Institution: Oxford Brookes University

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

Title of case study: The adaptive model of thermal comfort and energy saving: understanding the interaction between humans and buildings.

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

The Thermal Comfort Unit at Oxford Brookes University has, since its formation in 1992, been a world-leader in developing, applying and promoting the adaptive approach to thermal comfort and energy saving in buildings. Developed by Professor Humphreys and Professor Nicol, the adaptive model treats thermal comfort as a self-regulating system, placing human thermal behaviour at the centre of the system. The Unit, now part of the Low Carbon Building Group, has had a profound influence internationally on the way of thinking about comfort, and its research findings have been embodied in national professional guidance for building services engineers, influenced international standards bodies as well as developing global networks.

2. Underpinning research (indicative maximum 500 words)

The adaptive model of thermal comfort was first proposed in the 1970s by Humphreys and Nicol. The conceptual model demonstrated potential for significant energy saving in buildings from adaptive human environmental behaviour. The increasing concerns about global warming in the 1990s elevated the global recognition of the model, because of its potential to reduce 'greenhouse gas' emissions.

More recently the Thermal Comfort Unit at Brookes has developed the conceptual foundation of the adaptive model. It has designed and conducted field-experiments to acquire data quantifying thermal comfort in daily life to measure the thermal environment in buildings, and observe the occupants' thermal behaviour.

Co-operation with overseas research teams has led to the acquisition of data from a wide range of climates and cultures around the world. In cooperation with the Low Energy Architecture Research Unit of London Metropolitan University, the Unit organised the influential series of international Windsor conferences on thermal comfort and energy use in buildings. Since 1994 these conferences have been instrumental in building an informal international network of practitioners and researchers who have further advanced the adaptive approach to comfort, both through the collection of data worldwide, and the development and extension of models of human thermal behaviour in buildings.

The research projects of the Thermal Comfort Unit have included:

- Field experiments in Pakistan to provide climate-related national guidelines for temperatures in buildings.
- Year-round field experiments in offices in England (Oxford) and Scotland (Aberdeen) to establish the dynamic relation between changes in outdoor temperature and changes in comfortable temperatures indoors.
- Leading data-acquisition year-round field experiments in five European countries (France, Greece, Portugal, Sweden, and UK) to form a pan-European database. (The SCATs Project)
- Analysing the resulting database to provide pan-European guidance on the dynamic relation between changes in outdoor temperature and changes in comfortable temperatures indoors.
- The modelling of window-opening behaviour in buildings, quantifying it from their extensive databases, and (in collaboration with colleagues at Strathclyde University) incorporating it in computer simulation models used in the design of buildings.

Specific research insights underpinning the impacts:

The field experiments have demonstrated the prevalence of behavioural adaptation within buildings, resulting in the mean temperatures experienced in the building being strongly correlated with the temperatures found to be most comfortable. Essentially, populations can successfully adapt to become comfortable at widely differing indoor temperatures. The results also showed that the temperature for comfort in a building could be linked to the outdoor temperature by an

exponentially weighted running mean of the daily mean outdoor temperatures.

The weighting coefficient (alpha) of the exponential series was quantified from the field databases and found to be in the region of 0.8/day. This implies that people would take a week or two to respond fully to a step change in the daily mean outdoor temperature.

The opening and closing of windows was shown to be an important means of temperature regulation when a building is in the free-running mode i.e. no heating or cooling systems in operation. Data from the field experiments enabled window-opening behaviour to be modelled and quantified.

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

Grants:

Thermal comfort and indoor air temperature standards for the ENERCON agency in Pakistan funded by the Overseas Development Agency 1993 with extensions and developments to 1996 (£65,000)

Human thermal comfort and the formulation of temperature standards in buildings funded by the EPSRC grant No (1996-8) GR/K80280 (£140,000) plus DoE (1996) EnREI research fellowship focused on the assessment and improvement of the Humphreys/Nicol algorithm for controlling mechanical comfort cooling or air conditioning systems,(£98,000)

1997-2000 Leading partner of EU-funded SCATS project to develop smart controls for AC and NV buildings in 5 European countries (total project budget €1.44 M, EU funding €1.04M)

2004-2006 EPSRC-funded project (GR/S82855/01) Predicting the effect of occupant behaviour on thermal comfort and energy use in buildings (with University of Strathclyde), £140,000. Final Assessment: tending to Outstanding

