Institution: Cardiff University

Unit of Assessment: 16B (Architecture)

Title of case study: Energy and Environmental Modelling at Building and Urban Scale

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

The Welsh School of Architecture (WSA) is recognised internationally for its research in developing advanced computational numerical models for simulating the energy and environmental performance of the built environment. These models have been used by leading design practices in the design of major buildings and urban developments. This impact case study presents three models from this research activity that have been widely taken up by industry worldwide, namely, the 'building energy' model HTB2, the urban scale 'energy and environment prediction' framework EEP and the 'building environment' model ECOTECT.

- ***HTB2*** has been used by leading international practices in the design of over 100 exemplary low energy buildings, including Dubai's award-winning *Lighthouse* tower, and *EMPA*, the first zero energy office building in Switzerland.
- ***EEP*** modelling framework for urban simulation has been used to assess the energy performance of existing large estates, for example, for use in housing retrofit programmes, and, to plan low-carbon developments, such as the *Gateway City* in Ras al Khaimer. It is now accessible through *Google SketchUp,* a common design tool used by architects.
- **Ecotect** underwent significant development at the WSA before its sale to Autodesk in 2008, and by 2010 had over 2000 licenced users globally.

Application of the models, often linked (e.g. HTB2 is the numerical engine for EEP and is accessible within the ECOTECT framework), has resulted in **extensive environmental benefits**, through reductions in global CO_2 emissions. Additionally, there has been a marked **impact on practitioners and professional practices**, through new guidelines for major international developments (e.g. *Pearl Island* Qatar and the Chongqing *Ba'nan Low Carbon Development*).

2. Underpinning research (indicative maximum 500 words)

The three simulation models introduced above, ***HTB2*** (Senior Lecturer Don Alexander [1983-], Prof Phil Jones [1978-], Research Fellow Simon Lannon [1988-] and Dr Peter Lewis [1971-96]), ***EEP*** (Lannon and Jones [1999-]), and ***Ecotect*** (Research Fellow Dr Andrew Marsh [2001-06]), are outputs from a research programme at the WSA that has spanned four decades, intensifying over the last 10 to 15 years as attention to sustainability and low carbon energy performance of buildings has increased. These tools are specifically developed to inform the design process at an early stage, when major decisions are made and impact is greatest, as well as checking at the more developed detailed design stages. These tools now benefit the building industry, and their underpinning research is explained below:

HTB2 [1] is simulation software that predicts the thermal energy performance of buildings under varying weather and occupancy conditions. The software was developed solely within the WSA, with major developments in the last 15 years. Alexander has been responsible for its recent development and distribution, with contributions from Lannon and Jones. The flexibility and ease of modification of ***HTB2*** [2] has made it eminently suited for use in the rapidly evolving field of energy efficiency and the sustainable design of buildings. The model has kept pace with changes in the design and construction industry through a continuing process of extension, testing, and modification. Since 1988, reflecting the growing importance of energy efficient buildings, developments include: chilled and heated surface environmental systems, a range of infiltration and ventilation models, and detailed simulation of advanced glazing systems and multiple skin facades [3,4]. It has been combined with the HVAC model BEACON (funded through a Hong Kong Government Grant) to produce the model BEEP, aimed at the Hong Kong commercial market.

The motivation for creating ***EEP***, arose from a need to extend performance-based assessment from single buildings to urban scale. Research into urban modelling at the WSA began in 1994, funded through an EPSRC grant [GR/K19181: To Develop a Model for Energy and Environmental Planning for Sustainable Cities, 1994-98] continuing with further EPSRC funding [GR/L81536: Development and completion of the EEP model,1998–2001] and followed by EPSRC / MRC funded research [G9900679: Housing Neighbourhoods and Health 2001-3]. The main research aim was to integrate energy simulation tools with Geographical Information Systems (GIS), with additional models addressing transport, air pollution and health to support analysis of complex urban processes. This software framework allows different simulation tools to communicate and share data, for example, simple energy tools can be used, such as the UK SAP annual energy predictor,

