Institution: London South Bank University

Unit of Assessment: 12 – General Engineering

Title of case study: Improving energy efficiency by integrating Artificial Intelligence into Building Energy Management Systems

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:
Professor Sandra Dudley-McEvoy	Professor of Communication Systems	2005 – present
Professor Andy Ford	Professor of Building Systems Engineering	2014 – present
Professor Mohammad Ghavami	Professor of Telecommunications Engineering	2010 - Present

Period when the claimed impact occurred: 2014 - 2020

Is this case study continued from a case study submitted in 2014? N

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

Inefficient heating in large non-domestic buildings (e.g. high-rise office space and shopping centres) is a major contributor to carbon emissions and climate change. LSBU research has helped to improve the usefulness and efficiency of Building Energy Management Systems (BEMS, i.e. the main control systems of large building heating and cooling) by using artificial intelligence to quantify real faults and pivotally explain faults detected by BEMS. This has improved Demand Logic's Ltd products (an SME that produces buildings' BEMS platforms to optimise energy savings). Demand Logic's clients are benefiting from a reduction in energy costs of up to 30% and saving GBP6,900,000 (£6.9 million) annually. This improved energy efficiency has a beneficial impact on the environment by eliminating 37,000t of CO_2 emissions each year.

2. Underpinning research (indicative maximum 500 words)

Background context.

The Department for Business, Energy and Industrial Strategy (BEIS) has identified significant barriers to achieve substantial energy savings in the non-domestic building sector (e.g. large scale office blocks), including the cost of capital investment in energy management, lack of know-how in identifying energy inefficiencies and implementing interventions.

LSBU research used artificial intelligence (AI) to remove some of these barriers, demonstrating that improving the capability and usefulness of Building Energy Management Systems (BEMS, i.e. the main control system of non-domestic building performance data on heating and cooling) resulted in a step-change in energy efficiency. This approach provides inexpensive solutions to remote fault finding, leading to enhanced control of BEMS, hence vastly improving large-building energy performance and reducing CO_2 emissions.

Description of insight

The greatest cause of poor building performance is the malfunctioning of heating, ventilation and air conditioning (HVAC) systems. These systems are responsible for floor space heating and cooling and are controlled by the building's BEMS. Therefore, inefficiencies in these systems directly increase energy waste and impacts comfort. The device used to control the temperature of a particular area is known as a Terminal Unit (TU). It regulates the volume of conditioned primary air directed into the space from the central air handler (i.e. the central HVAC system). There can be hundreds or even thousands of TUs in a building, depending on its size.

Demand Logic Ltd. (DL) noted that current BEMS fault-finding is manual and crude. For this reason, DL contacted Professors Dudley and Ford to search for alternative methods to improve fault detection. Professor Dudley proposed an automated approach to: (a) enhance the detection of faulty TUs to improve BEMS usefulness and performance and reduce energy wastage; while, (b) breaking down the barriers to achieving substantial energy savings highlighted by BEIS.

Initial research by Dudley, Ghavami and Ford focused on improving domestic energy savings through AI **[R1]**. In particular, via data disaggregation and AI, energy wastage behaviours were automatically discovered without the need of end-user input. Two immediate gains that were feedback to end users were: a) recognition of inefficient set–up of home thermostats; and b) over estimation of timings required to heat hot-water tanks. Capitalising on these findings, they investigated AI approaches for to improve BEMS in non-domestic environments **[R2, R3]**.

BEMS' limitations, particularly in the monitoring and detection of TU inefficiencies, have been overlooked by researchers because of the vast number of these TUs in large buildings and their perceived complexity **[R2]**. LSBU and DL recognised that substantial energy wastage reductions could be made by investigating BEMS systems and their relationship with TU behaviour **[R2, R3]**.

