Institution: London South Bank University		
Unit of Assessment: 13 - Architecture, Built Environment and Planning		
Title of case study: Low-carbon solutions for existing buildings through optimised performance, decarbonising heat and scalable policy		
Period when the underpinning research was undertaken: August 2015 - July 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**:
Professor Andy Ford	Professor of Building Systems Engineering	2014 – present
Associate Professor Aaron Gillich	Director of the BSRIA LSBU Innovation Centre	2014 – present
Period when the claimed impact occurred: August 2016 – July 2020		
Is this case study continued from a case study submitted in 2014? N		

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

The built environment accounts for approximately 40% of the UK's carbon footprint. This research by Professor Andy Ford and Dr Aaron Gillich has realised a three-pronged, networked approach for decarbonising the UK's buildings. It comprises:

- Using Artificial Intelligence to eliminate energy inefficiencies in **Building Energy Management Systems** (BEMS), reducing energy costs by 10-30%, cutting CO_2 emissions by **37,000**t annually and yielding **GBP6,900,000 (£6.9m) annual cost savings.**
- The **Balanced Energy Network** (BEN) concept, the implementation of which has reduced fossil fuel use by 30% and carbon dioxide emissions by 9% in the blocks where it is installed.
- The creation of the **CEREB Policy Framework** for scaling up multi-stakeholder, low-carbon solutions across existing buildings, which has shaped a **GBP4,700,000** (£4.7m) UK Government programme.

2. Underpinning research (indicative maximum 500 words)

The UK Climate Policy has set a goal of net zero carbon emissions by 2050. This will not be achieved without a transformation of the built environment. Professor Ford has developed a three-pronged approach to decarbonising existing buildings, comprised of: 1) reducing energy use in buildings by optimising performance; 2) decarbonising the heating and cooling systems by reducing fossil fuel use; and 3) accelerating the adoption of these innovations by creating a market transformation policy framework.

Recognising that industry has been cautious towards innovation in the built environment, Professor Ford's approach embedded industry partners as key research stakeholders, pairing research with practical demonstration and implementation to maximise the uptake of low-carbon innovations.

Reducing carbon emissions by optimising building performance
Building Energy Management Systems (BEMS) monitor and control a building's energy needs. They provide building performance data, including data which isn't routinely analysed but can be queried in the event of problems. The complexity of this data and the lack of understanding of how to process and analyse the enormous datasets has hindered the ability of BEMS to deal with energy inefficiencies arising from components known as Terminal Units (TUs). These units regulate the volume of conditioned primary air directed into a particular space from the central

air handler (i.e. the central heating, ventilation and air-conditioning (HVAC) system). There can be hundreds or even thousands of TUs in a building, depending on its size.

LSBU investigated the use of Artificial Intelligence (AI) to develop and integrate energy efficiency into BEMS. This research was conducted with three commercial partners: Demand Logic, Verco and EDSL. The project focused on addressing the problematic building energy 'performance gap'. Verco led the portfolio scale decarbonisation work, EDSL supported the building level simulations, whilst the Demand Logic team worked with Professor Ford to ascertain extant practice for identifying TU issues: this was found to comprise manually investigating BEMS data. The team established that the development of an automated method for remotely identifying faults would revolutionise identification and management of faulty TUs, improve BEMS performance and transform energy efficiencies.

The outcome of the research was an AI-driven system which pre-processes, clusters and classifies TUs into well- and badly-behaved elements, displaying results in a user-friendly manner. Problems that were originally difficult to identify and characterise were automatically classified by the new technology. An additional benefit was the detection of non-faults wrongly classified as faults by BEMS. For instance, a building design fault such as a TU inadvertently not connected to its temperature sensor by a retrofitted partition wall, makes the normal TU persist, without success, to bring the room temperature to the desired level. These "false rogue" TUs are difficult to manually detect but were easily automatically identified and rectified **[R1]** by the developed system.

Low-carbon solutions for heat networking individual buildings
Achieving net zero carbon emissions in buildings requires ending the use of natural gas for heat generation. Heat pumps are a proven low-carbon alternative to gas boilers. However, heat pumps deliver heat at a lower temperature than a gas boiler and usually require other building upgrades such as insulation or larger heat emitters to maintain comfortable conditions. Heat networks can offer improved efficiencies compared to heating individual buildings, particularly 5th Generation (ambient temperature) networks linked with heat pumps, but there is slow uptake, in part due to a lack of proven demonstrations of the technology in the UK.

