Institution: University of Exeter

Unit of Assessment: 15 General Engineering

Title of case study: Climate Change Data for Future Proofing Building Design

1. Summary of the impact

Exeter's Centre for Energy and the Environment has created novel probabilistic weather files for 50 locations across the UK, consisting of hourly weather conditions over a year, which have been used by the construction industry to test resilience of building designs to climate change. They have already had significant **economic impact** through their use in more than £3bn worth of infrastructure projects, for example, Great Ormond Street Hospital, Leeds Arena, and the Zero Carbon Passivhaus School. The weather files are widely available to professionals and endorsed by internationally leading building simulation software providers such as Integrated Environmental Solutions.

2. Underpinning research

The Centre for Energy and the Environment (http://tinyurl.com/p7k4zqx), based in Exeter Engineering's Water and Environment Group, conducts applied research into sustainable buildings, energy policy and the impacts of climate change on the built environment. Members include EPSRC Career Acceleration Research Fellow Dr Matt Eames, (joined Exeter 2006), Research Fellow Dr Tristan Kershaw (joined Exeter 2008) and Senior Research Fellow Dr David Coley (Exeter employee 1992 –2011).

A key concern of the Centre is how and to what extent future climate change will impact on the design of UK buildings, including energy usage within them and energy efficiency of the whole structure. For example, mean temperatures are projected to increase from 2.5°C in the Scottish islands to over 4°C in southern England by 2080. As the European heatwave of 2003 has demonstrated, overheating buildings can have significant health impacts. So without additional understanding and prediction tools, the construction industry is exposed to risks of occupant dissatisfaction, ill health, regulation infraction and litigation.

These issues were comprehensively addressed by Centre researchers in the EPSRC-funded PROMETHEUS project and others (i-iii). The main aims were to create a new methodology for generation of probabilistic future weather on an hourly time scale, to be distributed freely to industry and academia, using UK Climate Projections (UKCP09). Crucially, such data would allow designers to conduct cost-benefit analysis of architectural/structural design alternatives and minimise risk of building failure in a changing climate.

The UKCP09 data are cumulative distribution functions which give probabilities of climate change variables being less than a given value and a weather generator capable of producing a near infinite amount of weather data. The PROMETHEUS project developed a methodology to implement UKCP09 projections into time series weather data files with hourly steps. Statistical techniques were used to reduce the climate change projections to a create typical weather data for each climate scenario with each representing a different climate change probability level. Sorting algorithms were then used to rank the monthly weather data in each year in terms of temperature, sampled and recombined to represent the full probabilistic range of climate change scenarios [1]. Thus, meaningful interpretation of the monthly, and not just the yearly, model predictions is possible. Algorithms and statistical relationships are used to generate hourly wind speed and direction, air pressure and cloud cover, to supplement the output from UKCP09 [2] to create a complete weather signal which is comparable to what is currently available to industry for current weather.

The files cover 50 locations across the UK, and consist of two emissions scenarios (medium and high), three time slices (2030's, 2050's, 2080's) and five percentiles referring to the severity of the

potential climate change (10%, 33%, 50%, 66%, 90%). As such they are compatible with most building simulation software and are available in *.epw ('energy plus weather' format).

The new methodology produced data which can be used for building simulations [1] as per previous weather projection data. Key predicted weather variables such as wind speed and air pressure, were found to be consistent with UKCP09 projections and are crucial to building simulation [1, 2]. Discretising weather into representative subsets (5 per emissions scenario, time slice, and location) meant that the data was of more use to industry practitioners, whilst still capturing the full distribution of climate change [3]. The study also demonstrated that the current practice of using only 14 locations is inadequate to represent local climate, crucial for simulation accuracy [4].

