Institution: University of Strathclyde

Unit of Assessment: 16

Title of case study: Building performance simulation with computational modelling software enables practitioners to realise a low carbon built environment.

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

Research by staff of the Energy Systems Research Unit (ESRU) at Strathclyde has resulted in advances in the state-of-the-art in dynamic building energy modelling as encapsulated within the Open Source ESP-r program. This new capability enabled practitioners to analyse phenomena and technologies hitherto not capable of being modelled in building simulation tools. The impact stems from the embedding of ESP-r within companies resulting in service improvement and job creation, and applications of ESP-r resulting in energy demand reduction, low carbon energy systems integration and environmental impact mitigation.

2. Underpinning research (indicative maximum 500 words)

Context:

Those who seek to improve the energy performance of the built environment must balance conflicting technical issues in the context of stakeholder and legislative requirements. This requires design tools that address domain complexity whilst supporting a rigorous appraisal of overall performance. The academic challenge is the creation of a building simulation capability to provide a paradigm shift in decision support by respecting the four intrinsic characteristics of buildings:

- dynamic evolution – the variables of state (temperature, voltage *etc*.) associated with constituent parts (constructions, electrical devices *etc*.) vary at different rates;
- non-linearity – the thermo-physical parameters required to formulate the underlying models depend on the time varying value of the above state variables;
- interactions – domains corresponding to heat transfer, fluid/contaminant movement, equipment behaviour, control system action, occupant behaviour, indoor/outdoor emissions, renewable energy capture *etc*. interact in a non-trivial manner; and
- uncertainty – due to occupant interactions, micro-climate phenomena and the variation of empirical parameters as a result of departures from standard test conditions.

This challenge has been addressed by a sustained research effort since the establishment of ESRU in 1988 to investigate cross-discipline approaches to energy demand and supply in the built environment, with outcomes disseminated to industry through supported computational tools. Since then, an evolving building simulation capability has been delivered via the ESP-r program, which is freely available under the GNU General Public License.

Key findings:

The 110 research projects and 350 industrial consultancies undertaken by ESRU staff to date have evolved the state-of-the-art in building simulation. The principal research achievements that contributed to the evolving capabilities of the ESP-r program prior to the current REF period are as follows.

Research into network representations of mechanical/natural ventilation and Computational Fluid Dynamics (CFD) approaches to zone air/contaminant movement led to a modelling capability for ventilation efficiency and indoor air quality. A unique feature, which continues to define the state-of-the-art at the present time, allows the dynamic configuration of the CFD turbulence model and boundary conditions in response to changing weather conditions, control actions and occupant behaviour [Ref 1].

Research into construction moisture flow and mould growth on building surfaces led to a modelling capability to estimate the likelihood of occurrence of mould types that adversely impact health and identify non-biocidal approaches to problem alleviation [Ref 2].

Research into the operation of small scale, low carbon generators (wind turbines, photovoltaic components, combined heat and power plant, heat pumps *etc*.) led to a modelling capability for the rational sizing and dynamic performance appraisal of hybrid energy schemes [Ref 3].

Research integrating electrical network and building simulation led to a seminal modelling capability for the appraisal of smart grid features such as load manipulation, demand response and voltage regulation, alongside the indoor comfort factors that determine the acceptability of

community scale energy projects [Ref 4].
Research into model validation techniques and parameter uncertainty within the design process resulted in the incorporation into ESP-r of algorithms for validity self-checking and the assessment of the operational risk associated with proposed designs [Ref 5].
The ESP-r program, encapsulating these and other developments, enables practitioners to model innovative buildings in a realistic manner, providing a rich source of data on the performance of new materials, technologies and facilities management approaches.

Key researchers at Strathclyde:
The research was conducted by staff in the Energy Systems Research Unit within the Department of Mechanical and Aerospace Engineering: Dr Joseph Clarke, Professor, Director ESRU (1977-present); Dr Nicolas Kelly, Senior Lecturer, Associate Director ESRU (2004-present); Dr Paul Strachan, Senior Lecturer, Director MSc in Renewable Energy Systems and the Environment (1992-present); and Dr Jan Hensen, Senior Lecturer (1994-8).

