Institution:	**Loughborough University**
Unit of Assessment:	**C16 Architecture, Built Environment and Planning**
Title of case study:	**Improved air quality, energy demand reduction and new controllers for advanced naturally ventilated buildings**

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

Research at Loughborough University during the period 2008-2013 in the areas of control, commissioning and design of advanced naturally-ventilated buildings has led to:

- Improvements in ventilation performance in an award-winning building in the USA;
- Confirmation of the performance of a globally applicable low-energy building design strategy; and
- Increased confidence in US design teams to produce naturally ventilated buildings.

A subsequent KTP project with SE Controls has led to:

- A new product range for a UK controls company;
- Increased turnover;
- Expanded capacity to exploit research for innovation; and
- Stimulated growth of its new product development team.

2. Underpinning research (indicative maximum 500 words)

The work discussed here was carried out by Professors Cook and Lomas *after* they moved from De Montfort University to Loughborough University in September 2008.

Naturally ventilated buildings are an important ally in the quest to reduce carbon emissions associated with buildings and so advanced naturally ventilated (ANV) designs are enjoying a resurgence. However, realizing their energy demand reduction potential while satisfying air quality and thermal comfort requirements requires effective commissioning and fine tuning of ventilation control systems, both currently poorly understood. The research underpinning the impacts reported here addressed these issues and spans three projects.

Fine Tuning and Commissioning

This research was conducted between September 2008 and December 2012, initially by Lomas during his tenure as a Leverhulme Research Fellow focusing on ANV buildings **[G1]**. The work involved the synthesis and interpretation of measurement data from the Harm A. Weber Academic Center (HAWAC) at Judson University in Illinois **[R1]**. This is the first US building to combine ANV with a conventional HVAC system. Cook and Lomas were the energy and environment design consultants and responsible for the monitoring, fine tuning and post-occupancy evaluation. The analysis of their data **[R2]** confirmed that the ANV strategy was functioning broadly as intended. However, the work uncovered failings in building components leading to excessive heating energy consumption, and unexpected flow conditions due to local mechanical ventilation systems. The work is of generic value, applicable to all ANV buildings worldwide, as it elucidates the barriers to practical, cost-effective, implementation of low energy building solutions and common design flaws that jeopardise effective control and commissioning **[R1, R2]**.

Hospital Design

This research, conducted between September 2009 and February 2013 by Lomas, was funded by the EPSRC **[G2]**. It showed that substantial energy demand reduction is possible using ANV whilst controlling hospital-originated infection and patient comfort even in a warming climate **[R3]**. Alternative refurbishment options for buildings operated by four hospital trusts, in Cambridge, Bradford, Watford and Leicester, e.g. **[R4]**, revealed the incompatibility of the current Health

Technical Memorandum HTM03 and the imperative of reducing CO_2 emissions **[R5]**.

New product research

This research, funded by a Knowledge Transfer Partnership **[G3]** between November 2008 and May 2011, continues as a PhD project (Khatami, under Cook's supervision). The realisation that successful ANV buildings require robust, reliable components, tailored fine tuning and commissioning, as well as innovative design, was central to collaboration with SE Controls (SEC). Computer simulation demonstrated that energy consumption can be reduced by at least 30% using CO_2-based control strategies to move dampers between multiple, discrete opening positions in a stepwise manner **[R6]**. A new controller was developed that incorporated an optimized control algorithm such that ventilation openings, commensurate with good air quality, are used in winter, thereby minimizing heating energy consumption. The research placed the company's headquarters at the centre of a monitoring study to field test and showcase the new controller. Several control strategies were trialled and simulated to arrive at detailed recommendations. This was subsequently implemented by SEC.