3. References to the research

1. Eames M, Kershaw T, Coley D. (2011) On the creation of future probabilistic design weather years from UKCP09, *Building Services Engineering Research & Technology*, **32**, 2, 127-142, DOI:10.1177/0143624410379934. **
2. Kershaw T, Eames M, Coley D. (2011) Assessing the risk of climate change for buildings: A comparison between multi-year and probabilistic reference year simulations, *Building and Environment*, **46**, no. 6, pages 1303-1308, DOI:10.1016/j.buildenv.2010.12.018.
3. Eames M, Kershaw T, Coley D. (2011) The creation of wind speed and direction data for the use in probabilistic future weather files, *Building Services Engineering Research and Technology*, **32**, pages 143-158, article no. 2, DOI:10.1177/0143624410381624.**
4. Eames M, Kershaw T, Coley D. (2011) The appropriate spatial resolution of future weather files for building simulation, *Journal of Building Performance Simulation*, **5**, 6, pages 1-12, DOI:10.1080/19401493.2011.608133. **

** Papers that best indicate quality of underpinning research

<u>Research Grants</u>

i. Eames, M (PI). "*The development of an early stage thermal model to protect against uncertainty and morbidity in buildings under predicted climate change*". EPSRC *£456,058.* 1st of July 2011-30th June 2016. [EP/J002380/1]
ii. Kershaw, T. (CoI) (UMBRELLA: FP7) '*Development and validation of new 'processes and business models' for the next generation of performance based energy-efficient buildings integrating new services.*' European Commission £75,502. 1st of September 2012 – 31st August 2015.
iii. Coley, D. (PI) "*The Use of Probabilistic Climate Data to Future-Proof Design Decisions in the Buildings Sector*" EPSRC £516,044, 1st July 2008 - 30 June 2011, [EP/F038305/1]

4. Details of the impact

The probabilistic hourly weather files for over 40 locations across the UK, across three time slices (2030's, 2050's and 2080's) and two emissions scenarios (medium and high), addressed the critical lack in accuracy and resolution that building designers faced in simulating building thermal behaviour. Such simulation has previously relied only on historical weather data, which is clearly unsatisfactory given the significant expected changes in UK climate. These data have enabled the construction industry to design new and formulate retrofit of existing buildings which perform satisfactorily and meet building regulations under a changed climate. The weather files are in .epw format in order to be compatible with most building performance software.

The weather files to date have been used in over 70 commercial construction projects and downloaded over 500 times by industrial designers and academics from the project website (http://centres.exeter.ac.uk/cee/prometheus/downloads). The weather files have been cited in the UK Government's **2011** Low Carbon Action Plan Response as being used in the design process of more than £3bn worth of building projects [a], including Britain's first zero-carbon school, an eco-

town, and 40 out of 48 of the climate change adaptation projects funded by the Technology Strategy Board's Design for Future Climate competition including, North West Cambridge urban expansion, Admiral Insurance Headquarters, London Bridge Station Redevelopment, the Cooperative head office and more [b].

Jacobs Engineering, with annual revenues exceeding $11bn and a key stakeholder engaged with the PROMETHEUS project, comments

"The new weather data provided were readily useable in the TAS modelling tools already being used in thermal simulations. The use of the new data generally indicated that thermal comfort objectives for the buildings would be challenged by future climate conditions and this is something we would like to give further consideration to." [b]

Great Ormond Street Hospital (GOSH) London was built in the early 20thC, is nearing the end of its useable life and is hence being extended in four phases for completion in 2025. The PROMETHEUS weather files have been used to assess the climate change risk of the GOSH Phase 2B as acknowledged in the **2012** WSP Ltd Report for the Technology Strategy Board and GOSH [c]. The building design consultants AECOM have also used the PROMETHEUS weather files to develop a **2011** climate change adaptation strategy for the London School of Hygiene and Tropical Medicine, Keppel Street Building and are cited in the Climate Change Adaptation Strategy [d]. The risks to the building and its users were identified as overheating, localised flooding from excess surface water runoff and water conservation, with overheating identified as the most significant.

Buro Happold was commissioned to develop the energy strategy and the design of a number of buildings within the Master-plan of the University of Salford. This provided distinct opportunities for examining climate change adaptation measures at both a site master-planning and a building scale. The **2013** climate change adaptation study and the sustainable design measures were developed using PROMETHEUS weather files [e].