as used in UK Building Regulation calculations, or, more complex energy models such as HTB2. EEP was initially developed to consider the existing built environment and allow planners and designer to address major urban retrofit projects [5,6]. After further research and development, the software now offers a comprehensive urban modelling tool for planning and designing new urban developments, predicting energy use, CO2 emissions and the potential for collecting solar energy. The latest version has replaced the original GIS framework with Google's *SketchUp* and Google *Earth,* to provide pre-processing computational environments that are commonly used by designers [7], and enabling the simultaneous simulation of 100's of buildings using advanced models such as HTB2, to provide annual hourly data on energy and thermal performance.

Marsh began the development of ***Ecotect,*** an integrated building analysis software package, initially through his PhD, before joining the WSA in 2001. During his 5 year tenure to 2006, as a Research Fellow, he collaborated with colleagues on the development and application of building simulation tools, carrying out major developments of ***Ecotect***, and integrating it with other modelling software, including ***HTB2,*** and the WSA's Computational Fluid Dynamic (CFD) airflow model ***WINAIR*** [8]. This research included testing numerical models against physical scale models of complex estates, allowing modelling of internal and external spaces on the same scale [9]. This version of ***Ecotect*** has since made significant worldwide penetration into architectural practice and teaching since its purchase by *Autodesk Inc.* in 2008.

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

All outputs below are available on request from HEI.

1 HTB2: Heat Transfer in Buildings (Version2), User manual 2.0c.12/11/97**, Alexander D K**, WSA

2 **Lewis, PT**, **Alexander, DK**, 1990. HTB2: A Flexible Model for Dynamic Building Simulation. Building and Environment, 25 1.

3 **Alexander D K, Mylona A and Jones P J**, *The Simulations of Glazing Systems in the Dynamic Thermal Model HTB2,* IBPSA, (Canada), (2005) p 11-18. ISBN 2-553-01152-0

4 **Sun, L**, **Jones, P Alexander, DK**, 2008. Energy Efficiency of Double-skin Façade in Office Buildings of Shanghai. Proceedings COBEE 2008, July 13-16, Dalian China.

5 **Jones P J and Patterson J**, *Modelling the Built Environment at Urban Scale* Landscape and Planning Journal (2007) pages 39-49. DOI: 10.1016/j.landurbplan.2007.05.015

6 **Jones, P, et al,** Retrofitting existing housing: how far, how much? Special Issue of Building Research & Information, Urban Retrofitting (Editors: Dixon and Eames), August/September 2013. (Paper also an output for EPSRC Retrofit 2050 project). DOI: 10.1080/09613218.2013.807064

7 **Phil Jones, Simon Lannon, Hendrik Rosenthall,** Energy Optimisation Modelling for Urban Scale Master Planning, 44th ISOCARP Conference 2009.

8 **Jones P, et al.** Intensive Building Energy Simulation at Early Design Stage, IBPSA, August 2013.

9 **Jones P, Alexander D.K., Marsh A.J.**, Burnett J., Evaluation of Methods for Modelling Daylight and Sunlight in High Rise Hong Kong Residential Buildings, Indoor and Built Environment, 13, pp249-258, 2004. DOI: 10.1177/1420326X04045177

10 **Bleil de Souza C**, **Knight IP**, **Marsh AJ** & Dunn GN. 2006. "Modelling Buildings For Energy Use: A Study Of The Effects Of Using Multiple Simulation Tools And Varying Levels Of Input Detail." International Conference on Electricity Efficiency in Commercial Buildings (IEECB 2006), Frankfurt, Germany April 2006.