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

During the period 1 January 1988 – 31 July 2013, Professors Cook and Lomas have published 29 refereed journal papers in the field of advanced naturally ventilated buildings, of which the following report on work carried out at Loughborough University and relate directly to this impact case study:

R1 Lomas KJ, Cook MJ and Short CA (2009) "Commissioning hybrid advanced naturally ventilated buildings: a US case-study", *Building Research and Information*, 37(4): 397-412. DOI: 10.1080/09613210902920797 (impact factor 1.476, 7 citations)

R2 Kaiser, KP, Ogoli, DM and Cook MJ (2009) "Harm A Weber Academic Center, post-occupancy building performance and comfort perceptions", *Architectural Research Centers Consortium (ARCC) Journal*, 6(2), 40-46, 2009 (awarded one of nine Best Paper awards)

R3 Lomas KJ and Ji Y, (2009) "Resilience of naturally ventilated buildings to climate change: advanced naturally ventilated buildings and hospital wards", *Energy and Buildings*, 41(6), 629-653, DOI: 10.1016/j.enbuild.2009.01.001, ISSN 0378-7788 (impact factor 2.809 [5-year], 29 citations)

R4 Lomas KJ, Giridharan R, Short CA, Fair AJ (2012) "Resilience of 'Nightingale' hospital wards in a changing climate", *Building Services Engineering Research and Technology*, 33(1), 81-103, DOI: 10.1177/0143624411432012

R5 Lomas, KJ and Giridharan, R, (2012) "Thermal comfort standards, measured internal temperatures and thermal resilience to climate change of free-running buildings: a case-study of hospital wards", *Building and Environment*, 55, 57-72, DOI: 10.1016/j.buildenv.2011.12.006 (impact factor 2.4, 15 citations)

R6 Khatami, N, Cook MJ, Firth, SK and Hudleston, N (2013) "Control of CO_2 concentration in educational spaces using natural ventilation", *International Journal of Ventilation*, 11(4): 339-352

Grants

G1 Lomas, *Research Fellowship: Advanced naturally ventilated buildings*, Leverhulme Trust, 2008-10, £29k.

G2 Lomas, *Design and Delivery of Robust Hospital Environments in a Changing Climate (DeDeRHECC)*, EPSRC (EP/G061327/1), 2009-13, £268k (total value £897k, with Cambridge and the OU)

G3 Cook and Firth, *Developing and embedding knowledge on how to improve energy efficiency and indoor air quality in the built environment using natural ventilation and intelligent control systems,* Knowledge Transfer Partnership, 2009 – 2011, £74k.

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

Three impacts are claimed here resulting directly from the research of Cook and Lomas: (i) improvements to indoor air quality, thermal comfort and energy performance through better design of ANV buildings in general, and the HAWAC building in particular, (ii) greater confidence of the US design team to design other low energy buildings, and (iii) a new product for industrial collaborator SEC leading to improved building energy performance for their customers.

i) Improvements to indoor air quality, thermal comfort and energy performance

Cook and Lomas planned, coordinated and undertook commissioning, fine-tuning and post-occupancy monitoring of the HAWAC building. By identifying the causes of disparities between actual and intended performance, this work enabled contractors and facilities managers to correct errors and thus restore air quality and temperatures to levels nearer those intended, whilst maintaining the low energy credentials of the building and the consequential low emission of greenhouse gases **[C1]**. The expertise gained is applicable to future projects of team members.

The low-energy credentials of the HAWAC building has raised the profile of Judson University and had a positive impact on its enhanced marketing strategy **[C1]**. The impact for the University culminated in the award of LEED Gold energy rating in Feb. 2009 in recognition of the building's design and performance **[C3, C4]**.

