Institution: University of Strathclyde		
Unit of Assessment: C13 Architecture, Built Environment and Planning		
Title of case study: Protecting occupant health, reducing energy and lowering carbon emissions through building ventilation regulation and control		
Period when the underpinning research was undertaken: 2000 - 2020		
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:**
Stirling Howieson Paul Tuohy Tim Sharpe	Senior Lecturer Lecturer Professor	01/03/1992 – present 01/10/2006 – present 10/02/2020 – present
Period when the claimed impact occurred: August 2013 – December 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Research into energy reduction and ventilation undertaken by the University of Strathclyde has improved building performance in Scotland and the UK to protect occupant health, save energy and reduce carbon emissions. Specifically, since August 2013 it has:

- Protected occupant health by influencing Scottish common law;
- Shaped UK Government policy and public health advice to reduce COVID-19 transmission; and
- Informed Building Regulations and industry guidance to improve building performance in Scotland and the UK.

2. Underpinning research

While post-war improvements to housing in the UK have brought many benefits, the drive for warmth and energy efficiency has had unintended consequences for indoor air quality and occupant health. Asthma, a chronic disease of the air passages commonly triggered by inhaled substances particles and allergens, has increased six fold in prevalence among Scottish children with a significant rise in hospital death rates due to acute incidents. Since 2000 researchers at the University of Strathclyde have undertaken extensive work to understand causes and how to address these. Central to this is the development of effective building design standards and regulation, with a particular focus on ventilation design and occupier behaviour.

Housing and health – fuel poverty, dampness, mould and lung function: Building on previous work, **Howieson** conducted research on the health implications of fuel poverty and excess winter deaths (2004-5). A subsequent project examined the role played by house conditions in the increasing prevalence of disease. The resulting monograph, covering all aspects of housing design and use, developed a clear focus on the role that planned ventilation can play in suppressing relative humidity – the key driver of house dust mite infestation and allergen generation. The book outlined a range of strategies to tackle the problems inherent in the existing and retro-fitted housing stock, as well as forging guiding principles for the design of new dwellings, together with a financial assessment of the proposals [**R1**].

Further research in collaboration with a team of respiratory consultants and immunologists at Gartnavel Hospital (University of Glasgow), a US biotech company and the US Environmental Protection Agency, quantified the effect on lung function of exposure to indoor biological contaminants using the samples taken as part of the initial study. This was done through two studies: a randomised double-blind placebo-controlled intervention trial (2009) which found that domestic mechanical ventilation with heat recovery (MVHR), systems in combination with a range of allergen de-naturing measures, can improve asthma control by inhibiting re-colonisation rates [**R2**] and; a cross-sectional study (2015) of non-smoking, asthmatic adults in Scotland that revealed a significant correlation between Environmental Relative Moldiness Index (ERMI) values in the homes and lung function testing, strongly suggesting that asthmatics should avoid high ERMI environments [**R3**].

Building energy and environmental performance: Since 2004, **Tuohy** has undertaken research into building energy and indoor environmental performance including projects funded by the Building Research Establishment (BRE) (2004-2013) and Scottish Government (2006-2018).

This research demonstrates inadequacies in current regulatory and industry methods and new methods to address these. Having investigated UK regulatory energy and carbon calculation methods, Tuohy developed a new design methodology encompassing a capability parameter to quantify robustness and identified root causes for gaps between intended and actual building performance [**R4**]. Further research explored processes used in non-construction Benchmark Industries and identified quality systems processes from electronics, aerospace and automotive Industries that could address the gaps. It was proposed that these BIM Benchmark Industry processes could be easily adopted in a BIM framework to routinely deliver comfortable healthy low-carbon buildings [**R5**]. This study demonstrated the importance of public domain performance data and the need for a quality systems approach to deliver intended performance in practice.

