Institution: De Montfort University

Unit of Assessment: 16 – Architecture, Built Environment and Planning

Title of case study: Advanced building simulation tools

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

Building simulation software tools developed through this research have provided engineering solutions to architects, contractors, engineers and manufacturers across the world. Two main developments are described: modelling of ground source heating, and the use of genetic algorithms and parallel processing for large numbers of building simulations. These tools have also been used to analyse the global impact of the adoption of bio phase change materials in the building energy sector and to create tools to, for example, help commercial building owners realize energy efficiency retrofit opportunities and to help manage risks and increase resilience in both the built environment and health sectors.

2. Underpinning research (indicative maximum 500 words)

A milestone on the pathway to the contemporary acceptance of dynamic building simulation programs as a tool in building design and the demonstration of compliance was the empirical validation study carried out under International Energy Agency Annex 21 (1988–1993) and led by Professor Kevin Lomas at DMU (1984–2008) [1].

The development of building simulation models and their implementation in commonly used simulation software environments has been a strong theme of the IESD's work. This is reflected in the research in geothermal heating and cooling system modelling that has been carried out by Dr Simon Rees (DMU, 2003–). This work has its roots in earlier collaborations (1999–2002) with Professor J Spitler of Oklahoma State University (OSU) and with the developers of the EnergyPlus building simulation tool. The objective has been to develop validated models of complex system components that are computationally efficient enough to be used in annual simulation problems. Models have included those for pond and pavement surface heat exchangers [2, 3]. These models have been validated with data from experiments at OSU. The challenge was to model accurately the complex environmental boundary conditions and achieve coupling with efficient conduction and fluid heat exchange models. The later models have been either novel response factor approaches or numerical methods using parametric mesh generation. This work continued with the implementation of a new borehole heat exchanger model. More recently this work has developed models for heat exchangers incorporated into building foundations. This technology has the potential to expand the uptake of residential geothermal systems due to the reduced excavation costs. The work has been developed in collaboration with OSU and Oak Ridge National Lab in the USA and has been based on further developments of response factor and numerical heat transfer models [4].

The complexity of input data for dynamic thermal models can inhibit their repeated use in exploring alternative design parameters and carrying out searches for sub-optimal solutions. Dr Yi Zhang (DMU, 2004–), working with Professor V I Hanby (DMU, 2001–) has developed novel approaches to the application of genetic algorithm methods for the configuration of large numbers of simulations and building envelope design [5]. These have led to new insights into best practice in building energy systems design and operation, and more efficient genetic algorithm optimisation methods. The work takes advantage of increased computing power and parallel processing facilities on high performance computer facilities at DMU. A key aim has been to make these optimisation methods and high performance computing facilities available for external users through a web interface [6]. The research was consolidated in the Advanced Design + OPTimisation (ADOPT) project (ref BQ190J, April 2010–31 March 2013), funded by industry and the Technology Strategy Board, PI Y Zhang.

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

All peer reviewed

[1] Lomas KJ, Eppel H, Martin CJ and Bloomeld D.P., (1997). Empirical validation of building energy simulation programs, Energy and Buildings, Vol 26, No 3, pp 253–276, ISSN 0378-7788.

[2] Chiasson, A.D., Spitler J.D., Rees, S.J. and Smith, M.D. 2000. A Model for Simulating the Performance of a Pavement Heating System as a Supplemental Heat Rejecter with Closed-Loop Ground-Source Heat Pump Systems. *ASME Journal of Solar Energy Engineering,* 122(4): 183–191. doi:10.1115/1.1330725.

[3] Chiasson, A.D., Spitler J.D., Rees, S.J. and Smith, M.D. (2001). A Model for Simulating the Performance of a Shallow Pond as a Supplemental Heat Rejecter with Closed-Loop Ground-Source Heat Pump Systems. *ASHRAE Transactions,* 106(2):107–121.

[4] Rees SJ & Fan D (2013). A numerical implementation of the Dynamic Thermal Network method for long time series simulation of conduction in multi-dimensional non-homogeneous solids, Int Journal of Heat and Mass Transfer, Vol 61, pp 475–489.

[5] Wright, J. A., Zhang, Y., Angelov, P.P., Buswell, R. A., Hanby, V. I. (2008). Evolutionary Synthesis of HVAC System Configurations: Algorithm Development (RP1049), HVAC&R Research, Vol. 14(1):33–55.

[6] Zhang, Y. (2009). “Parallel” EnergyPlus and the development of a parametric analysis tool, IBPSA BS2009, 27–30 July 2009, Glasgow, UK.

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

The research concerned with modelling geothermal heating and cooling systems led by Dr Rees has been implemented in the EnergyPlus building simulation tool [a]. This tool has been developed by a large group of researchers (primarily funded by the US Department of Energy) and has evolved into one of the most widely used building simulation programs internationally. The development philosophy has been to integrate state-of-the-art models and simulation methods into a ‘simulation engine’ that can be used in a variety of tools with user interfaces developed by commercial software vendors. The software is freely downloadable in the form of the simulation engine, simplified interface and data libraries. The software has many tens of thousands of users worldwide. The ground source heat pump and heat exchanger models developed by Dr Rees were incorporated into the EnergyPlus software initially in October 2001 (version 1.2) and updated in October 2012 (Version 7.2) [a]. The latest release of EnergyPlus was Version 8 in April 2013 and there were a total of 32,296 downloads of the program from October 2012 to May 2013. The highest usage of the software is in the USA (30%) with the remainder spread fairly evenly throughout the developed world. The proportion of downloads to the UK is 5% and continental Europe 30% [b].

