Institution: 10007140 Birmingham City University		
Unit of Assessment: UoA11. Computer Science and Informatics		
Title of case study: Optimising the retrofitting of energy-efficient systems using algorithms: saving costs and improving lives		
Period when the underpinning research was undertaken: **2012-2020**		
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:**
Dr Shadi Basurra (SB)	**(SB) Senior Lecturer in Software Engineering**	**(SB) 2014 – Present**
Prof Mohamed Gaber (MG)	**(MG) Professor in Big Data Analytics**	**(MG) 2016 – Present**
Period when the claimed impact occurred: **2016-2020**		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

BCU's research into the optimal design and manufacturing of a retrofit system for energy-inefficient houses, of which there are many in the UK, led to a project with Beattie Passive and other industrial partners to retrofit 3 houses and 12 flats. The success of the project, which between 2014 and 2017 demonstrated improved accuracy and time and cost savings in the manufacturing process, as well as much lower energy bills for residents, has resulted in a change in Beattie's policies and practices, helping to reduce costs and address the construction skills shortage through involving local housing providers in the building process. It has improved the health and well-being of residents, as well as had an impact on the environment through a reduction in energy use of around 85%. As of the end of 2020, BCU is working with Stroma, an environmental sustainability and compliance services provider to the built environment, on a project that will help to improve the accuracy of the 2,500 Energy Performance Certificates (EPCs) that its assessors issue each day on average.

2. Underpinning research (indicative maximum 500 words)

The UK Government has identified 6 million energy-inefficient homes, and has initiated various schemes aiming to retrofit 600,000 homes. Standard Assessment Procedure (SAP) tools are used to generate retrofit recommendations for the properties, based on the potential for energy saving and payback time on the investment required. However, SAP's simplistic calculations are based on a small number of attributes, and poor advice sometimes given as a result can affect a building's energy performance and carbon emissions for many years. Furthermore, the usual recommendation is for deep retrofit – a major upgrade to a building which is costly and causes disturbance to the residents. Home owners often refuse to join such schemes for these reasons.

Between 2014 and 2017 Dr Shadi Basurra led an Innovate UK-funded project called Retrofit Plus in partnership with Beattie Passive, iZDesign, InteSys and Birmingham City Council **[RG01]**. The BCU researchers digitised the process of deep energy retrofit, carried out on 3 council-owned houses and 12 flats in the West Midlands, and supported the development of 'TCosy', an approach in which a timber frame structure is installed around the home and insulation material is injected into the walls and roof cavity, thus 'wrapping' the building in a continuous insulated layer, eliminating heat loss and making the buildings draught free. Their holistic approach included: establishing a 3D model that characterises the existing building; carrying out design simulations which led to a hybrid construction approach combining off-site manufacturing and on-site installation; and carrying out instrumented monitoring, occupant studies and performance evaluation.

A detailed pre-retrofit survey used 3D scanning to generate simulation models which would help plan the best way to achieve a net-zero carbon rating **[R1].** These simulations are used as substitutes for the simplistic calculations of SAP in order to produce more precise and reliable recommendations for planning. To reduce the performance gap between the actual building and the model, Basurra et al. developed an automated calibration mechanism on the basis of past energy bills, using k Nearest Neighbour (k-NN) combined with recursive sensitivity analysis, allowing a much larger parameter set to be investigated (e.g. building materials and wall thickness) **[R2].**

In 2015, an ‘expert system’ or tool was developed that uses genetic algorithms (GAs) to determine multi-objective optimisation: the best thermal insulation materials and the optimal frame depth that will maintain an acceptable level of thermal comfort. The trade-off between making the house warm enough in the winter and comfortably cool in the summer **[R3]** helped the off-site factory to manufacture bespoke engineered units for the house that was being retrofitted. These parts were then assembled on site while occupants lived inside their properties **[R4].** Local suppliers of retrofit products can use the expert system to facilitate the take-up of retrofit solutions and improve their bottom line.

Since residents’ behaviour influences building energy performance, BCU researchers developed realistic human behaviour modelling that aimed to estimate occupants’ behaviour related to energy consumption, taking into account the number of people in the household, age and occupancy. This is significant as most popular simulation tools use oversimplified schedules, resulting in a great deal of uncertainty in predicting building energy. Another contribution is a non-intrusive messaging intervention that detects and sends incidents of inefficient energy use to occupants in order to help reduce energy consumption in buildings **[R5].** An assessor or policymaker can use this tool to forecast the effectiveness of different retrofit packages, including TCosy, while taking into consideration the occupants’ energy consumption behaviour **[R6].**

BCU has since been granted funding of GBP750,000 for the EcRoFit project by the European Regional Development Fund (ERDF) to employ multi-objective optimisation and Artificial Intelligence (AI) techniques to measure buildings' performance and recommend retrofit packages **[RG02]**. This will enhance the existing expert tool so that it can be used by any professional improving energy efficiency for new-build houses and the retrofit market.