(ii) Greater confidence of the US design team

For the US architects involved in the HAWAC building's commissioning, the concept of ANV was new. The experience has enabled them to go on to design other low-energy buildings using natural ventilation with greater confidence **[C2]**. The design strategy is applicable to office-type buildings in low-humidity climates across the globe. The work of Cook with SEC has had wide reaching and significant impact for the company's activity. The outcome of the monitoring and simulation work has been to replace the traditional, crude PC-based control system at SEC's headquarters, with a new controller in which CO_2, temperature and humidity sensors are integrated along with processing hardware in a single housing. The NV LogIQ^{TM} controller, which incorporates the new algorithm developed in the underpinning research, is now the centrepiece of a new product range launched in 2012 **[C5]**. The controller also incorporates a logging facility that enables data to be collected at 10-second intervals at a centralised location so that ventilation systems can be properly commissioned and fine-tuned. As noted in the underpinning research, a lack of post-occupancy commissioning can be a major cause of unexpectedly poor performance in naturally ventilated buildings. The new NV LogIQ^{TM} controller makes such commissioning possible as an integral part of SEC's offering to clients. The new control system was installed at SEC headquarters in 2012 and has been refined by Khatami (LU researcher), leading to an exemplary showcase facility for SEC with direct impact on their marketing strategy **[C6]**. Monitoring and occupant feedback has confirmed the performance advantages of the new control algorithm in terms of better indoor air quality, thermal comfort and energy performance **[C6]**. The first customers for the NV LogIQ^{TM} controller were secured early in 2013 and initial data has shown effective operation. For example occupant thermal comfort was maintained in the new naturally ventilated offices of the Diocese of Nottingham (Dunham House), despite the heat waves over the summer of 2013. The underpinning research on hospital design, which was incorporated into the control algorithms developed, has ensured that the NV LogIQ^{TM} controller is also fit for use in a wide range of healthcare facilities. At the time of writing, SEC had prepared quotations for supplying NV LogIQ^{TM} for use in offices, schools and dwellings **[C6].**

(iii) A new product

SEC sees its collaboration with Loughborough University as part of its 'aggressive new product development programme …' as 'The results of this research have been directly fed into new products' **[C7]**. When the KTP project began late in 2008, new product development commanded the efforts of three SEC staff. By 2012 this had grown to seven full time and two part time staff. The company's capacity to absorb new knowledge and practices from research has also improved substantially. In the summer of 2012, the company had a Loughborough University Masters student carry out a short study aimed at further improving the positioning of the ventilation controllers at their headquarters. The company now employs a Loughborough University graduate

as a full-time Design Manager (new post) to continue developing this area of the business.

The impact on SEC of Loughborough University's research motivated further collaboration with Loughborough University, e.g. financial support to enable Khatami to complete her doctoral research **[C6]**, the annual prize awarded by SEC to the best graduate from the Low Carbon Building Design and Modelling masters course **[C6]**, controls provided by the company for the University's new design school (completed in 2012) and sponsorship of the university's Doctoral Training Centre in Energy Demand Reduction.

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

The following sources of corroboration can be made available at request.

C1 Letter from the department of architecture chair to corroborate the improvements to user comfort and energy-use savings following rectification of problems identified in commissioning and post-occupancy monitoring at the HAWAC building, Judson University, Elgin, Illinois, USA.

C2 Letter from President/Principal, Andersson Architecture and Design, Geneva, Illinois, USA (formerly at Burnidge Cassell and Associates, Elgin, Illinois, USA) confirming knowledge from collaboration on design and commissioning.

C3 Judson University's LEED Gold-Certified Building on Display for "Green" Elgin Tour, http://www.judsonu.edu/Articles/Judson_University_s_LEED_Gold-Certified_Building_on_Display_for_Green_Elgin_Tour/ [accessed 5/5/13]. Hard copy available on request

C4 http://www.judsonu.edu/About/Sustainability/HAWAC/ Hard copy available on request.

C5 http://secontrols.com/assets/uploads/NV_Room_Controller.pdf [accessed 30/09/13]. Page no longer live. Hard copy available on request.)

C6 Letter from the managing director, SE Controls, Lichfield, UK, confirming the pivotal role of Loughborough University's Research in the development of the new product.

C7 http://www.secontrols.com/news/item/SE-Controls-Still-growing-After-30-years [accessed 28/01/13]. Hard copy available on request.)