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

Impact has been achieved through in-house application of software to design projects in collaboration with external partners, and through the use of such software by third parties at both international and national levels. As a result, construction professionals have been able to simulate more accurately the energy performance of buildings and large-scale urban developments and retrofit programmes. This has orchestrated significant **environmental benefits**. In the UK alone over a quarter of all CO2 emissions derive from the fuel used in homes. However tighter energy efficiency standards for homeowners can cut domestic CO2 emissions by 80%. Moreover, globally a considerable proportion of CO2 emissions and energy use is attributable to buildings - approximately 40% according to the international Energy Agency. Improved energy efficiency in buildings, as evidenced by the examples below, is considered to be capable of reducing global emissions by at least 1.8 billion tonnes of C02 (United Nations Environment Programme).

Additional impacts, stemming directly from Cardiff's research, are **economic savings** associated with a more efficient design process and reducing householders' annual energy expenditure (conservative estimates suggest this would save £100-200 per household on fuel alone). Furthermore, there is substantial **impact on practitioners and professional services**, including the provision of consultancy for global engineering firms and the development of enhanced design practices and guidelines that have been implemented worldwide.

Impact during the REF period:

Improved energy and environmental design and performance of residential, commercial and industrial buildings: The WSA has distributed ***HTB2*** widely and free of charge to many commercial organisations worldwide. Its application has enabled the simulation of energy performance at an early design stage on many hundreds of construction projects, which is an essential part of the low carbon sustainable design process. Examples include:

- *The **DIFC Lighthouse***, a 400 metre tower in Dubai, in collaboration with *Atkins Global, 'providing a full building physics and system analysis'* [1], identifying design options for, reducing internal heat loads, façade design, and HVAC systems. Simulations of the building design, which began construction in 2008 (but deferred during the economic downturn), identified solutions for achieving a 65% reduction in energy use compared to Dubai standards. The design won an international *Holcim Foundation* sustainable construction award [2].
- ***HTB2*** was used to help explore design options with *Atkins Global* for large scale building developments in the Middle East and China, including the *Al Akaria* 300,000m^2 mixed use and retail complex in Jeddah (2011), and an office tower with multi-floor atria in Tianjin (2008) [1].
- The WSA's involvement in developing the ***HK-BEAM*** assessment methodology led to R&D investment and collaborative development of the ***HTB2*** software with Hong Kong Polytechnic University [3]. ***HTB2*** has been used in conjunction with the HVAC model ***BEACON*** [4], and in 2010, ***HTB2*** was the 2nd most commonly used software tool in Hong Kong [5]. The product has been targeted specifically to meet the need for advanced environmental modelling software in China's rapidly expanding construction sector (4).
- Design modelling of the naturally ventilated and heated *REGAIN* business incubator building in Ebbw Vale, owned by the Local Government, used ***HTB2*** to model energy use, and ***Ecotect*** to analyse the day-lighting performance (2010 to 2012). The building won the 2012 Low Carbon Award from Constructing Excellence Wales, who said: "*The design was heavily influenced by analytical data from Cardiff University School of Architecture's Centre for Research into the Built Environment. This enabled the design of the glazing and building envelope to be optimised to maximise heat retention, and solar gain while minimising overheating."* [6]
- ***HTB2*** has been used by *Kopitsis Bauphysik AG* for dynamic simulations of over 100 buildings over the past 15 years, including Switzerland's first zero energy office, *EMPA EAWAG* (2005) and the Rem Koolhaas Laboratory in Zurich (2012) [7].

Examples of building and urban scale projects using, HTB2 (EMPA, DIFC Lighthouse), and EEP (Gateway City Ras al Khaima).

Improved urban-scale sustainable planning and design: The development of ***EEP*** has enabled city planners and other professionals to achieve low carbon sustainable design and master-planning, for new urban scale developments and large scale housing retrofit programmes. The ***EEP*** framework has been developed to quickly provide information for fundamental decision-making relating to energy performance, at early concept design stage, being able to simulate large

numbers of mixed use buildings simultaneously. Examples include:

