# Health Effects of Modern Airtight Construction

HEMAC Multidisciplinary Network

MACKINTOSH ENVIRONMENTAL ARCHITECTURE RESEARCH UNIT THE GLASGOW SCHOOL OF ART

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# Health Effects of Modern Airtight Construction

Summary Report

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Dr Gráinne McGill

The Mackintosh Environmental Architecture Research Unit
The Glasgow School of Art

Prof Tim Sharpe
The Mackintosh Environmental Architecture Research Unit
The Glasgow School of Art

Prof Graham Devereux
The Institute of Applied Health Sciences
The University of Aberdeen

Dr Steve Turner
The Institute of Applied Health Sciences
The University of Aberdeen

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Steering Group

Dr Miriam Byrne, School of Physics, NUI Galway
Prof Tom Woolley, Rachel Bevan Architects, Co. Down
Prof Sue Roaf, School of the Built Environment, Heriot-Watt University
Stefan Huber, Paul Heat Recovery Ventilation
Paul Farren, Assist Architects
Prof Jan Sundell, Tsinghua University
Dr James McGrath, School of Physics, NUI Galway
Prof Pawel Wargocki, Technical University of Denmark
Ian Mawditt, Fourwalls Consultants Limited
Jonathan McQuillan, Anderson Bell and Christie
Dr Steve Turner, Respiratory Group, Aberdeen University
Dr Nia White, Head of Graduate School, Abertay University
Dr Damian Downey, Northern Ireland Regional Adult Cystic Fibrosis Centre
Rachel Beven, Rachel Beven Architects, Co. Down
Prof Graham Devereux, Respiratory Group, University of Aberdeen
Dr Peter Keig, Smart-Vent Ltd
Dr Stirling Howieson, Engineering Institute, University of Strathclyde
Dr Gráinne McGill, MEARU, Glasgow School of Art
Dr Sean Semple, Respiratory Group, University of Aberdeen
Prof Tim Sharpe, MEARU, Glasgow School of Art
Prof John Moore, Bacteriology Department, Belfast City Hospital
Dr Paul Tuohy Engineering Institute, University of Strathclyde
Dr Atze Boerstra, BBA Binnenmileu BV, The Netherlands
Prof Jelle Laverge, Faculty of Engineering & Architecture, Gent University
Prof Hugo Hens, Department of Civil Engineering, KU Leuven
Chris Morgan, John Gilbert Architects, Glasgow
Dr Sani Dimitroulopoulou, Public Health England
Prof Rajat Gupta, Oxford Brookes University
Prof Cath Noakes, University of Leeds
Dr Michael Swainson, Building Research Establishment, Watford
Prof Anthony Seaton, Emeritus Professor, University of Aberdeen
Tim Beuker, BBA Binnenmileu BV, The Netherlands
Jack Harvie-Clark, Apex Acoustics
Prof David Waddington, Salford University
Prof Raymond Agius, Manchester University
Dr Catherine Lawrence, Strathclyde University
Lynne Sullivan, SustainableByDesign

# Executive summary

The HEMAC network (Health Effects of Modern Airtight Construction) was established to bring together researchers and practitioners from the fields of indoor air quality (IAQ), health and the built environment to identify shared research agendas and develop research questions and activity. The network has a particular focus on challenges concerning IAQ in new-build and/or retrofitted airtight dwellings.

The HEMAC network is made up of a steering committee of researchers and practitioners from medicine, indoor air science, microbiology, engineering, architecture and ventilation; including participants from the UK, Ireland, the Netherlands, Denmark, Belgium and China.

The network was established through funding received from the Arts and Humanities Research Council (AH/N006607/1) which supported a series of initial events, including a symposium (September 2016), a workshop (November 2016) and a sandpit (April 2017), all held at the Glasgow School of Art, Scotland.

The symposium provided a platform to bring participants together, to present recent findings and put forward ideas regarding gaps in the knowledge and possible research questions, which were deliberated during a discussion session at the end of the day. This was followed by an online survey, which collated opinions of symposium participants concerning key problems and challenges in the field.