Publications:

Nicol, F., Humphreys, M. & Roaf, S. (2012) Adaptive thermal comfort: principles and practice. Routledge, London. 173pp.
This book is the first of a trilogy on adaptive thermal comfort, and sets out the principles of adaptive thermal comfort and explains its methodology and its application. *Submitted to REF2014, Oxford Brookes University, UoA16-Architecture, Built Environment and Planning, F Nicol, REF2, Output identifier 9108.*

Humphreys M.A. (1995), Thermal comfort temperatures and the habits of Hobbits, pp 3-13 in: Standards for Thermal Comfort, Eds: Nicol F., Humphreys M., Sykes O. & Roaf S.; E & F N Spon (Chapman & Hall).

Nicol, J.F., Raja, I.A., Allaudin A. and Jamy, G.N. (1999) Climatic variations in comfort temperatures: the Pakistan projects. Energy and Buildings 30 (3) pp261-279. *Submitted to RAE2001, Oxford Brookes University, UoA33-Built Environment, F Nicol, RA2, Output 3.*

Humphreys M.A. & Nicol J.F. (1998), Understanding the adaptive approach to thermal comfort, ASHRAE Transactions, Vol 104(1), pp 991-1004. An exposition of the adaptive model up to 1997. *Submitted to RAE2001, Oxford Brookes University, UoA33-Built Environment, M Humphreys, RA2, Output 2.*

Humphreys M.A. & Nicol J.F. (2002), The validity of ISO-PMV for predicting comfort votes in every-day life. Energy and Buildings 34 (2002) 667-684. A thoroughgoing critique of the dominant heat exchange model of thermal comfort. *Submitted to RAE2008, Oxford Brookes University, UoA31-Town and Country Planning, M Humphreys, RA2, Output 1.*

Nicol J.F. & Humphreys M.A. (2002), Adaptive thermal comfort and sustainable thermal standards for buildings. Energy and Buildings 34 (2002) 563-572. *Submitted to RAE2008, Oxford Brookes University, UoA31-Town and Country Planning, F Nicol, RA2, Output 1.*

Nicol F., Humphreys M. (2010). Derivation of the adaptive equations for thermal comfort in free-

running buildings in European standard EN15251. Building and Environment, 45 (2010) pp 11–17.

Nicol, F, Hacker, J, Spires, B and Davies, H (2009) Suggestion for new approach to overheating diagnostics. Building Research and Information Vol 37 (4) 348-357. *Submitted to REF2014, Oxford Brookes University, UoA16-Architecture, Built Environment and Planning, F Nicol, REF2, Output identifier 9110.*

Rijal H.B., Tuohy P., Humphreys M.A., Nicol J.F., Samuel A. (2012), Considering the impact of situation-specific motivations and constraints in the design of naturally ventilated and hybrid buildings, Architectural Science Review 55(1) 35-48. *Submitted to REF2014, Oxford Brookes University, UoA16-Architecture, Built Environment and Planning, M Humphreys, REF2, Output identifier 9115.*

Humphreys M.A., Rijal H.B. & Nicol, J.F. (2013) Updating the adaptive relation between climate and comfort indoors; new insights and an extended database. Building and Environment, pp 40-55, http://dx.doi.org/10.1016/j.buildenv.2013.01.024

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

The adaptive findings of the experiments by the Thermal Comfort Unit have contributed significantly to a research based approach to understanding the relationship between humans and buildings and the potential to save energy in a wide variety of climates. The work of Nicol and Humphreys has placed Oxford Brookes University at the forefront of research into thermal comfort, contributing and influencing decisions that will have a lasting effect on energy saving in buildings.

Contributing to Thermal Comfort Standards in Europe, Pakistan and China

Data collected by the Unit in field-campaigns in Pakistan and the UK contributed to the ASHRAE RP884 international database of thermal comfort field experiments. This database underlies the adaptive relation included in the current version of the ANSI/ASHRAE Standard 55, which defines the range of indoor thermal environmental conditions acceptable to a majority of occupants.

The Unit was the lead institution in the collection and analysis of data for indoor environment and comfort in European countries (the SCATs Project). The Unit's meta-analysis of the data underpins the adaptive thermal comfort section of the current Standard EN 15251 on comfort and energy use in buildings. The Unit's research also provided the logical framework and the statistical analysis for this section of the European Standard EN 15251.

