Institution: University of Cambridge

Unit of Assessment: UoA 13 Architecture, Built Environment and Planning

Title of case study: Adaptation of existing buildings to boost resilience in a changing climate

Period when the underpinning research was undertaken: October 2009 – March 2019

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Prof. C. Alan Short	The Professor of Architecture (1970)	Sep 2001– present
Prof. Peter Guthrie	Professor Emeritus in Engineering for Sustainable Development, Director of Sustainable Development	2000–present
Prof. Hans Graf	Professor of Environmental Systems Analysis	October 2003–December 2015
Dr. Michael Herzog	Reader in Atmospheric Sciences	September 2007– present
Dr. Jiyun Song	Research Associate	Jan 2017 – July 2019
Dr. Laetitia Mottet	Research Associate	October 2016 – March 2019

Period when the claimed impact occurred: 2014 onwards

Is this case study continued from a case study submitted in 2014? Y

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

Short's research at the University of Cambridge focuses on the adaptation of post-war buildings to increase resilience to a changing climate, reduce carbon emissions and improve comfort. The UK Department of Health appointed Short to develop the NHS Energy Efficiency Fund (EEF) specifically to mitigate climate change effects by improving energy efficiency across the retained NHS Estate and subsequently commissioned him to redraft the primary NHS guidance on energy efficiency, promoting EEF findings and advocating refurbishment as often the superior option to newbuild. The concept has been taken up internationally by healthcare organisations and by stakeholders in China's Hot Summer-Cold Winter region responding to government carbon reduction policy.

2. Underpinning research (indicative maximum 500 words)

As a result of climate change, many parts of the world are experiencing greater extremes of temperature. This poses a particular problem in non-domestic buildings, notably hospitals, which treat vulnerable patients, and often constitute older building stock. The 2014 submission focussed on the NHS Estate. The problem is acute for the existing stock in geographic regions with increasing susceptibility to periods of extreme temperatures. The diagnosis and adaptation of a wider variety of building types in Continental climates is the focus of this submission. This highly interdisciplinary research, lead by Architecture at the University of Cambridge in close collaboration with Engineering, Geography and Applied Mathematics and Theoretical Physics in Cambridge and with Earth Sciences at Imperial College London and Chongqing and Zhejiang Universities in China, addresses these challenges in building the existing stock's resilience. Short's expertise in adapting relatively recent buildings to enable natural ventilation and passive

cooling whilst reducing solar and other gains derives from leading thirty years of research including design and delivery of a number of live adaptation projects: Future House in Beijing **[R1, Ch.8]**, Poole's 'Lighthouse' and the 'Garrick' theatre in Lichfield **[R1, Ch.5]**.

The research programme DeDeRHECC measured excessively hot summer conditions in UK buildings (hospitals) and in China (various) 2007-19. Theoretical adaptation proposals were developed to boost resilience in hot summers, following DeDeRHECC methodology: identifying recurrent building types; monitoring over two years; simulation; diagnosis of performance to inform re-engineering designs to increase resilience, reduce carbon emissions and improve comfort from a palette of interventions to reduce solar gains, expose latent thermal mass, encourage cross ventilation and/or stack ventilation through interventions in plan and envelope. **[R2]** proposes an adaptation of a typical Nightingale hospital ward. **[R3]** presents adaptation options for a medium-rise maternity hospital. DeDeRHECC type solutions were then applied across 248 NHS England Acute Hospitals, 12.4 million m^2 **[R1, Ch.9]**. Chongqing and Zhejiang co-researchers with policy advisors from the China Academy of Building Research, the Green Building Council of China and industrial partners Grace Corporation, Nantong Construction Group and others followed this work, evolving Short's adaptation schemes for a harsher Continental climate. The China-focussed project Low carbon climate-responsive Heating and Cooling of Cities (LoHCool) was developed out of DeDeRHECC and HTM 07-02 and adds wind-driven ventilation to UK type passive schemes to further reduce summer internal temperatures. **[R5, R6**]. In subsequent research, the Low carbon climate-responsive Heating and Cooling of cities (LoHCool) project, the methodology was extended to the 9 billion m^2 of building stock in China's Hot Summer-Cold Winter (HSCW) zone, population 550 million people where internal environments oscillate well beyond regionally derived comfort zones. Colleagues in Chongqing and Hangzhou sampled significant portions of their respective cities to identify recurrent building types. Representative buildings were selected by the international team, internal and external data were collected at the type buildings over two subsequent hot seasons to assist the team in diagnosing their malperformance and designing sets of coupled adaptation measures. Building internal environments were modelled in China whilst their external city environments were modelled at Imperial. Internal environments were coupled within the same FLUIDITY model predicting the external prevailing city-wide airflows, calibrated against measured data and remodelled with the proposed adaptation measures to enable the design of a standardised approach for each highly recurrent building type **[R5, R6]**.