This information, together with the outcomes of the symposium, was used to develop a series of workshop sessions to discuss the state of knowledge in the field and stimulate ideas for multidisciplinary projects, to address the challenges of designing healthy, energy efficient homes. Nine workshop sessions were held throughout the day, which culminated with a sequence of presentation pitches from the groups on proposed multidisciplinary projects, to an audience of invited participants.

The purpose of the sandpit event was to take these ideas further and develop them as funding proposals for collaborative projects. Six proposals were developed in total and are currently in development as multidisciplinary projects. Three multidisciplinary grant proposals have already been submitted to UK research councils following the workshop event in November, one of which has successfully received funding. It is hoped that the outcomes of these events will lead to large-scale multidisciplinary UK projects or initiatives to improve IAQ and ventilation provision in contemporary dwellings.

# Contents

# Background

Awareness of the impacts of climate change, rising energy prices, fuel poverty and a demand for energy security have prompted significant changes in design thinking, construction practice, building materials and building legislation aimed at reducing energy use and carbon dioxide emissions. A particular example of this is the fabric first approach and increasing requirements for air-tightness in housing. Whilst this achieves a primary objective of reducing heat loss through ventilation, it is not clear if the requirements for healthy ventilation have kept pace and there is emerging evidence of poor indoor air quality and inadequate ventilation. Poor ventilation in buildings has been linked to a multitude of public health issues, particularly for conditions such as asthma and COPD that are all known to be exacerbated by poor air quality.

However, it is clear that firstly, this is an under researched area, and secondly, a multidisciplinary approach is needed to investigate issues of health in the built environment. Our goal is to bring public health and building professionals together with architects and their clients to identify shared research questions and develop ways of addressing these issues, with an overall aim of supporting the design of healthy, low energy homes. Despite shared interests between the built environment, environmental health and medical research communities, they are generally not well connected. The network therefore aims to bridge the gap between these complementary fields, providing a platform for discussion and collaboration while facilitating knowledge exchange to the built environment industries, such as housing associations and architects.

# Aims and Objectives

1

To identify the current context for low energy design from a design perspective and to map out the research context concerning indoor environmental quality, health and well-being

Whilst the development of low energy approaches to housing is now well-established, led in part by design, but more generally by legislation, it is becoming increasingly evident that despite their underlying responsibilities and ability to directly affect the quality of the indoor environment through the physical design of buildings there is a lack of involvement from the architectural profession regarding issues of health and well-being (particularly indoor air quality). Given that it is estimated that only 10% of health factors are due to medical interventions (the remaining 90% are due to social and environmental factors), the research network aims to establish architecture at the forefront of emerging research in this area, and encourage collaborations that incorporate design perspectives, to achieve practical design solutions that can improve occupants' health and well-being. There is a strong case for knowledge translation between indoor sciences and building designers, which requires deep-rooted, well-established connections between the various academic and professional disciplines, which can only be achieved through an intensive, multi-disciplinary networking scheme.

2

To establish an inclusive and active network to identify existing research areas and expertise, areas of overlap and common purpose, and shared gaps in knowledge; and to promote dialogue between the various disciplines and stakeholders

Given the impending (and often conflicting) challenges of meeting carbon targets set out by the Climate Change Act (2008), whilst at the same time improving the quality of the indoor environment to promote occupant health and well-being; there is a critical need to establish a network that enables dialogue between the design, medical and scientific communities. Researchers and practitioners are prompted to step outside of their respective disciplines and engage in multidisciplinary debate, in an informal, creative environment. It is hoped that the network will help to build lasting relationships between participants and establish the foundations for future cross- disciplinary collaboration.

3

To establish well-founded, tangible project ideas, with the aim of developing these as grant applications

Through sustained engagement and intellectual discussions, the network aims to identify shared agendas and key research opportunities, and to develop these as tangible cross-disciplinary funding applications. It is envisaged that the research network will generate a number of shared outputs, funding applications and research grants, which will help to advance knowledge in the field.

