Institution: The Glasgow School of Art

Unit of Assessment: Sub-panel 32

Title of case study: Improving Indoor Air Quality and Ventilation Standards in UK Housing

Period when the underpinning research was undertaken: Between 2008 and 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:
1. Prof. Colin Porteous	1. Co-Director MEARU/Senior Researcher	1. 1986-2021
2. Prof. Tim Sharpe	2. Director MEARU/Senior Lecturer	2. 1991-2020
3. Dr. Gráinne McGill	3. Researcher	3. 2014-2020
4. Janice Foster	4. Researcher	4. 2013-2021
5. Rosalie Menon	5. Senior Lecturer	5. 2005-2021
6. Dr. Filbert Musau	6. Lecturer/Researcher	6. 2009-2021

Period when the claimed impact occurred: Between 2015 and 2020

Is this case study continued from a case study submitted in 2014? No

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

MEARU's body of research has created new knowledge about indoor air quality, an important element of making the commitment to zero-carbon housing work for everyone, including those living within new dwellings. This body of work has provided the evidence needed to make regulatory changes to building standards in Scotland to improve domestic ventilation, directly improving the indoor air quality of more than 86,450 new dwellings. The research has also informed professional practice, shaping the way both housing associations and architects consider indoor air quality and building performance, increasing employment and turnover, improving indoor air quality for residents and reducing carbon emissions in 5,000 homes through one project alone. Through a deliberate emphasis on sharing the research findings, the team have also engaged and enhanced the understanding of diverse audiences, including policymakers, architects, housing associations, developers, consultants, contractors, manufacturers, engineers and the housing occupants.

2. Underpinning research (indicative maximum 500 words)

As the UK and Scottish governments aim for zero-carbon housing, indoor air quality and its implications for health has become a matter of concern. However, much of the focus in new-build dwellings has been on increasing the levels of air tightness to reduce uncontrolled heat loss, rather than understanding either how people live within those spaces or how their behaviours affect housing performance. Research carried out by the Mackintosh Environmental Architecture Research Unit at the Glasgow School of Art (MEARU) – drawing on its recognised expertise in user-centred, low energy, eco-sensitive architecture research – has created a body of work that sheds new light on indoor air quality and building performance.

From 2008-2011, funded by EPSRC, MEARU research explored the provisions made for domestic laundering – particularly drying – in social housing, in order to understand likely negative environmental impacts, including: higher levels of ventilation with its concomitant energy penalty; high humidity levels and risk of mildew, mould, and large populations of dust mites; and attendant vulnerability to asthma and other respiratory complaints. By analysing data collected through 22 case studies drawn from a wider survey of 100 dwellings, the team found that internal air quality was reduced, caused by an increase in moisture levels, which was likely to boost dust mite populations and concentrations of airborne mould spores, leading to negative impacts on health. [R1; G1]

Building on this research, the MEARU team evaluated the building performance of a range of domestic dwellings across a number of projects, including: comparing social rented homes

with owner-occupied homes; two prototype low energy dwellings built for Glasgow Housing Association; five Certified Passive House homes in Scotland; and, between 2011 and 2014, IAQ research, monitoring and analysis in 7 developments in Innovate UK's Building Performance Evaluation (BPE) programme, culminating in a meta-study providing an overview of the performance and use of whole-house heat recovery ventilation (MVHR) systems in domestic projects. The research combined performance analysis with 'user' experience, generating a large, rigorous evidence base which underpins MEARU's expertise on indoor air quality, ventilation and methodologies for monitoring and analysis. [R2,3]

This research formed the basis for two further important pieces of research. The first, 'Building Tight – Ventilating Right?', measured CO_2 concentrations (a common proxy for indoor air quality) in occupied bedrooms across a range of recently completed dwellings, as well as volatile organic compounds and fine particle pollution. While acceptable levels of CO_2 range between 750ppm ('freshness') to 1,500ppm for limited periods, GSA researchers found concentrations in occupied bedrooms were at unacceptable levels (occupied mean peak of 2317ppm and a time weighted average of 1834ppm, ranging from 480ppm to 4800ppm). Findings confirmed that airtight dwellings with only trickle ventilators as the ventilation strategy did not meet the standards demanded by the Buildings (Scotland) Regulations 2004, largely because occupant behaviours were not taken into account. Lack of planned and effective ventilation strategies are likely to result in a more toxic and hazardous indoor environment, with the potential for significant negative long-term health impacts. [R4]