The expertise of Humphreys and Nicol contributed to the Chinese Government's first standard for thermal comfort in public buildings. Humphreys and Nicol were invited to Chongqing, China, by Professor Baizhan Li to advise on developing the standard. The Unit's research models and statistical methods were the foundation of the advice given. The standard was issued in October 2012.

Work for the Chartered Institution of Building Services Engineers (CIBSE)

The CIBSE is the UK professional body that provides guidance on building services engineering. The research of the Unit has informed the committee revising the thermal comfort section of the CIBSE Guide A, Environmental Design, the primary resource for building professionals. The Unit's research had a formative influence, by providing data and conceptual modelling, on the forthcoming edition, due to be published in 2013.

The CIBSE have also produced a Technical Memorandum which includes technical advice on avoiding overheating in European Buildings. It relies heavily on data from the SCATs project and various analyses that the Unit made of those data.

Influence of these guidelines and standards on building professionals and building regulations

These standards and guidelines have an ongoing impact on those responsible for the design, construction and operation of buildings. Adaptive standards and guidelines allow the indoor

temperature to change in sympathy with the prevailing outdoor temperature, in a manner consistent with comfort, and therefore contribute to energy conservation and a consequent reduction in greenhouse gas emissions. They have helped architects and building services engineers to design and construct naturally ventilated buildings that avoid the use of air-conditioning in an extended range of climates. Guidance on indoor temperatures and ventilation rates, including the method for predicting overheating given in CIBSE Guide A, underpins the calculation methods recommended in Part L (Conservation of fuel and power) of the building regulations for non-domestic buildings. Recently updated advice from the Department for Education for ventilation and thermal comfort in new schools uses the methodology given for naturally ventilated buildings in EN15251 and is based on data from the Unit's European work. The advice on avoiding overheating follows the method developed by in CIBSE TM52.

Impact on the community of building practitioners and building researchers:
The international Windsor conferences on thermal comfort and energy use in buildings have drawn together increasing numbers of participants from some 40 countries, developing an informal worldwide network of architects, building engineers and researchers, with a shared interest in adaptive thermal comfort. Some of these participants have contributed, and continue to contribute, to the application of the research to building design and to their thermal control.

The Brookes team has also been active in the Network for Comfort and Energy Use in Buildings (NCEUB) which is a 400 member network of architects, engineers, consultants and academics from many countries and now organises the Windsor conference.

The Unit has produced numerous research publications, most being in peer reviewed journals. Nicol and Humphreys have over 300 publications between them. Their international acclaim in this field has resulted in invitations to speak at numerous lectures and presentations to audiences of architects, engineers and building researchers in UK, Australia, China, Denmark, France, Greece, Hong Kong, Indonesia, Portugal, Japan and the USA.

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

a) Standards and guidelines:

ANSI/ASHRAE Standard 55-2004 (2004) Thermal Environmental Conditions for Human Occupancy (the adaptive section may also be seen in subsequent and current versions of the standard)

CIBSE Guide A1 (8th Edition 2013) Environmental criteria for design. (7th edition) The Chartered Institution of Building Services Engineers London. ISBN-10: 1-903287-66-9 & ISBN-13: 978-1-903287-66-8.

Technical Memorandum 52: the limits of Thermal Comfort, avoiding overheating in European Buildings, London Chartered Institution of Building Services Engineers. 2013

CEN Standard EN15251 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics Bruxelles: European committee for Standardisation

b) influence on community of building professionals and researchers

Proceedings of the Windsor Conferences:

First Windsor conference proceedings:

Nicol F., Humphreys M., Sykes O. & Roaf S. (Eds) (1995), Standards for Thermal Comfort, E & F N Spon (Chapman & Hall) (247 pp).

Most of the papers from Windsor conferences since 2008 are available available on NCEUB website (nceub.org.uk)

The following journal special issues are made up of papers which arose from papers given at the Windsor conference:

1. Energy and Buildings: Vol 34 (6) 2002, Vol 39(7) 2007
2. Building Research and Information: Vol 33(4) 2005, Vol 37(4), 2009, Vol 39(2), 2011
3. Special issues of Architectural Science Review (Vol 56(1) and Building Research and Information (Vol 41(2) will be published in 2013