Building Standards and indoor air quality: On the basis of their expertise and body of research on indoor air quality and ventilation, **Howieson** and **Tuohy** were key members of a collaborative research team (including **Sharpe** of Glasgow School of Art, now Strathclyde) selected by the Scottish Government Building Standards Division (BSD) in 2014 to investigate occupier influence on indoor air quality in dwellings. Following a detailed literature review, fieldwork was undertaken to gather quantitative data on occupant interaction with ventilation provision within the homes and undertake more detailed investigations into the effects on indoor air quality. The resulting report highlighted the relative lack of trickle vent use in contemporary housing, pointing to the prioritisation of thermal comfort over moisture and pollutant control, and outlined options for revising the Domestic Technical Handbook guidance to Standard 3.14 on natural ventilation [**R6**]. A further study commissioned by BSD into the effectiveness of decentral mechanical extract ventilation was completed in 2018. Since April 2020, **Sharpe** has drawn on these Strathclyde studies to provide research input as a member of the Scientific Advisory Group for Emergencies (SAGE) Environment and Modelling Group (EMG). Key insights on ventilation design and use have been incorporated into a series of papers examining various aspects of disease transmission and mitigations in the built environment to inform decision-making in relation to COVID-19.

3. References to the research (Strathclyde affiliated authors in **bold**)

R1 **S. Howieson** (2005) *Housing and Asthma*, London: Routledge, ISBN 9780203022504 https://doi.org/10.4324/9780203022504

R2 G. Wright, **S. Howieson**, C. McSharry, A. McMahon, R. Chaudhuri, J. Thompson, I. Donnelly, **R. Brooks**, **A. Lawson**, L. Jolly, L. McAlpine, E. King, M. Chapman, S. Wood, N. Thomson (2009), Effect of improved home ventilation on asthma control and house dust mite allergen levels, *Allergy*, 64: 1671–1680 https://doi.org/10.1111/j.1398-9995.2009.02098.x

R3 C. McSharry, S. Vesper, L. Wymer, **S. Howieson** , R. Chaudhuri, G.R. Wright, N.C. Thomson (2015) Decreased FEV1 % in asthmatic adults in Scottish homes with high Environmental Relative Moldiness Index values, *Clinical and Experimental Allergy*, 45(5): 902-907 https://doi.org/10.1111/cea.12482

R4 **P. Tuohy** (2009) Regulations and robust low-carbon buildings, *Building Research and Information*, 37(4): 433-445, https://doi.org/10.1080/09613210902904254 [REF2 in 2014]

R5 **P. Tuohy**, G. Murphy (2015) Are current design processes and policies delivering comfortable low carbon buildings? **and** Closing the gap in building performance: learning from BIM benchmark industries [consecutive articles], *Architectural Science Review*, 58(1): 39-56 https://doi.org/10.1080/00038628.2014.975779 https://doi.org/10.1080/00038628.2014.975780 [both submitted as REF2]

R6 T. Sharpe, **P. Farren, S. Howieson, P. Tuohy**, J. McQuillan (2015) Occupant interactions and effectiveness of natural ventilation strategies in contemporary new housing in Scotland, UK, *International Journal of Environmental Research and Public Health*, 12(7): 8480-8497 https://doi.org/10.3390/ijerph120708480. [Submitted as REF2] Full research report: T. Sharpe, J. McQuillan, **S. Howieson**, P. Farren, **P. Tuohy** (2014) Research Project To Investigate Occupier Influence On Indoor Air Quality In Dwellings, Scottish Government Technical Report.

Notes on the quality of research: All articles are published in peer-reviewed journals and Howieson's book [**R1**] is widely acclaimed. This research was supported with competitively won funding totalling approximately GBP1,500,000 from the Scottish Government Chief Scientist's Office, Building Standard Division, and various stakeholders including North and South Lanarkshire Local Authorities, Transco, Scottish Power, Energy Action Scotland, Vent-Axia Ltd, British Pre-cast Association and EAGA Charitable Trust.