DesignBuilder has been one of the early adopters of the EnergyPlus simulation tool and is the market leading provider of user interfaces to the tool. DesignBuilder has a global user base of over 5,000 [c]. One of the objectives of the ADOPT work, and the preceding work led by Dr Zhang, has been to extend the DesignBuilder software so that users have a convenient interface to advanced optimisation methods. Users are able to access off-site high performance computing facilities through a remote simulation interface called jEPlus.

The development and applications of the jEPlus research tools has led to substantial impact in both business and society. The jEPlus tools have been downloaded more than 3,000 times, by users from over 70 countries, including those from familiar names such as ENVIRON, Foster+Partners, Morrison Hershfield, Arup, Aedas, BRE, SNC-LAVALIN, Transsolar Energietechnik, and Hydro-Québec. The jEPlus website (www.jeplus.org accessed 29/08/13),

which has been online since January 2012 to provide guidance and resources on energy simulation tools, now receives around 200 unique visitors per month [d]. The value of jEPlus has been realized through research and commercial projects by others using the tools. PositivEnergy Practice LLC, Chicago, IL, has integrated jEPlus with a backend database of EnergyPlus models, to create the EnCompass Tool for helping commercial building owners realize energy efficiency retrofit opportunities, as part of the Chicago Metropolitan Agency for Planning's Energy Impact Illinois programme [e]. Similar methodology was used in the Community Resilience to Extreme Weather (CREW) project, to create the Building Retrofit Toolkit for dwellings [f]. This was developed using jEPlus to provide a database of building behaviour, but the Retrofit Toolkit itself is an entirely separate piece of software available on a website. The Toolkit was recommended by the Mayor of London in the Greater London Authority's 'Managing risks and increasing resilience – The Mayor's climate change adaptation strategy report', October 2011 [g] and guidance based on the research appeared in the 2012 NHS Heatwave Plan for England [h]. The jEPlus tool has also been used in analysing the global impact of the adoption of bio phase change materials in the building energy sector, by Phase Change Energy Solutions, Asheboro, NC [i]. Other ongoing projects include supporting the development of the Brazilian Building Labelling System through parametric simulations and the development of building energy standards for residential buildings in Ecuador.

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

[a] Dr Rees's models (references 2 and 3) are documented as 'Ground Heat Exchanger:Surface' and 'GroundHeatExchanger:Pond' on pages 960 and 956 of the EnergyPlus 'Engineering Reference' document http://apps1.eere.energy.gov/buildings/energyplus/pdfs/engineeringreference.pdf (accessed 19/09/13)

[b] Information about the downloads of EnergyPlus were provided by a senior engineer from the US National Renewable Energy Laboratory (NREL) – details available on request. The Director of DesignBuilder Software Ltd is happy to provide verification of the claims made in this case study about the global user base for the software and the contribution that Dr Zhang and the EnergyPlus tool have made to their product.

[c] The Director of DesignBuilder Software Ltd. is happy to provide verification of the claims made in this case study about the global user base for the software, and the contribution that Dr Zhang and the EnergyPlus tool have made to their product.

[d] The jEPlus tool was developed in-house by the researchers, and evidence for the claimed users can be provided by the research team upon request in the form of email communications etc.

[e] For more information about the Chicago Metropolitan Agency for Planning - the Energy Impact Illinois program: EnCompass Tool please see http://encompass.energyimpactillinois.org/methodology (accessed 19/09/13) – This link states that 'These models were scaled to create a backend database of more than 275,000 EnergyPlus models run parametrically with jEPlus v1.1 using private and cloud computing clusters. Users of the system describe their own building through an online set of questions, and a best fit building in the backend database is made to provide information on energy use.'

[f] For more information about the CREW Project and the Adapting Dwellings to Climate Change - Retrofit Advice Tool please see http://www.iesd.dmu.ac.uk/crew/ (accessed 19/09/13)

[g] The Mayor's climate change adaptation strategy, October 2011: Greater London Authority, Managing risks and increasing resilience – http://www.london.gov.uk/sites/default/files/Adaptation-oct11.pdf see pp76–77 for the explicit reference to the CREW toolkit. (accessed 19/09/13)

[h] Public Health England: Heatwave Plan for England 2012: Protecting health and reducing harm from severe heat and heatwaves.

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/216525/dh_134157.pdf (accessed 19/09/13).

[text removed for publication]

[i] The application of the JEplus tool in phase change analysis can be verified by the Senior Analyst at Phase Change Energy Solutions; jEPlus is mentioned specifically in this link: http://www.phasechange.com/index.php/en/information/modeling – which states: "We use a combination of the USDOE building energy simulation engine called "Energy Plus" and **De Montfort University's** java interface to Energy Plus called "jEPlus" to run parametric and optimization modelling studies as an integral part of our product specification process. The chart below is of an office in Denver, Colorado, and indicates rough potential for energy savings, reduction of discomfort, reduction of average cooling and load simple return on investment. The study evaluates the ASHRAE 90.1 2007 wall types of steel framed, metal, mass, wood & other, with an added wall type of spandrel, all with minimally compliant 90.1 2007 insulation. BioPCM M27,M51,M91 & Q23,Q25,Q27 were studied for each of the building's 4 orientations." (accessed 29/08/13).