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

R1. Short, C. A. (2017). *The recovery of natural environments in architecture: Air, comfort and climate* (Ch.9). Routledge. [Link]
R2. Short, C. A., Noakes, C. J., Gilkeson, C. A., Fair, A. (2014). Functional recovery of a resilient hospital type, *Building Research & Information,* 42(6), 657-684. [Link]
R3. Short, C. A., Renganathan, G., Lomas, K. J. (2015). A medium-rise1970's maternity hospital in the east of England: Resilience and adaptation to climate change. *Building, Services, Engineering, Research and Technology*, special issue - *Indoor temperature and air quality*, 36(2), 247-274. [Link]. Winner of the Carter Bronze Medal 2016, Chartered Institute of Building Services Engineers for best paper 2016.
R4. Department of Health (2015). *NHS Energy Efficiency Fund Final Report - Summary*. [Link].
R5. Short, C. A., **Song**, J., **Mottet**, L., Chen, S., Wu, J., Ge, J. (2018). Challenges in the low-carbon adaptation of China's apartment towers. *Building Research & Information*, special issue - *Urban form density and microclimate*, 46(8), 899-930. [Link]
R6. Mottet, L., Song, J., **Short**, C. A., Chen, S., Wu, J., Yu, W., Xiong, J., Zhang, Q., Ge, J., Yao, R., Li, B. (2020). The hot summer-cold winter region in China: Challenges in the low carbon adaptation of residential slab buildings to enhance comfort, *Energy and Buildings*, 223:110181. [Link]

Producing outputs published in well-established, peer-reviewed journals, the research was conducted with support from several institutions, including the following grants:

1. Professor A. Short - Design and delivery of robust hospital environments in a changing climate (DeDeRHECC) (EP/G061327/1) - EPSRC - 2009-2014 - GBP896,583. With an additional GBP120K from NHS Trusts including GBP10K from the Dept. of Health (total GBP1.05 million). Short as Principal Investigator with Prof. John Clarkson, UoC Engineering Design Centre; Prof. K. Lomas, Loughborough University; Dr Claudia Eckert, Open University; Prof. Cath Noakes, Pathogen Control Research Centre, Dept of Engineering, Leeds University.

2. Professor A. Short - Low carbon climate-responsive Heating and Cooling of Cities (LoHCool) (EP/N009797/1) – EPSRC & NSF - 2015-2019 - GBP987k (at 80% fEC + equivalent in China). Short as Principal Investigator with Baizhan Li, Chongqing University; Prof. Jian Ge, Zhejiang University; Prof. Peter Guthrie, University of Cambridge Department of Engineering, Prof. Hans Graf, the University of Cambridge Institute of Atmospheric Physics; Prof. Runming Yao, University of Reading and Prof. Kevin Lomas, Loughborough University Department of Civil and Building Engineering.

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

Changes to UK health policy and guidance: The UK Department of Health commissioned Short to develop the 2013-14 NHS Energy Efficiency Fund 'to mitigate the effects of climate change by improving energy efficiency across the existing NHS Estate'. GBP49.3m was expended on 117 energy efficiency projects in 48 NHS organisations predicted to save 100.6Mkg CO_2 pa, 2.4% of the entire NHS building energy related carbon footprint. Reporting of the fund outcomes contributed to the REF2014 impact case study **[E1].** Short/Guthrie's 2015 Executive Summary captures the key outcomes **[E1]**. The unpublished full report includes 31 case studies, revealing wide variations in the relative benefits of different approaches and the challenges and limitations of the schemes such as: too tight timescale disqualifying failing Trusts, lack of building level energy data, skills gaps in NHS organisations, lack of staff trust and engagement. Unanticipated requirements for planning approvals eliminated most renewable energy schemes, important learning for the DH: '*The NHS EEF was regarded as having been particularly successful and your report highlights a series of exemplar projects setting a clear policy direction for future physical adaptation of the retained estate which clearly aligns with the Government's move towards retention and refurbishment of the NHS'* **[E4]**. Opportunities were identified in upgrading planned maintenance with easy wins such as lighting upgrades **[R4, p.11]**. Lord Carter (NHSi) took findings from Short's 20 lighting improvement case studies and launched an NHS fund exclusively for lighting upgrades in 2017 **[E11].**