3. References to the research (indicative maximum of six references)

[R1] Basurra, S. and Jankovic, L. (2016) Knn & Sensitivity Analysis As An Integrated Approach For Calibration Of Building Energy Models For Retrofit. In: Proceedings of Zero Carbon Buildings Today and in the Future. Birmingham City University, Birmingham. ISBN 978-1-904839-88-0. Available at http://www.open-access.bcu.ac.uk/3969/

[R2] Basurra, S., Jankovic, L. and Huws, H. (2015) The use of optimisation in the calibration of building simulation models, in Proceedings of the 14th International Conference of the International Building Performance Simulation Association (IBPSA) (Hyderabad, India), IBPSA ’15, 2015, pp. 2905–2912. Available at http://www.ibpsa.org/proceedings/BS2015/p2620.pdf

[R3] Basurra, S. and Jankovic, L. (2015) Bringing building simulation to a wider audience - a web based simulation and optimisation system, in Proceedings of the 14th International

Conference of the International Building Performance Simulation Association (IBPSA) (Hyderabad, India), IBPSA '15, 2015, pp. 83–90. Available at http://www.ibpsa.org/proceedings/BS2015/p2264.pdf

[R4] Jankovic , L. and Basurra, S. (2016) Taking a passivhaus certified retrofit system onto scaled-up zero carbon trajectory, in Proceedings of Zero Carbon Buildings Today and in the Future (Birmingham, United Kingdom), Birmingham City University, 2016, pp. 45– 51, ISBN 978-1-904839-88-0. Available at http://www.open-access.bcu.ac.uk/3971/

[R5] Abdallah, F., Basurra, S. and Gaber, M. (2019) "A Non-Intrusive Heuristic for Energy Messaging Intervention Modeled Using a Novel Agent-Based Approach," in IEEE Access, vol. 7, pp. 1627-1646, 2019. Available at https://www.open-access.bcu.ac.uk/6733/ Received IEEE Access Best Multimedia Award Winner 2018

[R6] Abdallah, F., Basurra, S. and Gaber, M. (2018). An Agent-Based Collective Model to Simulate Peer Pressure Effect on Energy Consumption: 10th International Conference, ICCCI 2018, Bristol, UK, September 5-7, 2018, pp. 283-296, Available at https://www.open-access.bcu.ac.uk/6024 Received ICCCI 2018 - Best Student Paper Award

Funding

[RG01] March 2014 – May 2017: The Retrofit Plus project (101614) funded by Innovate UK, with GBP1.1 million in external funding, collaboratively contributed by Beattie Passive and Technology Strategy Board, Birmingham City Council as well as industrial partners Carillion Energy Services Ltd, InteSys Ltd and iZdesign Ltd. Birmingham City University had the largest share of funds among academic participants (GBP324,055). For further information http://gtr.ukri.org/projects?ref=101614

[RG02] June 2020 – 2023: The EcRoFit Project funded by European Regional Development Fund, with GBP1.5 million project value. In collaboration with ABBE, the Accreditation Body for the Built Environment, to enhance and scale up the use of the Expert System developed in the Retrofit Plus project (2013-2023)

4. Details of the impact (indicative maximum 750 words)

Working with Beattie Passive and other industrial partners, Dr Shadi Basurra and his team used computational methods, including genetic algorithms, to assist the design strategy, manufacturing process and performance evaluation of the Beattie Passive Deep Retrofit System, TCosy, in order to improve the energy-efficiency of buildings. They developed a precision software tool for smart building energy assessment that is based on building simulations which can benefit any retrofit scheme. The research has had an impact on the building industry, enabling it to work more efficiently and cost-effectively and in partnership with local housing providers to mutual benefit. It has also benefited the residents of the retrofitted homes, improving their health, well-being and quality of life and saving them money by reducing energy consumption by 85% and carbon emissions by 70% **[S01].**

a. Impact on Beattie Passive: new policies and practices

By using a hybrid construction scheme, a practice enabled by this research, Beattie Passive was able to speed up the time of the installation from 5 weeks to 2 weeks, as constructing the panels off-site in factories made the retrofit less dependent on weather conditions thus reducing costs. Factory-controlled quality assurance also improves the quality of the panels in comparison to panels being built on-site by local builders: 3D scanning offers a low-error rate with ±2mm accuracy. Moreover, off-site manufacturing minimised disturbance to occupants who were able to continue living normally while their homes were being retrofitted **[S01].**

The introduction of the 3D modelling by Basurra et al. and the development of a framework to use input from 3D models through their research also helped greatly as a case study for their trainees in Beattie Passive Academy, where attendees on the courses can learn to build a 27m^2 house in just 5 days **[S02].**