- *The Pearl*, Qatar, an artificial island of residences for 40,000 people. Working with *Building Energy Partnership*, the ***EEP*** framework was used to produce guidelines for plot developers to reduce energy consumption. The project is due for completion in 2015 but already has more than 5,000 residents. The guidelines require the developers to achieve energy savings 50% lower than the ASHRAE 90.1-2004 international standard for energy efficient buildings [8].
- Working with *Hyder* Hong Kong, ***EEP*** was used to provide early stage energy predictions in master planning *Gateway City*, Ras al Khaima (UAE), for 200,000 people, to reduce its carbon footprint. ***EEP*** was also used on a *Hyder* study for a future urban cluster in Hanoi, Vietnam.
- The latest version of ***EEP***, linked to *Google SketchUp*, was used to provide Low Carbon Master-plan Guidance for the Ba'nan Project in Chongqing. This guidance contained the results of the simulation of different construction options and their potential impacts on operational energy use, and the potential for using building integrated solar energy.
- ***EEP*** has been used in collaboration with the community interest company *Warm Wales*, to assess over £50 million of energy saving measures on large scale housing energy retrofit projects in Wales, including the Welsh Government's *Arbed* programme [9]. Some 50,000 houses in Wales have been upgraded, resulting in CO_2 emission reductions of 10 to 40% taking hundreds of families out of 'fuel poverty', and improving indoor living conditions

Commercial impact: As of 2010, ***Ecotect*** had over 2,000 licensed users [10]. ***Ecotect*** was bought in 2008 by Autodesk Inc., the industry leader in computer aided design software. The acquisition marked a step change in the funding and impact of the software, significantly enhancing market penetration. New clients include:

- Architects working on NASA's Ames Research Centre, Silicon Valley, a $20.6 million facility, used ***Ecotect*** to predict the cost impact of design decisions, including the integration of daylight.
- China Construction Design International, one of Asia's leading multidisciplinary design firms, with more than 2,000 offices and employees throughout the People's Republic of China.

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

1. Testimony from Director, WS Atkins & Partners Overseas confirms the use of Cardiff software in the Atkins construction projects listed.
2. Holcim Foundation website http://www.holcimfoundation.org/T858/A08AMbr.htm (accessed 13 04 2012) confirms Dubai Lighthouse Tower as Bronze award-winner for sustainable construction, 2008, Africa and Middle East.
3. BEAM Society, 2010. BEAM Plus for new Buildings. Page 6-37 of http://www.beamsociety.org.hk/fileLibrary/BEAM%20Plus%20NB%20Version%201.1.pdf (accessed 13 04 2012) confirms HTB2 used as preferred software in HK-BEAM assessments.
4. Testimony from Technical Director of Atal Building Services Engineering Ltd confirms that HTB2 was the second most commonly used software tool in Hong Kong in 2009.
5. Yik, F.W.H., Lee, W.L. and Lee, S.H. (2009) 'The state of use of building energy simulation tools in Hong Kong and preview of a proposed tool'. In: Proceedings of Joint Symposium 2009, Design for Sustainable Performance, HKIE (BSD) / CIBSE (HK Branch) / ASHRAE (HK Chapter) / HK Polytechnic University, Nov. 25, Hong Kong confirms HTB2 is the second most commonly used tool in Hong Kong.
6. Constructing Excellence Wales Awards 2012. Confirmation of Cardiff's contribution to the design of the Low Carbon winner. http://www.cewales.org.uk/awards/award-winners-2012/ (Accessed 5 November 2012).
7. Testimony from Director of *Kopitsis Bauphysik AG* confirms that HTB2 has been used on a range of buildings by Kopitsis Bauphysik in Switzerland and other international locations.
8. Testimony from Partner of *Building Energy Partnership* confirms that the software was used for thermal analysis and design guidelines for the Pearl, Qatar.
9. Testimony from CEO of *Warm Wales* confirms that they used EEP in the assessment of a range of energy reducing options for large scale retrofit housing projects in Wales.
10. US Department of Energy description of Ecotect, including figures for number of licences in 2010 before acquisition (assessed 5 November 2012). http://apps1.eere.energy.gov/buildings/tools_directory/software.cfm/ID=391/pagename=alpha_list