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

1. Clarke J A (2001) 'Domain integration in building simulation', *Energy and Buildings*, 33, pp.303-8.
2. Clarke J A, Johnstone C M, Kelly N J, McLean R C, Anderson J A, Rowan N J and Smith J E (1999) `A technique for the prediction of the conditions leading to mould growth in buildings', *Building and Environment*, 34(4), pp.515-21.
3. Ferguson A, Kelly N J, Griffith B, Weber A (2009) 'Modelling residential-scale, combustion-based cogeneration in building simulation', *Building Performance Simulation*, 2(1), pp.1-14.
4. Clarke J A and Kelly N J (2001) 'Integrating power flow modelling with building simulation', *Energy and Buildings*, 33(4), pp.333-40.
5. Macdonald I and Strachan P (2001) 'Practical application of uncertainty analysis', *Energy and Buildings*, 33(3), pp.219-27.

Other evidence for quality of research:
Endorsement of the research quality is reflected in the award of approximately £26M in research grants and £1.5M in consultancy contracts since 1989, along with honours bestowed on the group and its members owing to the recognised quality of the research: ESSO Energy Award, Royal Society; formation of the Centre of Excellence in Energy Utilisation by the Building Research Establishment (BRE); Elected Fellows, International Building Performance Simulation Association; ICE Baker Medal; Honorary Fellow, Society for the Environment; Energy Institute Technology Award; Fellow, Honorary Degree, Slovak Technical University.
The national standing of the research is indicated by the above BRE Centre of Excellence award (funding to establish a Chair + 3 PhD studentships per year); while the international standing is indicated by staff involvement, by invitation, in International Energy Agency projects: Task 34/Annex 43 on validation of building energy simulation tools; Annex 42 on modelling of cogeneration systems; Annex 46 on retrofit measures for government buildings; and Annex 58 on building energy performance characterisation.

4. Details of the impact (indicative maximum 750 words)
Process from research to impact:
ESP-r has been made available under the GNU General Public License since the late-90s and has an international community of around 50 developers. The freely available modelling tool can be used for the simulation of the thermal, visual and air quality performance of buildings, and the energy use and gaseous emissions associated with associated environmental control systems. This open availability has resulted in myriad 'downstream' impacts by government, industry and research groups within and outwith the UK [Source A]. Since this time companies have been supported in their attempts to embed the simulation-assisted design approach within their businesses and apply it in practice [Source B]. Research outcomes have been promoted through innovative knowledge exchange. One major project assisted 250 UK Architectural Practices and Energy Consultancies (mostly SMEs) to embed energy simulation within their business as a means to address the emerging opportunities relating to a low carbon built environment. Individuals within these organisations were assisted in applying building performance simulation to schemes that

achieved energy use reductions of the order of 75-90% as quantified by the industry and confirmed by independent audit [Source B].

Types of impact:
The impacts in the REF period stem from (a) application of the program by practitioners and ESRU academic staff to substantially improve building performance and (b) from business process changes resulting from the embedding of ESP-r in construction sector companies.

Improving building standards and performance:
By facilitating a detailed appraisal of low energy/carbon options prior to deployment, the application of the software enhances energy performance and reduces emissions.

- **Ventilation efficiency and indoor air quality:** ESP-r has been applied in over 20 projects to establish innovative approaches to wind/solar induced hybrid ventilation schemes most notably within the Navan Credit Union Headquarters Building in Ireland, which won the 2010 Local Authority Members Association Award for best eco-friendly building [Source C].
- **Occurrence of mould growth:** Approximately 250,000 Scottish dwellings have a mould infestation problem and previous research commissioned by Scottish Homes to identify non-biocidal approaches to the control of condensation and mould growth influenced emerging policy in the area: e.g. the published mould isopleths were used in 2008 by University College London to inform UK Building Regulations [Source D].
- **Sizing and operational appraisal of hybrid community energy schemes:** a simulation-based capability has been established in several companies, most notably SSE's Home Services Group, which has applied the technology to design zero carbon solutions (e.g. in their Greenwatt Way development of 2010 in Slough, Berkshire) [Source E].
- **Smart grid features appraisal:** during the period 2009-13, ESP-r was established as the basis of aggregate energy demand forecasts as part of active network control applied to the Shetland Islands electricity grid. These 48-hour-ahead forecasts allow the Utility (Scottish and Southern Energy) to schedule domestic space and water heaters as a means to prioritise renewable generation [Source F].
- **Validation and operational risk assessment:** tests based on ESP-r simulations, as embodied in CIBSE TM33 [Source G], have been incorporated in procedures for program accreditation. These tests must be passed by dynamic simulation programs before they can be used in compliance calculations addressing Part L of the building regulations or for the generation of energy performance certificates.