The second, connected piece of research (carried out for the Scottish Government in 2014 and won through a public procurement process in collaboration with the University of Strathclyde) gathered information about occupant use of natural ventilation and its relation to indoor air quality by investigating: a) the frequency that dwelling occupants open and close trickle ventilators in the normal course of their daily lives; and b) the triggers for doing so. The project combined a literature review, survey (200 homes), sample monitoring of ventilation, temperature, humidity and CO_2 (subset of 40 homes) and detailed monitoring (drawing on MEARU building performance evaluation research), in order to understand the ventilation habits of dwelling occupants in Scotland. The findings revealed a consistent picture of the relative lack of trickle vent use, coupled with a lack of information for occupants on the benefits of ventilation, pointing towards the need for revisions both in building regulations and guidance. For example, the research found that occupants had very little interaction with background ventilation, and fewer than 20% had received advice about it. While more than 80% thought internal air quality was good, measured data indicated that it was in fact poor, even when available background ventilation was being used. Recommendations for minimal revisions identified by the research included: improving performance and specification of trickle vents to promote better performance and use; monitoring and indicators for CO_2 and pollutants; encouraging the use of decentralised mechanical ventilation with the requirement for undercuts or pass vents; and improving and increasing compliance testing of ventilation provision. [R5]

Between 2015 and 2017, MEARU worked with John Gilbert Architects on a Knowledge Transfer Partnership, 'Hab-Lab,' exploring ways in which the performance of housing could be improved. The team examined 20 on-site monitored flats and the retrofit of 48 properties, finding that new energy efficiency standards did benefit occupants by reducing heating costs and increasing thermal comfort, but also had a number of unintended consequences, including poor air quality. [G2] MEARU also undertook two KTPs with Cartwright Pickard Architects, the first of which (2012-2015) specifically related to air quality and the performance of ventilation systems in energy-efficient houses built by 5 registered social landlords in London. Research findings revealed significant gaps between the designed and actual dwelling performance, both in terms of energy use and environmental performance, with indoor air quality a particular concern. [G3]

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

R1. C. D. A. Porteous, T. R. Sharpe, R. Menon et al (2014) 'Domestic Laundering: Environmental audit in Glasgow with emphasis on passive indoor drying and air quality.' *Indoor and Built Environment*, 23 (3), pp. 373-392. ISSN 1423-0070. [Journal article]

R2. T. Sharpe, J. Foster and L. McElroy. (2014) *Building Performance Evaluation, Final Report, Domestic Buildings, Phase 2: In-use performance and post occupancy evaluation, Scotland's Housing Expo.* Technology Strategy Board, 450073, pp. 134-139. [Research report]

R3. J. Foster, T. Sharpe, A. Poston, C. Morgan and F. Musau. (2016) 'Scottish Passive House: Insights into Environmental Conditions in Monitored Passive Houses.' *Sustainability*, 8 (5). Article 412. ISSN 2071-1050. [Journal article]

R4. S. G. Howieson, T. Sharpe and P. Farren. (2014) 'Building tight – ventilating right? How are new air tightness standards affecting indoor air quality in dwellings?' *Building Services Engineering Research and Technology*, 35 (5). pp. 475-487. ISSN 0143-6244. [Journal article]

R5. T. Sharpe, P. Farren, S. Howieson, P. Tuohy and 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). pp. 8480-8497. ISSN 1660-4601. [Journal article]

R6. T. Sharpe, J. McQuillan, S. Howieson, P. Farren and P. Tuohy. (2014) *Research Project to Investigate Occupier Influence on Indoor Air Quality in Dwellings*. Building Standards Division, Livingston, The Scottish Government. A8460492. [Research report]

Selected Grant Funding

G1. Colin Porteous, 'Environmental Assessment of Domestic Laundering (EP/G00028X/1)' EPSRC, December 2008 - November 2011, GBP438,902.

G2. Prof Tim Sharpe with John Gilbert Architects Ltd (KTP), KTP No. 9734: 'To develop knowledge of the performance of retrofit measures to buildings, develop a capability to undertake building performance evaluation in the energy and environmental refurbishment of existing housing and relate this to architectural design', InnovateUK and Scottish Funding Council, May 2015 - October 2017, GBP113,085.