In order to address these barriers, Professor Ford developed the Balanced Energy Network (BEN) research project into a successful GBP2,900,000 (£2.9m) Innovate UK Proposal (#102624) **[G1]**. The BEN project integrated innovations from five industry partners and two universities in order to: 1) demonstrate the UK's first 5th Generation heat network at scale; and 2) link this network to heat pumps that could replace a gas boiler like-for-like and offer a simple low-carbon heating retrofit solution to existing commercial buildings.

BEN links two buildings together using an ambient temperature network served by two open-loop boreholes connected to the London aquifer. One of the outputs of the research was bespoke heat pumps that sit within each building and produce heat at the same temperature as a gas boiler. This allows the pumps to link with the existing systems without requiring any other modifications to the buildings. The heat pumps reduce carbon emissions by offsetting gas use. BEN's heat pumps not only proved to be a viable like-for-like replacement for the gas boiler, but also they could maintain a high coefficient of performance by linking with a 5th Generation Heat Network. This reduces overall electricity use and the burden on the National Grid. Finally, Professor Ford's BEN research proved that these low-carbon heating innovations could be integrated within an active campus environment in central London, offering a low-carbon heating retrofit solution which is highly generalisable across other UK buildings **[R2, R3, R4]**.

BEN also catalysed a major programme of LSBU applied research funded by BEIS **[G2, G3]** into how to further refine heat pump design and extract low-carbon heat from other sources such as the ground and the sewer networks.

Policy development to scale up implementation of retrofit decarbonising solutions across

the UK building stock
Professor Ford and Dr Gillich investigated policy pathways to deploying technical solutions at scale. Most policies targeting technical measures focused on the measures in the short term, rather than the enabling systems necessary to support their delivery longitudinally.

Dr Gillich used a policy theory-based evaluation methodology to investigate over 50 retrofit market transformation programmes across the UK, Canada, and the United States **[R5]**. This was among the first applications of this methodology into the study of retrofit market transformation, producing new insights into the range of market actions needed to support long-term change beyond the period of public subsidy.

A common policy outcome is for market activity to surge during a subsidy program, then collapse when the subsidy is removed. The Market Transformation approach advanced by Dr Gillich's research proposes a novel methodology to use program funds to invest in activities that result in lasting market effects after the subsidy is removed. This yielded the *CEREB* (Centre for Efficient and Renewable Energy in Buildings) Framework, articulating five pillars of Retrofit Market Transformation: 1) Programme Design and Stakeholder Networks; 2) Marketing and Outreach; 3) Workforce Engagement and Training; 4) Financial Incentives; and 5) Data Collection and Evaluation. For each pillar, the CEREB Framework gives activities, indicators, and success factors required to decarbonise existing buildings **[R6]**.

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

[R1] 2016 – Eaton, C, Randal, T., Darby, M., **Ford, A**. Analysis of high-resolution terminal unit performance data. CIBSE Technical Symposium, Edinburgh, UK.
[R2] 2017 - **Gillich, A**, **Ford, A**., Zagoni, C., Hewitt, M., Oakes, G. (2017). A smarter way to electrify heat – The Balanced Energy Network approach to demand side response in the UK. ECEEE Summer Study, Hyeres, France, June 2017.
[R3] 2018 - Arif, M., **Gillich, A.**, **Ford, A**., and Wang, Y. Overcoming Practical Challenges and Implementing Low-Carbon Heat in the UK: Lessons from the Balanced Energy Network (BEN) at LSBU. CIBSE Technical Symposium, London, April 2018.
[R4] 2019 - William Hasung Song, Yang Wang, **Aaron Gillich**, **Andy Ford**, Mark Hewitt (2019) Modelling development and analysis on the Balanced Energy Networks (BEN) in London. Applied Energy, Volumes 233–234, 1 January 2019, Pages 114-125 DOI: https://doi.org/10.1016/j.apenergy.2018.10.054
[R5] 2016 – **Gillich, A**., Sunikka-Blank, M. & **Ford, A**. Lessons for the UK Green Deal from the US BBNP. Building Research & Information Volume 45, 2017 - Issue 4. DOI: https://doi.org/10.1080/09613218.2016.1159500
[R6] 2017 – **Gillich, A**., Sunikka-Blank, M, & **Ford, A**. Designing an 'optimal' domestic retrofit programme. Building Research & Information Volume 46, 2018 - Issue 7. https://doi.org/10.1080/09613218.2017.1368235