4

Develop an online platform to facilitate and promote sustained communication, and a knowledge base to be shared between the research domains and industry partners

The online platform was developed to promote and support networking activities, to disseminate results and to act as a database and resource for knowledge and outputs. The platform also facilitates the sharing of findings with international researchers and industry professionals, and helps to sustain communication between network members.

# Committee

| | |
|---|---|
| Dr Miriam Byrne | School of Physics, NUI Galway |
| Prof Tom Woolley | Rachel Bevan Architects, Co. Down |
| Prof Sue Roaf | School of the Built Environment, Heriot-Watt University |
| Stefan Huber | Paul Heat Recovery Ventilation |
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| Dr Sani Dimitroulopoulou | Public Health England |
| Prof Rajat Gupta | Oxford Brookes University |
| Prof Cath Noakes | University of Leeds |
| Dr Michael Swainson | Building Research Establishment, Watford |
| Prof Anthony Seaton | Emeritus Professor, University of Aberdeen |

# Event 1: Symposium

The symposium brought together a cross-disciplinary group of 89 participants from the fields of health, architecture, engineering and environmental design. The event which took place on 21st September 2016 provided a platform for participants to present their latest research findings and knowledge concerning indoor air quality and ventilation in modern airtight homes. Presentations from health, engineering, ventilation, indoor air sciences and architecture communities provided a summary of recent evidence in the field and identified key priorities for research on the Health Effects of Modern Airtight Housing.

It was agreed at the previous steering group meeting that whilst the network may be informed by existing knowledge of schools and offices etc. or by studies of ambient air quality, the focus should be on housing given that total exposure to air pollution is greatest in the home environment.

Presenters were asked to consider:

- What is known, i.e. key problems and challenges related to their specific area of expertise
- What are the current gaps in knowledge? What don't we know? What do we need to know? What is the research question?
- What are the solutions? How do we move forward?

The aim of the day was to establish and refine areas for future research. Prior to the event, a list of key research questions were identified by the committee, to form part of the discussion at the symposium. These questions were presented on a series of A1 posters in the breakout spaces. During the lunch break, participants were asked to identify which questions they believed were most important and which they would like to contribute to. Participants were also given the opportunity to add to the list of key research questions. The outcomes are presented in Table 1.

To collate ideas and feedback to inform future events, a survey was distributed to symposium participants via SurveyMonkey after the event. Responses were received from 30 participants.

Survey questions included the following:

- Overall, how satisfied were you with the symposium event?
- What topics would you most like to learn about or discuss at the follow-up workshop event?
- What outcomes would you like to see from the HEMAC network?
- Who else should be involved in the network?
- Do you have any other comments about the symposium or the HEMAC network?

## Symposium Programme

| | |
|---|---|
| 10:00 | Registration, tea/coffee |
| 10:30 | **Tom Inns**, *Director of the Glasgow School of Art*<br>Welcome |
| 10:35 | **Tim Sharpe**, *Mackintosh Environmental Architecture Research Unit*<br>Welcome and introduction to the network |
| 10:50 | **Anthony Seaton**, *University of Aberdeen*<br>The air and how the body reacts to it |
| 11:20 | **Raymond Agius**, *University of Manchester*<br>Ill-health related to air contaminants |
| 11:50 | Tea and coffee break |
| 12:20 | **Ian Mawditt**, *Director of Fourwalls, Bristol*<br>The state of ventilation in the UK |
| 12:40 | **Sani Dimitroulopoulou**, *UKIEG and Public Health England*<br>Healthy indoor environments: Challenges for Policymakers |
| 13:00 | Lunch break |
| 14:00 | **Mich Swainson**, *BRE, Watford*<br>Observed effects of poor ventilation in modern homes |
| 14:20 | **Atze Boerstra**, *Director of BBA Binnenmilieu, The Netherlands*<br>Residential ventilation, health, comfort and control: the NL experience |
| 14:40 | **Pawel Wargocki**, *Technical University of Denmark*<br>Links between Ventilation and Health |
| 15:10 | Tea and coffee break |
| 15:40 | **Jan Sundell**, *Tsinghua University Beijing*<br>Ventilation in homes and health |
| 16:10 | **Lynne Sullivan**<br>What do designers need to know? |
| 16:30 | **Discussion** |
| 17:00 | Close |