The Department of Health commissioned Short and colleagues to draft new guidance on energy efficiency, the updated Health Technical Memorandum (HTM 07-02) *Encode 2015*, *Making energy work in healthcare* **[E2]** reinforcing the trajectory of government policy established by the EEF emphasizing, *'From a financial and resource efficiency perspective, the refurbishment of an existing building is often a superior option to constructing a new one*'. (p. 29) The HTM is now the required point of reference for approvals for all NHS Estates and Facilities projects. In his foreword, the then Head of Profession for NHS Estates & Facilities Policy, wrote *'The (Energy Efficiency) Fund enabled the NHS to go further, faster in mitigating the effects of climate change, by improving energy efficiency, whilst retaining the resulting benefits within the NHS organisations for re-investment directly into frontline patient services. The lessons learnt from these energy efficiency projects are embedded in Encode 2015 as best practice guidance'* [**E4**]. The Department of Health Chief Architect wrote to Short on the published HTM, *'I just would like to pass on my gratitude and thanks this is a real source of best practice and knowledge sharing'* **[E3].**

International healthcare charity 'Health Care Without Harm' alerted Fraser Health, which manages 99 health care facilities in British Columbia, to Short's adaptation research in September 2016, citing Short's film 'Robust Hospitals in a Changing Climate'. Fraser Health's Director of Energy and Environmental Sustainability has commented that *'the Climate Risk and Resilience Lead at Fraser Health and her Energy and Environmental sustainability (EES) colleagues subsequently translated Short's principles and methodologies to a British Columbia*

*context, developed projects with national-level partners, and shared results and insights with communities of practice. Drawing on research from 2016, firstly a National Research Council study which provides a Climate Resilience Feasibility Study of Facilities at Fraser Canyon Hospital…. Inspired by Short's video on retrofitting hospitals for extreme heat, and included the evaluation of six options, the same measures as highlighted in Short's own research and shows a clear incorporation and implementation of his concepts and methodological approach in the Canadian Healthcare context'.***[E5]**

A Director in multi-disciplinary, international design practice BDP and project partner wrote in March 2020 that: 'Such [Short et al] research has enabled us to both advise our clients in effectively assessing the suitability of retaining existing buildings, and provide evidence to support the reduced use of 'energy-hungry' air conditioning and increase the use of low-carbon mixed-mode natural ventilation in healthcare buildings and across other sectors ... ' **[E6]**.

Extending Adaptation and Retrofitting to the Chinese Construction Sector, Hot Summer-Cold Winter Region (HSCW) estimated total annual energy consumption for residential floorspace 90-135 Billion kWh. LoHCool proposals mitigate a potential future 320.11- 415.8 Billion kWh of energy consumption per annum **[R6]**. Short and Yao of Chongqing and Reading held two-day workshops in 2018 for Nantong Sanjian Holdings Co. Limited, parent of the China Nantong Third Construction Company **[E7],** and the Grace Corporation, Yibin Sichuan **[E8],** introducing low energy adaptation of existing stock as a novel concept rather than wholesale demolition and replacement. Grace Corp. emphasizes their interest in exploiting LoHCool's low energy concepts at the city planning scale, 'At the planning stage in April 2018, Prof. Alan Short intensively worked with us and had a two-day workshop and a site visit. He provided a low carbon sustainable planning concept that we have adapted in the our (sic) final plan...Prof. Short's low carbon design and model are very helpful in our building design practice. The research provided evidence of important implications to developing policy in this area within which we are able to play an active part' **[E8]**. In Hangzhou, Zhejiang Shimao Real Estate Group costed the LoHCool Hangzhou case study projects **[R5, R6]**, the real estate developer Hangzhou Sanxiang Impression Co. Ltd. states it will reconsider approaches to existing buildings given the clear national and regional sustainability agenda **[E9]** and the leading design agency Zhejiang Huazhi Building Technology Promotion Centre cites a broader approach to the existing building stock **[E10]**.