G3. Prof Tim Sharpe with Cartwright Pickard Architects Limited (KTP), KTP No. 8869: 'To develop and embed the capability to undertake detailed performance evaluation in sustainable, low energy housing and utilise findings to influence future architectural design,' Innovate UK, October 2012 - January 2015, GBP96,995

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

MEARU's body of work since REF2014 has focused on indoor air quality and systems of ventilation in energy-efficient housing, with positive impacts resulting for all those concerned with its procurement, management and maintenance, as well as on the health and wellbeing of residents. The subheadings below capture key areas of impact.

Creating an evidence base to underpin regulatory changes to Building Standards in Scotland

MEARU research on the ventilation habits of dwelling occupants in Scotland was used as the underpinning evidence for regulatory changes in Scottish building standards for domestic ventilation. Research findings directly influenced 2015 updates to the Technical Handbooks and Guidance, which specify how to achieve the requirements of the Buildings (Scotland) Regulations 2004. Specific changes that resulted from the GSA findings include: 'Ventilation Awareness in Dwellings,' which stipulated the provision of CO_2 monitoring equipment in principal bedrooms, plus guidance on its use as part of a ventilation strategy; and enhanced specifications for trickle vent efficiency to promote improved airflow. The Building Standards apply to newly constructed, airtight dwellings in Scotland; 86,450 such dwellings were

completed between Q4 2015 and Q1 2020. Stephen Garvin, Head of Building Standards Division, confirms that the GSA research 'has resulted in improved ventilation capacity in those buildings, and (we predict) improved awareness of and interaction with ventilation components by occupants, contributing to better air quality, and health and wellbeing.' The MEARU team was commissioned as a result of this research to undertake a second study exploring the performative shortcomings of decentralized mechanical extract ventilation and findings from this research are currently being used to inform new BSD policy. [S1, S2]

Influencing professional practice, in housing associations and architectural firms
Through their collaborative approach to research into low energy design, health and wellbeing, MEARU has developed multiple relationships with housing providers and architects (including grant funded collaborations with 9 architecture practices and 10 housing associations/ developers, 2014-20), supporting upskilling, increased economic competitiveness and improved environmental standard of buildings. The 2015 'Hab-Lab' Knowledge Transfer Partnership with Glasgow-based John Gilbert Architects has resulted in a 20% increase in practice turnover, the direct employment of 3 new staff members, and significant reduction in carbon emissions from around 5,000 homes. The partnership has also enabled the development of new expertise within the firm, improving the delivery of new build projects, with the research directly contributing to the development of technical guidance and policy. Testimony from a Director of John Gilbert Architects confirms the relationship enabled the whole practice's design work to become more 'evidence-led': 'It is clear that the work we have undertaken with Glasgow School of Art and MEARU has been a key catalyst to this change and has affected all our staff. In short, the impact of MEARU has been significant on our practice and on our architecture over the last 5 years.' [S3]

Collaboration with Gannochy Trust and ABC architects (2016-2019, funded by Construction Scotland Innovation Centre) drew directly on MEARU's Innovate UK BPE projects to inform the design of 48 new healthy homes, including application of a novel, combined BPE and computational modelling process to inform design choices and bespoke specification by GSA for an innovative passive stack ventilation system to safely maintain healthy air quality, air flow and temperature, including in bedrooms. The completed homes, incorporating these design improvements, won the Large Residential and Sustainability Award at the GIA Design Awards 2020, and have been "life changing" for tenants. [S4] BPE research with Queens Cross Housing Association (completed 2015) has directly influenced organisational policies and practice, particularly in the areas of air quality, system performance and new resources to help inform residents about the importance of good ventilation. The 'Ventilate Right' video created by the MEARU team (with investment of GSA QR funds) has been distributed to residents by Queens Cross Housing Association and made publicly available, with over 3,000 views to date. [S5] MEARU research has also been used in a RIAS Practice Note on indoor air quality and ventilation in airtight homes, disseminated to approximately 480 architecture practices in Scotland. [S6]