Grants

[G1] Balanced Energy Network (BEN) 2016-18 – Innovate UK #102624 - £2.9 million (PI – Professor Ford)
[G2] Home Energy 4 Tomorrow (HE4T) 2017-19 – BEIS - £559k (PI – Dr Gillich)
[G3] Endothermic Heat Project (ETHD) 2018-20 – BEIS - £760k (PI – Dr Gillich)
[G4] Affordable Heat Networks – Bridgend Council 2020-20 - £50k Phase 1 (PI – Dr Gillich)
[G5] EPSRC/TSB (currently named Innovate UK – IUK) funded project, "Energy Management and Analysis Exploiting Existing Building Management Systems Infrastructure and Data", EP/M506734/1 2014-17. Total budget of £633K (about £210K LSBU share, PI: Dudley-McEvoy, Co-I. Ford).
[G6] Net Zero Innovation Programme 2020-21 – UCL Networks - £18k (PI – Dr Gillich)

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

Reducing carbon emissions by optimising building performance:
The collaboration with Demand Logic (DL) benefited the company in a number of ways. Testimony from the CEO states that: "*Overall the collaboration provided a step change in our product features, our working practices regarding implementing AI analysis and enabled us to investigate more around the end user's role in building energy consumption (and reduction*

techniques), leading us to further product developments. Specifically, the research conducted at LSBU enabled BEMS data of any type to be pre-processed automatically and to be made easily available via a RADAR chart (an easy to read visual chart that classifies and displays the good and misbehaving terminal units in a building) to determine which are the terminal units who are operating as designed, and which are causing energy and comfort problems, and pivotally why they seem to be misbehaving." **[S1]**

The BEMS AI tool is now used by leading property companies. The main beneficiaries of the improved Demand Logic products are their clients. Demand Logic report **[S2]** that their clients save GBP6,900,000 (£6.9m) in energy costs annually and reduce annual CO_2 emissions by 37,000t.

The number of deployed installations by Demand Logic improved by LSBU's research contribution has grown substantially over time. The platform is currently in use in 118 buildings totalling 1,400,000 m^2 of real estate. The following example looking at just one installation is typical of the impact in each of these buildings.

Demand Logic at 20 Fenchurch Street (Landsec) **[S3]**
Landsec Group plc, the largest commercial property development and investment company in the UK, owns and manages 335,000 m^2 of buildings. One of their most familiar commercial sites is 20 Fenchurch Street, London (known colloquially as the "Walkie-Talkie"). HVAC systems account for approximately two-thirds of 20 Fenchurch Street's energy consumption. The environment in this 34-storey tower is controlled by 1,200 air conditioning units, with over 175,000 data points which generate 17,000,000 data values on building performance every day **[S4]**. Day-to-day management of the building's performance is split between the landlord and tenant's engineering teams. This is common for multi-tenanted buildings and often presents a challenge for reducing operational energy consumption. The Landsec team now uses Demand Logic data visualisation to engage with the tenant, Allied World; consequently, Allied World agreed to re-set the temperature set-points and to widen the temperature range. The impact was immediate, as monitored by Demand Logic: analysis revealed a 27% reduction in demand of both heating and cooling as well as a 62% reduction in heating power **[S3]**.

The approach also allowed for a change in operating procedure by the facilities management team. The usual mode is reactive maintenance, responding to tenants' complaints and concerns. The use of Demand Logic's LSBU research-enabled, AI-driven interface, facilitated a proactive way of working, using data to identify individual components which are misbehaving. It is effective in reducing energy consumption; enabling engineers to focusing their time on assessing and prioritising issues; and reducing the number of complaint calls requiring reactive maintenance **[S3]**.