4. Details of the impact

By advancing understanding of the causes of poor indoor air quality and how to address its effects, Strathclyde research has improved building performance in Scotland and the UK to protect occupant health, save energy and reduce carbon emissions. More specifically, it has:

- Protected occupant health by influencing Scottish common law;
- Shaped UK Government policy and public health advice to reduce COVID-19 transmission; and
- Informed Building Regulations and industry guidance to improve building performance in Scotland and the UK.

Protected occupant health by influencing Scottish common law

As well as shaping professional practice, Howieson's research findings [**R1**, **R2**, **R3**] have prompted public action by raising awareness of the health consequences of poor indoor air quality (with significant UK media coverage between 2001 and 2009 influencing behaviour and laying the foundation for subsequent changes after August 2013). A clear example of this is the surge in legal claims being made by tenants against their landlords in Scotland. As an expert witness, listed on the Scottish Legal Register under housing and energy, dampness, defects and accidents (since 1995), Howieson has applied his expertise to approximately 1,500 cases since 2000 (referrals from over 50 law firms across Scotland) to test and establish the legal responsibility landlords should carry for providing dwellings that have a detrimental impact on occupant health due to mould fungal spore growth, house-dust mite (HDM) infestation, or the sub-standard energy performance that does not allow the tenant to achieve 'thermally safe' indoor temperatures. In support of pursuers claiming health issues due to poor air quality in rental properties, his evidence resulted in several test case wins and multiple out of court settlements that established a legal precedent in common law. Confirming this, the Principal Solicitor and Solicitor Advocate at Conway Accident Law Practice Ltd acknowledges that *'Strathclyde's research on fuel poverty, affordable and dampness free housing, and illnesses associated with damp housing, conducted by Dr Stirling Howieson, has assisted greatly with the prosecution of cases for affected persons claiming both damages and repairs'* [**S1**]. Referring to the *McGuire v Monklands District Council* and *Burns v Monklands District Council* test case wins, he notes that it was *'Howieson's mastery of the issues which effectively ended the previously ubiquitous defence that condensation was the tenant's fault for failure to heat… It is perhaps a testimony to his reputation that these kind of cases now rarely go to trial if defenders know he has been instructed'* [**S1**]. Likewise, affirming that *'Dr Howieson has acted as an independent expert witness for my clients tenants in cases all over Scotland'*, the Principal Solicitor at Lanarkshire Accident Law notes: '*Dr Howieson's opinions, reports and expertise have had a significant impact over the course of 20 years in my client's successfully pursuing housing claims… these clients are typically at the lowest end of the socioeconomic spectrum. They have been assisted by Dr Howieson's knowledge, skills and expertise in facilitating improvement works to their homes, together with obtaining compensation. In other cases, they have been rehoused…His expertise has been instrumental in helping to shape the common law in relation to the obligations of a landlord'* [**S2**].

Shaped UK Government policy and public health advice to reduce COVID-19 transmission

Sharpe's expertise around ventilation and health (recognised as being *'developed through collaborative research undertaken with the University of Strathclyde'*) led to his appointment to the Government's Scientific Advisory Group for Emergencies (SAGE) as part of the Environment and Modelling Group (EMG) in April 2020 [**S3**]. Comprising 14 members, the EMG has developed and assessed the evidence base for the Government's response to the COVD-19 pandemic, particularly around efforts to reduce transmission in buildings. Outlining Sharpe's involvement and the value of the group's work, the UK Government Chief Scientific Adviser notes:

'As a member of the SAGE EMG, Prof. Sharpe attended 25 meetings between April and December 2020 and contributed his research-informed expertise to the production of 27 papers relating to COVID-19 transmission, with specific input into a series of 12 papers that have focussed on the role of the built environment generally and ventilation in particular. These research and analysis papers were considered by SAGE, which drew on the evidence to advise decision makers and support the ongoing government response to coronavirus. Attesting to the value of Prof. Sharpe's input, the EMG paper on the 'Role of ventilation in controlling SARS-CoV-2 transmission' (September 2020) makes specific reference to a building performance and end-user interaction

study undertaken at the University of Strathclyde to support statements about user behaviour and the wider consequences of changes to ventilation. These papers have informed Government policy and public advice and have also been adopted by a range of industry bodies to provide advice to building owners and managers and the public' [**S3**]. Specific examples highlighted are:

- SAGE EMG papers shaped 4 Coronavirus (COVID-19) advice documents issued by the Chartered Institution of Building Service Engineers (CIBSE) to provide evolving guidance for building owners/ managers and businesses to facilitate emergence from lockdown [**S3**]. These were updated multiple times during 2020.
- Principles outlined in 'EMG/SPI-B: Mitigating risks of SARS-CoV-2 transmission associated with household social interactions' (26 November 2020) were published on the government website as a standalone, accessible policy paper on 7 December 2020, with links to the household plans endorsed by SAGE. This informed the UK Government, Scottish Government and Welsh Government joint statement on staying safe at Christmas issued on 16 December 2020 which advised the UK public: 'If you meet indoors, ensure good ventilation by letting in fresh air' [**S3**].
- This paper also underpinned the public information campaign launched by the Department of Health and Social Care on 18 November 2020. A short video on the risks of transmission in housing showing how coronavirus lingers in enclosed spaces and providing advice on how to keep homes ventilated was widely shared on news channels, via social media and as a download on vimeo.com (viewed approximately 13,700 times by the end of 2020) [**S3**].
- The SAGE-EMG/NERVTAG paper on the emerging risk of aerosol transmission was referenced by the Ministry of Housing, Communities and Local Government in response to a House of Lords written question on the adequacy of current building regulations and guidance on provision of artificial and natural ventilation, particularly air exchange rates (UIN HL8966, tabled on 9 October 2020). This indicates the Government's intention to consult on changes to the Building Regulations ventilation standards, including a number of measures to enhance the ventilation provision for non-domestic buildings to mitigate the risk of transmission of infectious agents [**S3**].

Informed Building Regulations and industry guidance to improve building performance

Research at Strathclyde on issues of ventilation and indoor air quality has informed various changes to statutory Building Standards and guidance documents. As detailed below, key contributions since August 2013 include informing the development of Scottish Building Standards, enabling a review of Scottish Government energy standards to reduce carbon dioxide emissions, and changing CIBSE engineering guidelines to reduce humidity levels and promote ventilation use.

Scottish Building Regulations

The research commissioned by the Scottish Government Building Standards Division in December 2013 [**R6**] has been used to inform the development of the Scottish Building regulations since 2014. According to the Head of Building Standards, *'the findings of the occupier influence on indoor air quality research project undertaken by Strathclyde directly informed the revision of the 2015 Building Standards. This included changes to the requirements for background ventilation in dwellings and a requirement for CO_2 sensors to be installed in all new build homes due to the occupier influence on indoor air quality and this requirement was incorporated into the Scottish Government Domestic Technical Handbook which came into force on 1 October 2015. All new housing built since this time has been subject to these regulations (approximately 85,000 new homes built between October 2015 and December 2020). The Strathclyde research report has also been cited and used in the current proposals for amendments to Building Regulations in England and Wales. This also led to further work being commissioned by BSD (Ability of decentralised mechanical ventilation to act as 'whole-house' ventilation systems in new-build dwellings) by Strathclyde, which is also informing the development of new regulations'* [**S4**].

The new clause (3.14.2) on ventilation awareness stipulated that *'CO_2 monitoring equipment should be provided in the apartment expected to be the main or principal bedroom' to 'raise occupant awareness of CO_2 levels (and therefore other pollutants) present in their homes and of the need for them to take proactive measures to increase the ventilation'* [**S5**]. This was accompanied by revised guidance for occupants and has been applied by Local Authorities (LAs) across Scotland, with ongoing advice from the Scottish Government. For instance, in January 2018, the Local Government and Communities Directorate wrote to all LA Building Standards

Managers reiterating the clause and drawing attention to *'CO_2 monitors on the market that do not meet the objectives of the guidance'* to ensure compliance [**S6**].