## Speakers

**Prof Tim Sharpe**

A graduate of Dundee and Strathclyde Universities, Professor Sharpe is an architect with both practice and research experience in a number of fields, including user participation, environmental architecture and low energy design. He co-founded and now directs the Mackintosh Environmental Architecture Research Unit. MEARU was established in 1986 within the Mackintosh School of Architecture and undertakes strategic and applied research into a wide range of aspects of sustainable environmental design, responding to a growing commitment to user-centred, low energy, eco-sensitive architecture in the context of increasing global concerns. Recent work has led to the significant expansion of MEARU, widening its portfolio of expertise to include: health and wellbeing in buildings; indoor air quality; energy efficient refurbishment; and building performance evaluation. Funded projects include building performance evaluation of a range of low energy houses across the UK, and research into ventilation, health and well-being in housing, including work for the Building Standards Directorate. He is an expert evaluator on the Innovate UK Building Performance Evaluation Programme, chair of the NHBC Scottish Technical Committee and member of the national Standards committee and is an expert witness for dampness and construction cases.

**Prof Anthony Seaton**

Professor Seaton qualified from Cambridge University in 1962 and trained as a junior doctor in Liverpool. After senior posts in respiratory medicine in West Virginia, USA, and Cardiff, he was director of the Institute of Occupational Medicine in Edinburgh from 1978-90. He edited Thorax from 1977-81. From 1988 until he retired in 2003 he was head of the department of Environmental and Occupational Medicine in Aberdeen University. Since retiring, he is emeritus professor at Aberdeen and has rejoined the Institute of Occupational Medicine as an honorary senior consultant. He has published seven books and over 300 papers on respiratory and occupational medicine and other topics. He chaired the UK Government's Expert Panel on Air Quality Standards (EPAQS) and was on the Royal Society's Working Group on nanotechnology. His research interests have been in environmental effects on health, particularly dust and chronic lung disease, air pollution and the heart, diet and the early causation of asthma, and chemicals and chronic neurological disease.

**Prof Raymond Agius**

Raymond Agius is a Professor of Occupational and Environmental Medicine and Director of the Centre for Occupational and Environmental Health at the University of Manchester. He is also an honorary consultant in two Manchester University Hospital NHS Trusts. His previous workplaces included the Department of Community Medicine at the University of Edinburgh and the Institute of Occupational Medicine. His research interests encompass occupational and environmental ill health ranging from cardio-respiratory disease to psychological stress. He has conducted epidemiologic studies on air pollution in Scotland and elsewhere, as well as in methods of predicting and preventing novel respiratory hazards. He is a Fellow of the Royal Colleges of Physicians of London and of Edinburgh, a Fellow of the Faculty of Occupational Medicine of the Royal College of Physicians of London and an Honorary a Fellow of the Faculty of Occupational Medicine of the Royal College of Physicians of Ireland. He is a Past President of the British Occupational Hygiene Society.

**Ian Mawditt**

Ian is a building researcher, specialising in the field of energy performance and occupant comfort. He is the founding director of Four Walls – an independent building performance and research consultancy based in Bristol. The company specialises in post-construction testing and evaluation; in-use studies of building performance, including energy use analysis, indoor air quality investigations, ventilation effectiveness; and occupant satisfaction studies. Ian's work and field experience help to provide an evidence base for informing building performance standards. He was part of the technical team that supports DCLG in the development of amendments to Part F and Part L of the Building Regulations. He was recently engaged by Innovate UK as an expert evaluator under the Building Performance Evaluation programme, and provided technical guidance for the Retrofit for the Future programme. Ian has also worked with organisations such as the Zero Carbon Hub, the Sustainable and Traditional Buildings Alliance, and the NHBC Foundation supplying strategic and technical support to their research programmes.