The Deputy General Manager and Main Board Director at Nantong Sanjian Holdings Co., Ltd. writes, 'Prof. Short introduced the LoHCool project ...Prof.Short's research provides a new concept in housing design and retrofitting that explained in the film, which is very interesting. We are keen to explore future the retention and adaptation of existing buildings and new builds'. Nantong is no. 26 in ENR table of world's 250 largest contractors, no. 9 out of top 200 construction companies in China **[E7]**. Hangzhou Sanxiang Impression Co. Ltd. a leading real estate developer writes, ''this research project has important implications to developing lower energy residential buildings in this area within which we are able to play an active part. Our company has reviewed its benefit to the existing building stock and the research has greatly broadened the range of approaches which we can consider when we plan for new construction, we can see greater value to be recovered in our existing building stock as a consequence in the region of Hot Summer and Cold Winter'. **[E9]**. From the Zhejiang Huazhi Technology Promotion Centre letter, 'The research and our interactions with Professor C. Alan Short have had important impact on designing lower energy buildings in this region. The research has broadened the range of methods which we can consider when we plan for refurbishment or new construction'. **[E10]**. Regarding the influence on BDP's operations in China: 'More directly, the case study buildings, such as Liubo ... look very familiar both in China and other countries where we work ...The wind-catcher design developed within the project provides evidence for the effectiveness of a retro-fit solution and indeed evidence for similar approaches to be integrated into new-build construction' **[E6]**.

Environmental film award citations for Short's team's film of the LoHCool findings: A Low Carbon Future for China's Furnace Cities winner in 2019 **tve** Global Sustainability Film Awards: **AI and**

Digital Innovation Award; Best Short Documentary at the Vegas Film Awards July 2020; ARFF Amsterdam Film Festival Semi-Finalist Best Short Documentary October 2020.

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

E1. Department of Health (2015). *NHS Energy Efficiency Fund: Executive summary*. [Link]

E2. Health Technical Memorandum (HTM) 07-02: EnCO_2de 2015- making energy work in healthcare, Part A: Policy and Management and Part B: procurement and energy considerations for new and existing building facilities, 2.1.1. p. 29, published 25 March 2015 [Link]

E3. E-mail: Chief Architect UK Department of Health, 19.03.2015.

E4. Letter: CEO and former President of IHEEM, former Director of Estates and Facilities Department of Health, to Short, 14.05.2020.

E5. Testimonial: 13.01.2021 to REF Assessment Panel, Fraser Health, Providence Health Care, Provincial Health Service Authority, Vancouver Coastal Health: Director, Energy and Environmental Sustainability, Facilities Management.

E6. Letter: BDP's Architect Director leading the science, research and technology sector worldwide to Short, 09.03.2020.

E7. Letter: 05.01.2020 to whom it may concern, Deputy General Manager and Main Board Director at Nantong Sanjian Holdings Co., Ltd. owners of the China Nantong Third Construction Company. Nantong is a vast international construction conglomerate, no. 26 in ENR table of world's 250 largest contractors, no. 9 out of top 200 construction companies in China, no. 157 of largest enterprises [all sectors] in China.

E8. Grace Corporation Yibin Grace Land Co. Ltd. Sichuan real estate developer, letter to whom it may concern, 02.02.2020, emphasizes their interest in exploiting LoHCool's low energy concepts at the city planning scale.

E9. Hangzhou Sanxiang Impression Co. Ltd. a leading estate developer writes, *'...the research has greatly broadened the range of approaches which we can consider when we plan for new construction, we can see greater value to be recovered in our existing building stock as a consequence in the region of Hot Summer and Cold Winter'*.

E10. The Zhejiang Huazhi Technology Promotion Centre letter 29.01.2020 to whom it may concern, *'The research and our interactions with Professor C. Alan Short have had important impact on designing lower energy buildings in this region. The research has broadened the range of methods which we can consider when we plan for refurbishment or new construction'.*

E11. 'Plans for 2016, Lord Carter', *Health Estate Journal*, January 2016.