Details of insight

Integrating DL's knowledge of large building monitoring with LSBU's experience in applied algorithm development (Dudley) and building management (Ford) led to a unique RADAR Graphical interface for BEMS fault detection **[R2].** This AI-driven system pre-processes, clusters and classifies TUs into well and badly behaved elements, displaying results (the TU and its fault) in a user-friendly manner **[R2].** Problems that were originally difficult to identify and characterise were thus automatically classified by the new technology as:

a) hunting (i.e. competing heating/cooling sources trying to achieve a set temperature in a single area), thus the system can never settle **[R2];**
b) overpowering/saturation (i.e. using too much power) **[R2];**
c) on-ness (i.e. TUs being always on) **[R2];** and
d) set-point deviation (i.e. failure to achieve the comfort target) **[R2].**
A key finding was that 99% of all faults detected fell into a) to d) **[R2, R3]**.

Finally, a positive unintended consequence of the above approach was detecting non-faults wrongly classified as faults by BEMS **[R3]**. For instance, a building design fault: e.g. a TU accidentally not connected to its temperature sensor by a retrofitted partition wall, makes the TU persist (as it should), without success, to bring the room temperature to the desired level. These "false rogue" TUs are difficult to manually detect but were quickly automatically identified and rectified.

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

Peer-reviewed journal articles. R1 and R2 are submitted as outputs for REF2021 in UoA 12.

R1: R. Brown, N. Ghavami, H. Siddiqui, M. Adjrad, **M. Ghavami**, and **S. Dudley**, "Occupancy based household energy disaggregation using ultra-wideband radar and electrical signature profiles", Energy and Buildings, vol. 141, pp 134-141, April 2017. https://doi.org/10.1016/j.enbuild.2017.02.004

R2: M. Dey, S. P. Rana and **S. Dudley**. "Smart Building Creation in Large Scale HVAC Environments through Automated Fault Detection and Diagnosis," Future Generation Computer Systems, https://doi.org/10.1016/j.future.2018.02.019

R3: M. Dey, S. P. Rana and **S. Dudley**, "A Case Study Based Approach for Remote Fault Detection Using Multi-Level Machine Learning in A Smart Building," Smart Cities 2020, 3(2), 401-419; https://doi.org/10.3390/smartcities3020021

Grants

Grant 1. 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 (~£210K LSBU share, PI: Dudley-McEvoy, Co-I. **Ford**).

Grant 2. EPSRC funded project, Digital Agent Networking for Customer Energy Reduction (DANCER) EP/K002473/1, and EP/K002643/1; 2012-17. Total budget ~£1.65 million (~£911K LSBU share, P.I Ghavami, Co-I. **Dudley-McEvoy** and **Ford**).

4. Details of the impact (indicative maximum 750 words)
Inefficient heating in large buildings is a major contributor to carbon emissions and climate change. Throughout the UK and Europe almost 20% of the electrical energy we use in manufacturing and commercial operation is consumed by the HVAC systems. Heating makes up 40% of a business energy costs on average, according to the Carbon Trust. The LSBU research presented above has improved the performance of BEMS by using AI methods to improve detection of faulty Terminal Units (TUs), dramatically reducing energy wastage. This had a direct impact on the quality of Demand Logic's (DL) products since 2015 and added value through the application of research methods to their commercial activities **[S1]**. This in turn benefited DL's UK and EU clients by helping them reduce energy waste (environmental Impact) and energy expenditure (economic impacts).

Demand Logic's CEO confirms the impact and value of LSBU's research input: "*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. The set-up is now more intuitive and the complex parts of installations have been automated or eliminated. This research is certainly valuable to our customers.*" **[S1]**

Using AI to enhance the value derived from BEMS data has helped DL to:
- support and streamline the commissioning process, validating that equipment has been correctly installed and configured through automatic fault detection;
- provide a user-friendly graphical interface overlaying the BEMS for building teams, making data immediately accessible in a familiar format. This included a table view providing an overview of many devices and problem classification;
- empower building management teams to rapidly identify malfunctioning equipment, saving both time and money on maintenance as well as extending plant lifespans. This was particularly useful for equipment in difficult to access areas; and
- improve comfort levels for building users, proactively managing temperatures, lighting and air quality, e.g. reducing likely hot and cold spots.