**Dr Sani Dimitroulopoulou**

Dr Sani Dimitroulopoulou is a Senior Environmental Scientist within the Air Pollution and Climate Change Group, Environmental Change Department in Public Health England. She is also an Honorary Senior Lecturer at the UCL Bartlett School Environment, Energy and Resources. Her research interests include air pollution related effects on health, exposure assessment to air pollution, based on modelling and monitoring of outdoor and indoor air pollution and ventilation, health impact assessments and development of environmental public health indicators. She has over twenty year experience developed through her PhD at Imperial College, her work at Imperial College and Building Research Establishment in the UK, as well as at the National Centre for Environment and Sustainable Development (Greek Environment Agency) and the University of West Macedonia in Greece. She has published more than 60 peer-reviewed papers in international scientific journals and conferences and more than 50 technical research and consulting reports. She is a member of the Scientific Secretariat for COMEAP (Committee on the Medical Effects of Air Pollutants), Member of the Cross Government Group on Gas Safety and Carbon Monoxide, the Secretary of the UK Indoor Environments Group (UKIEG) and Member of the Executive Committee of MESAEP (Mediterranean Scientific Association of Environmental Protection).

**Dr Michael Swainson**

Michael Swainson is principal engineer in BRE's HVAC Engineering and Building Diagnostics team. He has over 20 years' experience designing and undertaking practical investigations into the performance of heating, ventilation and air conditioning systems within buildings, both laboratory based and on site. Michael is largely responsible for implementation of SAP Appendix Q for ventilation products and heat pumps. He was technical author of the; Installation Guidelines for systems 3 and 4 for the Domestic Ventilation Compliance Guide, supporting documentation to AD-F, NF46, Overheating in new homes, and ZCH Solutions to overheating in homes, Evidence review. his is currently testing MVHRs for PHI listing.

**Dr Atze Boerstra**

Dr. Atze Boerstra is founder and managing director of BBA Indoor Environmental Consultancy, a consultancy company specialised in indoor air quality and thermal comfort based in The Hague. He is a fellow at the Eindhoven University of Technology, REHVA fellow and honorary member of the Dutch chapter of ISIAQ (International Society of Indoor Air Quality and Climate). Atze was recently elected as vice-president of REHVA.

**Prof Pawel Wargocki**

Assoc. Prof Pawel Wargocki graduated from Warsaw University of Technology with honours in 1990. He received his PhD from the Technical University of Denmark in 1998, where he has been teaching and performing research ever since. He has more than 20 years of experience in research on human requirements in indoor environments. He is internationally known for his seminal work demonstrating that poor indoor environmental quality affects performance of office work and learning. Other work influenced requirements for ventilation and air cleaning. Recent research includes studies on emissions from humans including effects of exposure to CO2, on sleep quality and on performance of green buildings. He has collaborated with leading research institutions, universities, and industrial partners around the world such as National University of Singapore, Jiao Tong University in Shanghai, Syracuse Center of Excellence, United Technologies and Google. He was President and is a long-standing board member of the International Society of Indoor Air Quality and Climate (ISIAQ), Vice President of Indoor Air 2008, and Chair of ASHRAE committees. Currently he is the member of ASHRAE's Research Administration Committee. He has received several awards for his work including Rockwool Award for Young Researchers, ASHRAE Ralph Nevins Award, ISIAQ's Yaglou Award and Best Paper Award in Indoor Air. He is the Secretary of Academy of Indoor Air Sciences. Published intensively.