Evaluation of the Retrofit Plus project showed that retrofit costs range from GBP25,000 to GBP85,000 per house **[S03].**The success of the Retrofit Plus project with BCU and partners led Beattie Passive to set up a Flying Factory scheme, **[S04]** whereby housing associations, local authorities, social enterprises and property developers wanting to offer Passivhaus standard homes to their residents can partner with Beattie Passive, who provide over a 6-week period the know-how and support to set up and run a Passivhaus factory. This scheme enables housing providers to utilise a local labour force or train unskilled people, thus delivering social and economic benefits for the community. It also reduces logistical challenges and transport costs. To the end of 2020, at least 9 partnerships had taken place across England and Wales, and the scheme, enabled by the research from BCU, has become Beattie's default practice **[S04].**

The CEO of Beattie Passive stated*: "Our collaboration with Dr Shadi Basurra and his team helped Beattie Passive develop internal company policies and helped with a change of practice during the period of the Retrofit Plus project."* **[S01]**

b. Impact on the residents: improved health and well-being, plus energy savings

To validate the effectiveness of BCU's retrofit measures, various sensors were installed in the retrofitted properties to provide remote monitoring. Monitored data showed a reduction in energy consumption of up to 85%, which equates to an annual energy bill of around GBP1,064 being reduced to GBP166, while maintaining an acceptable level of thermal comfort throughout the year **[S05, S06].** Moreover, occupants' thermal comfort after retrofitting has significantly improved compared with the duration before the retrofit as almost 50% of the time occupants experience internal temperature around 21°C **[S03].**

Tenants of the retrofitted flats and houses confirmed that the holistic retrofit approach made their homes a more comfortable and healthier environment to live in. Their feedback to the questionnaire **[S07]** shows that there was a behaviour change in the occupants due to increased internal temperatures and fewer warm clothes needed in winter.

One resident said: "*Before the retrofit my house was cold all the time, even with the heating on and we did not feel very comfortable living here in the winter…Having a warm house and reduced energy bills is the best thing about this project. Energy is now not lost from the building and I have started to save money already, which is very important to us."* **[S05]**

Another said: *"The heat didn't stay in the house for very long. To keep warm, we would often spend most of our time in the living room with blankets. We used to top up the gas all the time. Now we don't need to. It feels good and we are very happy with the house."* **[S05]**

The scheme improved the housing stock in areas of deprivation by also fitting homes with high-quality new facades. Birmingham City Council's Contract Team Manager said: "*We can see the benefit and are fully on board with the reasons to encase or 'TCosy' a property as this reduces our building repair commitment due to a brand-new exterior, and changes such as removing gas fires eliminates the need and cost of annual gas checks. This system does also address our social responsibility commitments when targeting fuel poverty, which remains a major issue affecting tenants in our region."* **[S05]**

Performance evaluation also showed that the project is estimated to deliver CO_2 savings in the range 2-4t CO_2 per year per dwelling. **[S03]** On assumptions of scale-up to between 1,000 and 5,000 properties a year, this will contribute up to 20,000t CO_2 savings a year to the national effort to reduce CO_2 emissions.

c. **Impact on environmental sustainability and the wider building industry: new methods of energy assessment and further rollout.**

Following BCU's research into the limitations of SAP tools, and the subsequent introduction of its energy assessment tool, Dr Basurra is working with Stroma, a provider of compliance services to ensure environmental sustainability in the built environment, on a project to refine the expert tool to facilitate its integration with Stroma's workflow. **[S08]**

Stroma, which has 600 live projects and had completed over 100,000 projects in the UK at the end of 2020, uses Standard Assessment Procedure (SAP) as a methodology to assess and compare the performance of buildings and verify compliance with the regulations for low carbon emission. The Director of Energy Certification at Stroma says: "*We have developed a roadmap to offer an enhanced tool (iRET) that supplements the current Stroma SAP government approved calculator. During the EcRoFit Project, alongside BCU, we are working with energy assessors to refine the methods and tools from BCU and develop suitable energy training and certification programmes to support their deployment*." Thus, the benefits described in sections **a** and **b** will be passed on to the customers of Stroma. Stroma provides certifications and training for 50% of the energy assessors in the UK, who collectively issue on average 2,500 Energy Performance Certificates (EPCs) per day. **[S08]**

5. Sources to corroborate the impact (indicative maximum of 10 references)

[S01] Testimonial: Chief Executive of Beattie Passive **[Named Corroborator 001]**

[S02] Beattie Passive Five Step Plan, https://beattiepassive.com/self-builders.php [Accessed on 12 January 2021].

[S03] Paper entitled "Lessons learnt from design, off-site construction and performance analysis of deep energy retrofit of residential buildings".

[S04] Flying Factory Partnership: https://www.beattiepassive.com/flyingfactory.php.

[S05] Retrofit Plus Project – Birmingham, Beattie Passive website promoting the scheme. http://beattiepassiveprojects.com/RetrofitPlusBirmingham/ [Accessed 28 January 2020].
[S06] Beattie Passive Blog: https://beattiepassiveblog.wordpress.com/category/birmingham-tcosy-blog/

[S07]: Questionnaire from occupants of retrofitted houses

[S08]: Testimonial: Director of Energy Certification at Stroma