The main beneficiaries of the improved DL products are their clients. DL report **[S2]** that their clients save GPB6,900,000 (£6.9m) in energy costs annually and reduce CO_2 emissions by 37,000t. Specific examples are given below.

The Better Buildings Partnership (BBP) is a collaboration of leading commercial property owners who aim improve the sustainability of existing commercial building stock. Six of their members (Canary Wharf Group, Land Securities, M&G Real Estate, TH Real Estate, The Crown Estate and Transport for London) have revealed specific benefits arising from installing DL's system.

The economic impacts include **[S3, S4, S5]**:

- average energy cost savings of 10%-30%;
- average payback on investment within nine months; and
- GBP1,800,000 (£1.8m) energy cost savings annually

The main environmental impact for the six BBP members listed above **[S2- S4]** was the annual saving of 11,800t of CO_2 emissions. **[S3]**.

Standard Chartered Bank HQ **[S6]**
The headquarters of Standard Chartered Bank in London contains 200,000 ft² (18,581 m²) of

office floor space. In order to reduce its carbon emissions, as well as to reduce costs (energy spend was GBP610,000 (£610k) at the time), Demand Logic was installed in May 2017. The remote detection and improvements enabled problem solving without direct user interaction. By December 2017 significant improvements were already evident:

- a reduction of 10% (GBP61,000 (£61k)) on energy spend;
- chillers were running to a proper demand schedule. One engineer with six years' experience on the site had never seen this; "hunting" behaviour had meant that the chillers were always on;
- the Demand Logic system discovered several faulty Fan Coil Units (FCUs) that the BMS said were working fine; and
- users experienced a more comfortable environment, with a 59% reduction in the number of spaces which were judged too warm (>25^{o}C).

20 Fenchurch Street (Landsec) **[S7]**
Landsec Group plc, the largest commercial property development and investment company in the UK, owns and manages 335,000m^2 of buildings.

One of their most familiar commercial sites is 20 Fenchurch Street, London (known colloquially as the "Walkie-Talkie"). This environment in this 34-storey tower is controlled by 1,200 air conditioning units, with over 175,000 data points and generating 17,000,000 data values on building performance every day **[S5]**. HVAC systems account for approximately two-thirds of 20 Fenchurch Street's energy consumption. 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 tenant was able to make these changes themselves and 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 **[S7]**.

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 AI-driven interface enabled by LSBU research allowed a proactive way of working, using data to identify individual components which are misbehaving. It is effective in reducing energy consumption, focusing engineering time and reducing the number of complaint calls requiring reactive maintenance **[S7]**.

The number of deployed installations by Demand Logic improved by LSBU's research contribution has grown substantially over time **[S4]**. The platform is currently in use at sites covering 118 buildings totalling 1,400,000m^2 of real estate. The Financial Times headquarters in London has reported that comfort complaints have halved since the platform was installed.

Finally, DL technology enhanced by LSBU research has been mentioned in a debate in Parliament **[S7]** (Bill 267 – Energy Consumption (Innovative Technologies) where it is reported that "*Demand Logic technology could help to cut costs for businesses and public authorities in that respect. It provides data intelligence on how a building operates, and can ensure that maintenance work is prioritised to where it is most effective. Better comfort levels should encourage us to be more productive in our work, so it is a win-win all round*."

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

S1: Letter of support from Demand Logic CEO.

S2: Demand Logic website (figures from March 2021) https://www.demandlogic.co.uk/index.html

S3: https://www.betterbuildingspartnership.co.uk/bbp-members-use-big-data-improve-comfort-

and-efficiency

S4: https://www.betterbuildingspartnership.co.uk/legal-general-appoints-demand-logic-buildings-systems-partner-cut-carbon

S5: https://www.gov.uk/government/case-studies/demand-logic-energy-savings-breakthrough-in-buildings

S6 Standard Chartered case study, Demand Logic

S7 20 Fenchurch Street case study, Demand Logic

S8: https://hansard.parliament.uk/Commons/2018-09-12/debates/CA27F448-2032-4055-8A11-6