Scottish Government Energy Standards

By contributing to the 'Low Carbon Building Standards Strategy for Scotland' (2007, with revisions in 2013), Strathclyde research has driven standards and innovation on a wide range of topics, including the delivery of very low carbon buildings in support of climate change objectives. Having undertaken research for the Scottish Building Standards Agency (SBSA) to determine the impact of further limitation of CO2 emissions on the costs of new buildings and on Scottish construction practice [**R4**, **R5**], Tuohy was appointed to the expert panel tasked with advising Scottish Ministers on measures to improve the energy performance of houses and buildings in Scotland and thereby reduce CO2 emissions [**S7a** p.33] As noted on the Scottish Government website, this report *'was integral to recent review of energy standards, both the 2010 standards and the announcement on 2015 energy standards'* [**S8**]. Further recommendations made by the same panel in 2013 [**S7b**] were adopted, leading to the successful implementation of the new standards from October 2015 which enabled the Government to make *'substantial progress in reducing carbon dioxide emissions from both new and existing building stock in Scotland'* [**S8**]. This is apparent in the Committee for Climate Change's 2019 progress report to the Scottish Parliament which highlighted a 4% reduction in emissions from residential buildings between 2016 and 2017 (down to 5.9 $MtCO_2e$), accounting for 15% of total emissions [**S9**, p.67].

CIBSE guidance for building service engineers

As a member of the CIBSE Health Issues Task Group (convened in 2005 to advise on changes and additions to CIBSE Guide A: Environmental Design), Howieson provided key evidence on HDM colonisation and proliferation which led to a significant change in the guidance. On the basis of his housing and asthma research, specifically findings on HDM viability in micro-climates and the link between HDM and increasing asthma rates [**R1**], Howieson successfully argued for a reduction in the recommended relative humidity level from 70% to 60% [**S10** pp.5,12]. This guidance was published as CIBSE TM40: Health issues in building services and incorporated into Guide A which is considered *'the premier reference source for designers of low energy sustainable buildings'* and is used by CIBSE members (approximately 21,000) and other interested parties worldwide [**S10** p.3]. Although both documents have been updated since 2006, the humidity level guidance has not changed and remains a core part of the performance criteria for health and comfort in buildings [**S10b**]. By bringing about this change and shaping industry best practice, Howieson has informed building service design and management throughout the period to date; alongside his legal work, this has contributed to lowering HDM levels and reducing asthma prevalence.

5. Sources to corroborate the impact

S1 Factual statement from Principal Solicitor and Principal Advocate, Conway Accident Law Practice Ltd, dated 23 February 2021.

S2 Factual statement from Principal Solicitor, Lanarkshire Accident Law, dated 11 March 2021.

S3 Factual statement from UK Government Chief Scientific Adviser, Government Office for Science, dated 5 March 2021.

S4 Factual statement from Head of Building Standards, Scottish Government, dated 4 March 2021.

S5 Scottish Government (2015) Domestic Technical Handbook (in force from 1 October 2015).

S6 Scottish Government, Carbon dioxide monitors standard 3.14: letter to local authority verifiers, dated 22 January 2018.

S7 a. Scottish Building Standards Agency (2007) A low carbon building strategy for Scotland: report of a panel appointed by Scottish Ministers chaired by Lynne Sullivan **b.** Scottish Building Standards Division (2013) A low carbon building standards strategy for Scotland: report of a panel appointed by Scottish Ministers chaired by Lynne Sullivan.

S8 Scottish Government website, 'A low carbon building standards strategy for Scotland' [accessed 16 November 2020].

S9 Committee on Climate Change (2019) Reducing emissions in Scotland 2019 Progress Report to Parliament.

S10 a. CIBSE (2006), Guide A: Environmental design. Confirms Howieson's role in the Task Group on p.5, with the relative humidity TM40 guidance on p.12 **b.** Factual statement from CIBSE Technical Manager, dated 23 March 2021. Confirms reference to Howieson's research on domestic ventilation rates, indoor humidity and dust mite allergens in TM40 2006 and 2020.