Low-carbon technical solutions for individual buildings and district heat networks
The Balanced Energy Network (BEN) installed at LSBU's campus has had the direct impact of reducing fossil fuel use by 30% and carbon dioxide emissions by 9% for the connected buildings in its first year of operation **[S5]**. This has also contributed to the wider impact of phasing out gas from the LSBU campus. Through BEN and a range of other measures including light bulb replacements and switching to renewable electricity tariffs, LSBU has achieved an overall 85% reduction in carbon dioxide emissions in the past decade.

This project has had significant beneficial outcomes for the industry lead, ICAX Ltd. Some of these are now outlined.

Commercial benefits: ICAX has developed a second generation of the heat pumps created for the BEN project and is currently installing these on several projects: to date, ICAX has been commissioned to install 3.7MW of these second generation heat pumps, with eight further projects currently in the pipeline. ICAX is also currently installing 3.4MW of these heat pumps across three sites for the London Borough of Southwark, in three housing estates consisting of 2,175 households **[S6, S7]**.

Ability to Deliver Environmental Benefits: Three systems currently being installed in Southwark are designed to save over 57,000t of CO_2 emissions over a twenty-year time span through an energy saving of 17,690,743kWh per annum **[S6].**

In addition, the approach has enabled ICAX to participate in several projects across the UK looking at the feasibility of town-wide networks and smaller scale domestic heat pumps. As a result of the success of these projects, ICAX has won a coveted place on the competitive BEIS Scale-Up programme (one of only 40 businesses across all sectors in the UK), and is currently on track to manufacture residential heat pump products in the UK in 2021. The company is targeting growth to a turnover of GBP101,000,000 (£101m) by 2025 (from a 2020 base of GBP1,500,000 (£1.5m)), largely driven by the domestic heat pump products originating from the BEN research **[S7]**.

Industry guidance has been influenced. The 2020 version of the CIBSE CP3 Heat Networks Codes of Practice (COP) being updated to increase reference to heat pumps and include mention of 5th Generation networks **[S8]**. This Code of Practice is a widely referenced document in the UK for Heat Network design guidance and project specification.

Policy implementation to scale up research across the UK building stock
The 'market transformation' concepts advanced in Dr Gillich's CEREB Framework have gained traction recently as the UK seeks successors to the Green Deal. Dr Gillich has contributed to a number of evidence reviews including the '*What Works*' paper, the Policy Exchange Scotland Evidence Review, and the GLA's *Green New Deal* mission. Dr Gillich's research led to his working directly with BEIS on secondment and informed development of the GBP4,700,000 (£4.7m) '*Local Supply Chain Demonstration*' program, which delivered retrofits in 6 pilot projects across the UK. The policy focused on investing in local intermediaries such as contractor networks and enablers such as 'retrofit advisors' to link up homeowners with suitable installers. Retrofit policies incentivise the measures themselves during the program, but typically do not use program funds to support networks and intermediaries that can keep on installing them once the program has ended. Investing in this type of supply chain network is among the pillars of the CEREB Framework and was not common practice for BEIS at the time **[S9]**. This in turn led to Dr Gillich working with Local Authority Sustainability Officers to implement pillars of the CEREB Framework in Lambeth Council, who have recently declared a climate emergency and are using Dr Gillich's Framework to inform their strategy to decarbonise existing buildings **[S10]**.

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

[S1] Testimonial from CEO, Demand Logic, stating the impacts of the LSBU research partnership for their business.
[S2] Demand Logic website (figures from March 2021) https://www.demandlogic.co.uk/index.html
[S3] 20 Fenchurch Street case study, Demand Logic
[S4] https://www.gov.uk/government/case-studies/demand-logic-energy-savings-breakthrough-in-buildings
[S5] Testimonial from the Energy Manager LSBU Estates quantifying the carbon emissions savings attributable to BEN.
[S6] Testimonial from Strategic Project Manager, Housing Asset Management, Southwark Council
[S7] Testimonial from Director of ICAX stating impact that BEN and follow on projects have had for ICAX Ltd.
[S8] 2020 CIBSE CP3 Heat Networks Code of Practice and Open-loop groundwater source heat pumps Code of Practice
[S9] Testimonial from UK Department for Business, Energy, and Industrial Strategy on the impact of LSBU research on changes to policy making.
[S10] Testimonial from Lambeth Council on the ongoing collaboration to implement LSBU research on low-carbon policies in the Borough.