Incorporation of software into third party products:
Another significant application of the research was the encapsulation of ESP-r's computational engine, through commissioned projects, within third party products as a means to enhance their rigour, application scope and future extensibility. Examples include

- a project (2009-10) for the Carbon Trust to develop a biomass heating system design tool (200 current users with an estimated £4M capital and £1M running cost saving per annum (0.5 MtC) [Source H]
- a project with the Building Research Establishment (BRE) from 2009-11 relating to the UK Government's Standard Assessment Procedure for housing [Source I];
- a project for Honeywell (2010-13) to develop a method for the assessment of the energy saving and carbon reduction benefits of advanced domestic heating control systems, this has allowed the company to refine their range of zone-based control systems and gain recognition for these in the context of pending legislation. [Source J];
- and a project for Natural Resources Canada (2007-9) to develop a residential energy analysis and rating tool which has a user base approaching 25,000 people in 150 countries and has been used to rate the performance of approximately 650,000 homes for Canada's ecoENERGY Retrofit Programme [Source K].

Training and consultancy:
ESRU operated an industrial consultancy service, which applied ESP-r to projects on behalf of clients. Income from this activity was around £100K per year over ~20 projects. The energy/carbon

reductions to result were significant. For example, the analysis of retrofit options for New Gorbals Housing Association, Glasgow (2010) resulting in an energy saving in excess of 20% per annum over the estate.
To support the growing use of ESP-r, ESRU delivered advanced training courses to around 100 participants per year and seconded researchers to assist industry with in-house simulation: a notable example in the latter category was the one year (2010) secondment of Dr Jon Hand, an ESRU Senior Research Fellow, to Samsung Korea resulting in the application of ESP-r to in-house projects with substantial energy saving impact (e.g. a 20% reduction in chiller plant capacity in one case).

Reach and significance:
From January 2008 to July 2013, ESP-r has been applied to evaluate and improve over 150 building designs incorporating energy demand reduction and/or low carbon technologies. Additionally, the tool has been employed by other organisations, including: Samsung and SK Telecom in Korea; The Government of Canada (Natural Resources Canada and Canadian National Research Council); National Renewable Energy Laboratory and Department of Energy in the USA, Owens Corning in China; and the Fraunhofer Institute in Germany. In the UK, the Building Research Establishment, Scottish and Southern Energy, ScottishPower, Atkins, Alstom and around 200 construction sector SMEs have all been beneficiaries.
Other confirmed impacts (average per year over the REF review period) include: 360 practitioners given innovation assistance; 12 new jobs created and 22 current jobs safeguarded; 10 major deployments of simulation tools within supported companies; assistance given during 40 in-house tool applications; £0.7M increase in sales by assisted businesses; £0.64M increase in company investment in innovation and RTD; introduction of new services in10 SMEs; and 3 licensing deals between SMEs and the science base (Source B).

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

A. President, International Building Performance Association can be contacted to confirm that ESP-r is an internationally leading system and has had widespread international take-up leading to the claimed impacts.
B. Director, Eclipse Research Consultants can be contacted to confirm that the embedding of ESP-r in practice has had the impacts as listed.
C. Director, Gaia Ecotecture can be contacted to confirm the impact of applying ESP-r to this major award winning building design.
D. Altamirano-Medina H, Davies M, Ridley I, Mumovic D and Oreszczyn T (2008) 'Moisture performance criteria to control mould growth in UK dwellings', *Proc. 8th Symposium on Building Physics in the Nordic Countries,* Copenhagen.
E. http://www.sse.com/PressReleases2012/DomesticRenewableHeating/
F. Ofgem, 'Decision to approve changes to Scottish Hydro Electric Power Distribution plc's Northern Isles New Energy Solutions (NINES) project', www.ofgem.gov.uk/ofgem-publications/43523/nines-change-requesr-decision-letter-24.05.2013.pdf, Page 4.
G. https://www.cibseknowledgeportal.co.uk/component/dynamicdatabase/?layout=publication&revision_id=77/
H. http://www.carbontrust.com/resources/tools/biomass-decision-support-tool/
I. Director, BRE Scotland will confirm the claim that the Government's Standard Assessment Procedure has been equipped with an ESP-r engine.
J. Portfolio Manager, Honeywell Control Systems Ltd. will confirm the claim that ESP-r has allowed the company to refine their range of zone-based control systems and gain recognition for these in the context of pending legislation.
K. http://canmetenergy.nrcan.gc.ca/software-tools/hot2000/84/