pod, but at a larger scale [9]. It has been demonstrated that since completion in September 2016, the Active Classroom has been capable of operating independently of the electricity grid for at least two days. This is the first time that this has been discussed. Both buildings have monitoring systems installed to record environmental and energy data during their operation. In addition, to examining the quantitative data recorded from the buildings, the author will conduct online surveys with questionnaires and structured interviews at workshops of stakeholders, used to determine how effective the buildings have been to the people designing, constructing and using them. The parameters for examination will include the effectiveness of thermal comfort, aesthetics, design satisfaction, buildability, usability and maintainability. Where possible, actual performance will be compared to the design performance metrics for heating, ventilation and lighting used in design modelling tools; identifying any discrepancies and using this information to improve the tools and BPS and GSRTs building design parameters and technologies.

It is envisaged that users of BPS buildings will become more aware of the energy they are using and how they can adapt their behavior to use energy in the most efficient way. The research project will also focus on how building users adapt and use the BPS and GSRTs technologies, and whether a reduction in energy use is observed.

The findings from the first two case studies will be used to influence the design of case studies three and four and any future case studies.

The third case study is a Healthcare Technology Centre, which is a five storey building in Swansea, UK, which incorporates treatment rooms, teaching spaces, laboratories and offices. The building will use the BPS concept and the associated relevant technologies, and will enable the concept to be tested on another different building type. This project is currently at feasibility stage and is due to be completed by September 2018. The first author is working with the client and design team to advise on suitable technologies to include and will be working with their environmental engineers to ensure the building design maximises the potential to reduce energy usage within the building, through incorporating design concepts such as use of natural light and stack effect ventilation to dissipate heat build-up, in conjunction with GSRTs.

The fourth case study is a housing development for the Pobl Group housing association, based in Swansea, UK. The first author is advising the Pobl Group on how to design, build and operate a housing development in Neath that uses the innovative BPS concept on sixteen units – eight houses and eight walk-up flats. Involvement in the project from its inception in December 2015, initially included influencing the design team in their consideration of site layout and in addition advising on the design of the buildings, including the aesthetics, incorporation of photovoltaic roofs, locations of battery storage, and potential for solar thermal technologies. Construction of the project is due to commence in October 2017 and to be completed by November 2018. Both qualitative, such as from user surveys, and quantitative data [14] on how BPS houses perform in practice, both from the design and construction point of view and from the occupant's and landlord's perspective will be collected, i.e. energy use and contribution to the energy positive strategy.

Within the research project, the building performance data collected from the control systems of the building demonstrators will be examined, and also qualitative data from the surveys conducted with the users. Feedback will be obtained from designers, contractors, facilities managers and user occupiers on their experience of energy usage of a BPS.

Some of the aspects that will be considered include the building fabric and the impact the building envelope has on the energy use of the building – a fabric-first approach is needed to ensure the success of a BPS. Issues that SPECIFIC have already identified through building demonstration projects will be highlighted, for example, the use of a new construction methods expected to offer a high-performance fabric against its actual performance as-built, combined with the installation of novel energy systems, and the testing of new products and technologies, alongside new energy strategies for buildings.

Combining the knowledge and experience that has been gained through the first author's education and work in a commercial practice, with knowledge gained at SPECIFIC on renewable technologies places the organisation in a unique position to be able to advise clients, designers, contractors and other stakeholders on integrated solutions for their buildings. With access to the performance data collected by the demonstration buildings, the predicted in-use performance and consumption can be compared to the as-modelled and any significant discrepancies used to correct or inform future designs. Whether this be technical performance or behavioural variations, the future designs can assess these and compensate for them, resulting in more accurate models and potentially more energy savings.

Throughout the research project a systematic literature review of both academic and grey literature related to: theories of change within architecture [14] will be conducted, in addition to the building performance literature documenting low energy and energy positive buildings, in order to identify how successful they are and whether they could be further improved by integrating GSRTs into their building envelopes.

This research project will explore how using facades to influence or utilise the elements and control the building environment, i.e. thinking of the building interfaces as 'interventional opportunities', can lead to accomplishing both people friendly and environment-friendly buildings, known as human ecological design [15]. The consequences of allowing aesthetics to compromise the effectiveness of sustainability goals, as happens with so many buildings – think fully glazed facades in office buildings – will be investigated.

4. Outcomes

One possible outcome of this project could be a design guide for Architects and Developers, which will include benchmarks for ensuring the creation of BPS buildings at all stages in the process – briefing, design, construction and operation. From the first authors professional experience as an architect in practice, the tools that currently exist to encourage energy-efficient buildings are often seen as another layer of complication to add to the design process in order to meet regulations. It is intended that any design guides developed through this project will be simple and easy to use, explaining a logical process to the design of BPS buildings. A second output could be a user guide for building users of buildings that use GSRTs. These two outputs would add significant credibility to the BPS concept as a solution to reduce energy consumption, costs and associated carbon emissions in buildings and move towards greater energy positive buildings, in addition, to instilling confidence in those choosing to implement the BPS concept.