**Prof Jan Sundell**

Jan Sundell is a Swedish multidisciplinary scientist, with a Master's degree in HVAC engineering from Royal Inst. of Technology, 1969, and a MD degree in environmental medicine from Karolinska Inst (1994). He has been involved in several governmental inquiries, about allergies, and environmental health. He has worked for NKB (the Nordic countries), WHO, and EU about ventilation and health. JS has been professor at the Technical University of Denmark, UT Tyler and now at Tsinghua University and Chongqing University, China. He has led a multitude of multidisciplinary scientific reviews, on indoor air and ventilation, VOCs and health, indoor pets and health, indoor particles and health, but also on breastfeeding and allergies. His primary research focuses is on human exposure to air pollutants and health. He has initialized several large epidemiological studies to examine children's exposure to indoor air pollutants and associated adverse health effects, in Sweden, Bulgaria, Denmark, Texas, South Korea, Taiwan, Singapore and China. His research has resulted in 200 peer-reviewed scientific articles. JS was Editor-in-chief of Indoor Air Journal from 2000-2010 and a founding member of the International Society of indoor Air Quality and climate (ISIAQ) and of the International Academy of Indoor Air Sciences (President 2005-2008). Many scientific Awards, including the highest award in indoor air sciences, "The Pettenkofer Award" 2011.

**Lynne Sullivan**

Lynne Sullivan is a practising Architect and was founding Partner of sustainableBYdesign, finalists in all three 2010-2012 BRE UK Passivhaus Housing Competitions, specialising in low-energy new and retrofit projects in a range of sectors, including a European funded demonstration project at Thamesmead to Passivhaus Enerphit standard. Previously Lynne was Sustainability Director for 9 years at Broadway Malyan, and for 10 years Associate Director at ECD Architects, where she was co-author and winner of the UKs first government-sponsored Zero CO2 housing competition. Lynne now acts as a design consultant and collaborator, sits on local and national design review panels, and has authored and chairs a number of policy review and research projects for UK governments and others, including the Expert Panel for the Scottish Government whose report "A Low Carbon Building Standards Strategy for Scotland", first published in 2007, was updated in 2013. She was awarded an OBE for services to Architecture in 2011, chairs the Good Homes Alliance, and is a member of the UK Government's Green Construction Board.

Table 1. Summary of research priorities identified

<table>
<tr><th colspan="4">Health Issues</th></tr>
<tr><td colspan="4">
<ul>
<li>Does ventilation lead to ill-health in housing? If so, what is the interval between exposure and ill-health?</li>
<li>What are the significant factors? Pollution? Moisture? Temperature? Comfort (does this matter)?</li>
<li>How can poor health be measured and defined?</li>
<li>What are the costs of health impacts?</li>
<li>How to link IAQ with health effects using predictive (processed based) models</li>
</ul>
</td></tr>
<tr><th>Pollution</th><th>Moisture</th><th>Temperature</th><th>Comfort</th></tr>
<tr>
<td>
<ul>
<li>What are the most significant sources of pollution in homes & what health effects do these lead to?</li>
<li>Is source control or removal through ventilation better?</li>
<li>What is known about source control in building materials and how can this knowledge be made available to construction professionals?</li>
<li>What is the potential exposure to VOCs and HCHO from consumer products and activities?</li>
<li>What concentrations of indoor air pollutants are typically found in new-build airtight homes and how does this compare to older, draughtier homes?</li>
<li>Does airtightness and controlled environments protect against external pollutants?</li>
</ul>
</td>
<td>
<ul>
<li>How does moisture in buildings affect health?</li>
<li>What are high / low moisture levels?</li>
<li>What health problems do they cause?</li>
<li>What are the potential implications of entropy/ humidity recovery heat exchangers with regards to indoor moisture?</li>
<li>How might decarbonisation strategies impact on hygrothermal properties of building fabric and what are the potential implications of this?</li>
<li>What is the causal link between mould and health?</li>
<li>What evidence is available on the performance of hygroscopic and moisture buffering materials? Can these materials reduce demands on ventilation systems?</li>
</ul>
</td>
<td>
<ul>
<li>What are the health impacts of overheating? This includes physiological health, obesity, and related effects, for example, from off-gassing</li>
<li>Are the benefits of warmer homes outweighed by poor ventilation and increased pollution emissions from higher indoor temperatures?</li>
</ul>
</td>
<td>
<ul>
<li>How significant is occupant behaviour on IAQ and how can behaviour be influenced effectively?</li>
<li>What is the relationship between ventilation performance, IAQ and health status among more vulnerable groups, such as respiratory patients?</li>
</ul>
</td>
</tr>
</table>