The weather files have also been used in the design process of the £60m 13,500 capacity Leeds Arena (started in **2009**) [b], specifically designed to 'set the benchmark' for sustainable arenas of the future with rainwater harvesting and air source heat pumps. Due to the high density of occupants, heat waves may present an issue and thus adaption strategies were considered such as increasing wall insulation and solar reflectivity of the roof to reduce heat transfer into the building. Cumulatively these recommendations added another 4.5% to the overall cost. Studies using the climate weather files showed that the strategies would eliminate any periods in which the internal temperature exceeded 28ºC, or to only 2.6% of occupied hours using the upper climate change scenario.

The Government announced its ambition in the **2008** budget that new domestic buildings should be zero carbon from 2016. The Department for Children, Schools and Families established the Zero Carbon Task Force to develop a strategy for zero carbon school buildings, to make recommendations on its implementation, and oversee exemplar projects such as the Montgomery School Exeter [f]. Montgomery School, with a capacity of 420 pupils, is the UK's first zero-carbon school based on Passivhaus. The PROMETHEUS weather files were used throughout the design process. The project totalled over £9m and the school will exist in its current form until 2080. Studies using the files highlighted the factors that needed most attention during any value engineering [f].

The files are now (since **2011**) included within Integrated Environmental Solution's (IES) 'Virtual Environment', the world leading simulation software for future proofing buildings [g]. They have also been incorporated into Sefaira concept software [h], a cloud based building design tool with several thousand users across more than 200 architecture firms worldwide. As IES state:

"To be truly sustainable, a building needs to last in excess of 100 years, and current design regulations and sustainability rating systems only require you to design against weather data that

represent at best the next decade or so. Sustainable designs really need to make some assessment of the impact of climate change on determining built form suitability for the long term. Weather files such as those being distributed by the University of Exeter and IES can help the building sector adapt to the challenges of climate change." [b]

5. Sources to corroborate the impact

a. HM Government Low Carbon Action Plan 'Government Response to the Low Carbon Construction Innovation and Growth Team Report' June 2011.*(Cites research p.69 and 70)* http://www.bis.gov.uk/assets/BISCore/business-sectors/docs/l/11-976-low-carbon-construction-action-plan.pdf
b. ARCC PROMETHEUS Final Summary Report, November 2011. *(indicates pictorially on a map of the UK where projects have used weather files p.2)* http://www.arcc-cn.org.uk/wp-content/Summaries/PROMETHEUS-summary-final.pdf
c. Great Ormond Street Hospital (GOSH) Phase 2B Climate Adaptation Risk and Opportunities Report FINAL. WSP Ltd for the Technology Strategy Board, February 2012. *(Cites research p.21 and 29)* *https://connect.innovateuk.org/documents/3197389/3713428/Re-revised%20Summary%20Report.pdf?version=1.0*
d. AECOM. London School of Economics and Tropical of Medicine Climate Change Adaption Strategy, September 2011. *(Cites research p.5, 17 and p.71)* *https://www.innovateuk.org/c/document_library/get_file?groupId=3197389&folderId=3713419&title=LSHTM+final+report+on+CCA+project.pdf*
e. Buro Happold. University of Salford Climate Change Adaptation Study, June 2013. (Cites research p. 15, 57, 75). PDF supplied.
f. Tatchell, A. NPS Group. Designing and constructing an exemplar zero carbon primary school in the city of Exeter, United Kingdom, OECD 2012.*(Cites University of Exeter p.5 and 6)* http://www.oecd.org/edu/innovation-education/centreforeffectivelearningenvironmentscele/50128171.pdf
g. Integrated Environmental Solutions (2011) 'IES and University of Exeter Create Free Comprehensive UK Future Weather Files' http://www.iesve.com/news/ies-and-university-of-exeter-create-free-comprehensive-uk-future-weather-files_1680_/corporate
h. Confirmation available by representative from Sefaira UK Ltd.