5. Conclusions

This paper has set out the background and context to a research project entitled 'Testing and validation of 'building as power station technologies' in practise, to maximise energy efficiency and user comfort and minimise carbon emissions'. The context includes the current energy and construction industry landscapes in which the research work being undertaken at SPECIFIC and within this project sits. The challenges facing the UK in terms of reducing carbon emissions and energy use [16] will be explored further in the research project and the role BPS solutions will play in addressing some of these challenges.

The proposed research methods have been outlined, as well as possible outcomes from the research project. These include both design guides and user guides on the design and use of BPS buildings, which the authors anticipate will assist in the implementation of the BPS solution for buildings of the future.

6. Acknowledgements

The first author wishes to acknowledge support of the European Regional Development Fund through the Welsh Government in addition to Innovate UK and EPSRC, all of whom contribute funding to SPECIFIC.

7. References

[1] Swansea University. 2017. The UK's First Energy Positive Classroom is Switched on in Swansea. Cited at: http://www.swansea.ac.uk/campus-development/news/theuksfirstenergypositiveclassroomisswitchedoninswansea.php, accessed 17th February 2017 (available).

[2] Global Buildings Performance Network. 2013. *Positive Energy Buildings*. Cited at: http://www.gbpn.org/laboratory/positive-energy-buildings, accessed 17th February 2017 (available).

[3] Chestney, N. for Reuters. 2016. Britain's power supplies enough to meet winter demand - National Grid. Cited at: http://uk.reuters.com/article/uk-nationalgrid-electricity-supply-idUKKCN0ZO138. Accessed 22nd February 2017 (available)

[4] Green Construction Board. 2013. *Low Carbon Routemap for the UK Built environment*, Cited at: http://www.greenconstructionboard.org/otherdocs/Routemap%20final%20report%2005032013.pdf, accessed 19th February 2017 (available)

[5] Anon. 2016. Final Energy Consumption in Households by Fuel, Cited at: http://ec.europa.eu/eurostat/web/environmental-data-centre-on-natural-resources/resource-efficiency-indicators/resource-efficiency-scoreboard/thematic-indicators/key-areas/improving-buildings, accessed 19th February (available)

[6] Adams, E. 2016. *Buildings as a Power of Good*, Cited at: http://digitaledition.theengineer.co.uk/TES1116lkdfhOWJU/html5/index.html?page=1&noflash, accessed 28th April 2017 (available)

[7] Bishop, S. 2017. *How to turn Buildings into Power Stations*. Energy World, pp.18 – 19.

[8] SPECIFIC. 2015. *First Building as a Power Station*, http://www.specific.eu.com/assets/downloads/casestudy/First_Building_as_Power_Station_FINAL.pdf, accessed 28th April 2017 (available)

[9] SPECIFIC. 2016. Active Classroom, http://www.specific.eu.com/assets/downloads/casestudy/Active_Classroom_Web_Case_Study.pdf, accessed 28th April 2017 (available)

[10] Bearpark, T. 2017. *Exploring local energy: A regulator's perspective*. Cited at: https://www.ofgem.gov.uk/news-blog/our-blog/exploring-local-energy-regulators-perspective. Accessed 19th February 2017 (available)

[11] Ofgem. 2017. *Local Energy in a Transforming Energy System*. Cited at: https://www.ofgem.gov.uk/system/files/docs/2017/01/ofgem_future_insights_series_3_local_energy_final_300117.pdf. Accessed 19th February 2017 (available)

[12] BSRIA. 2014. The Soft Landings Framework for better briefing, design, handover and building performance in-use. Cited at:

http://usablebuildings.co.uk/UBTOverflow/SoftLandingsFramework.pdf. Accessed 9th December 2016 (available)

[13] Zero Carbon Hub. 2014. *Closing the Gap Between Design & As-Built Performance. End of Term Report*. Zero Carbon Hub. Cited at: http://www.zerocarbonhub.org/sites/default/files/resources/reports/Design_vs_As_Built_Performance_Gap_End_of_Term_Report_0.pdf. Accessed 25th January 2017 (available)

[14] Bryman, A. 2015. Social Research Methods – Fifth Edition. Oxford University Press, Oxford, UK.

[15] Caplan, B. 2016. *Buildings are for People: Human Ecological Design*. Libri Publishing, Faringdon, UK

[16] Committee on Climate Change. 2016. Next steps for UK heat policy, https://www.theccc.org.uk/wp-content/uploads/2016/10/Next-steps-for-UK-heat-policy-Committee-on-Climate-Change-October-2016.pdf, accessed 11th April 2017 (available)