Enhancing understanding of the importance of indoor air quality

Policy makers:
MEARU's research has enhanced the understanding of policy makers, influencing and informing the 2018 White Paper created by the UK-wide All-Party Parliamentary Group for Healthy Homes and Buildings, *Building our Future*, which reflects MEARU's research findings in its recommendations. MEARU researchers presented evidence to the All-Party Parliamentary Group on two occasions (2016 and 2017, invited through the HEMAC network – see 'professionals,' below) and shared their research at a Scottish Government 'Evidence in Policy' event in November 2019. [S7] On the basis of his research with MEARU, Sharpe sits on the Building Regulations Advisory Committee for Ventilation and Airtightness and the British Standards Institute (BSI) retrofit working group. He was an invited member of the Scottish Government Energy Efficiency Standard for Social Housing (EESSH) Review group in 2017. Sharpe sat on the Royal College of Physicians and Royal College of Paediatrics and Child Health working group on 'The effects of Indoor Air on Children's Health across Life-

course,' co-authoring the final report. He also acted as a topic expert on the National Institute for Clinical Excellence (NICE) Public Health Advisory Committee on Indoor Air Quality Guidelines. Both resulting reports, published in early 2020, have raised awareness of air quality within housing, receiving widespread coverage in mainstream and trade media. Since April 2020, Sharpe (at Strathclyde from February 2020) has advised UK Government on its Covid-19 response through his involvement in SAGE (Environmental and Modelling Group), drawing on the research he carried out over many years at GSA and contributing to 27 papers, 12 on built environment and ventilation. These papers have informed Government policy and public advice and have been adopted by industry bodies to provide advice to building owners and managers and the public. For example, CIBSE issued four Coronavirus (Covid-19) advice documents influenced by the SAGE group during 2020. [S8]

Professionals:
MEARU's broader dissemination of research through engagement with architects and construction industry professionals has also helped to enhance industry understanding and awareness of indoor air quality and the performance of energy efficient dwellings. This has included articles in trade magazines – including *The Architects' Journal* (7,000 paid subscribers), *Scottish Construction Now*, *CIBSE journal*, *PassiveHouse+* (print circulation 17,000) and the *REHVA journal* (distributed to 120,000 engineers from 27 European countries) – and through trade show presentations (e.g. EcoBuild, ASBP Expo, Vision London, RIBA Guerrilla Tactics event, Zero Carbon Hub and Better Homes Dublin). MEARU also contributes to industry committees, including the NHBC, an organisation providing warranty and insurance for new homes. [S9] MEARU furthered its reach by establishing the AHRC-funded Health Effects of Modern Airtight Construction (HEMAC) international multidisciplinary network in 2016, which combines built environment, indoor air quality and medical fields to support the design of healthy low energy homes. A third of the steering group and over half of the network are made up of non-academic professionals, including architects, sensor and ventilation product manufacturers and building professionals.

General public:
MEARU's work has also improved public awareness of indoor air quality and health in UK homes, through widespread coverage in the media. Sharpe discussed the issues and challenges on BBC Breakfast in April 2016, with additional coverage on BBC news and in other news media, including the *Belfast Telegraph* and *The Scotsman*. Outcomes from MEARU's contribution to public health guidelines have also received media attention. [S10]

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

S1. Testimony from Head of Building Standards Division, Local Government and Communities Directorate, Scottish Government, corroborating changes to statutory ventilation standards in response to underpinning research.
S2. Evidence of changes to building standards in Scotland, the number of new homes affected, and research undertaken by MEARU for Building Standards Division
S3. Testimony from John Gilbert Architects, demonstrating impact of participation in KTP project with MEARU.
S4. Testimony from Gannochy Trust, and summary of CSIC-sponsored project.
S5. Testimonial from Queen's Cross Housing Association, and details of 'Ventilate Right' instructional film promoted to their tenants.
S6. Royal Institution of Architects in Scotland (RIAS) practice note on IAQ and ventilation co-authored by McGill, circulated to c. 480 architecture practices.
S7. Evidence of MEARU's (Sharpe, McGill) contribution to All Party Parliamentary Group for Healthy Homes and Buildings.
S8. Evidence of Sharpe's contribution to NICE, Royal College of Paediatrics and Child Health, Royal college of Physicians, SAGE working groups and expert panels.
S9. Evidence of MEARU enhancing professional understanding of IAQ and ventilation issues via trade press.
S10. Evidence of MEARU enhancing public understanding of IAQ via BBC coverage.