| Policy and legislation |
| --- |
| ○ How can we develop and evaluate IAQ criteria for inclusion in sustainable assessment schemes?<br>○ How do we define good IAQ and how can we monitor/ assess this economically and feasibly in a domestic context?<br>○ Could IAQ criteria be effectively embedded in the RIBA plan of works?<br>○ Are current building regulations relating to ventilation provision being met in practice and are these standards adequate to ensure good IAQ? |
| **Design of the built environment** |
| ○ What are the causes of poor ventilation?<br>○ How are ventilation systems performing in new-build airtight homes?<br>○ What is the long term performance of ventilation systems?<br>○ What impact do inadequately maintained ventilation systems have on ventilation rates, noise, electrical consumption and heat recovery efficiency?<br>○ What is an acceptable performance standard for ventilation? How relevant is $CO_2$?<br>○ Is social housing at greater risk of poor IAQ?<br>○ What do architects currently know about indoor air quality principals and strategies, and how can they be better informed?<br>○ What are the typical maintenance requirements of MVHR systems and has the market adequately evolved to provide these services?<br>○ Who is ultimately responsible for IAQ in housing projects and how can we assign responsibility of IAQ, to include architects, suppliers, contractors, installers?<br>○ What are the potential psychological impacts of the responsiveness, noise and complexity of technologies to control the indoor environment?<br>○ What are the actual energy savings in homes with MVHR systems where occupants habitually open windows? |
| **Outcomes** |
| ○ How can ventilation systems be better designed?<br>○ What are UK building professionals perceptions and experiences towards IAQ and the use of MVHR?<br>○ How do we translate existing knowledge from IAQ sciences to practical design guidelines for built environment professionals?<br>○ How does the choice of ventilation and airtightness standards impact on the indoor microbiome and what are the potential consequences on occupant health?<br>○ How do we improve the design of indoor environmental control strategies & interfaces to promote occupant use and engagement, particularly for ventilation systems?<br>○ How can we improve passive ventilation solutions for increasingly airtight housing?<br>○ How do we convince industry to take source control seriously?<br>○ Is there currently a gap in the market for effective ventilation strategies for airtight dwellings? |

## Symposium presentations and discussion

The symposium began with presentations from Prof Anthony Seaton (University of Aberdeen) and Prof Raymond Agius (University of Manchester), which provided an overview of the constituents of air (bacteria, fungi and other pollutants) and common consequences of inhaling these in clinical terms.

Prof Seaton presented evidence of how the body reacts to all inhaled particles as invading organisms, which can increase the population risks of heart attacks, stroke and asthma attacks. Prof Agius demonstrated the importance of outdoor air pollution and provided evidence of the known health risks associated with indoor air pollutants. This included information on the toxic potential of chemicals found in indoor environments.

The discussion that followed highlighted the need for a statutory reporting system (similar to the yellow card system) within the medical profession, to provide evidence of unexpected reactions to consumer products or materials. Issues relating to bio-accumulative pollutants were also discussed; where it was highlighted that investigating the effect of accumulative agents requires long term studies, which can be extremely difficult to get funding for. The complexity of measuring health effects were emphasised, due in part to interactions between physiological and psychological outcomes, chemical interactions, and susceptibility.

Following the coffee break, Ian Mawditt (Fourwalls, Bristol) provided an overview of the state of the art of ventilation in the UK, revealing significant issues regarding poor measured airflow rates in modern dwellings. He noted a number of key research gaps, including whether minimum ventilation guidance is fit for purpose and the need for research to establish the health burden of poor ventilation in UK homes.

Following this, Dr Sani Dimitroulopoulou (Public Health England and UKIEG) emphasised important factors affecting indoor air quality in a home environment and outlined a number of key challenges, including the need for a coordinated approach to built environment policy.

The Q&A session raised some important issues regarding the disconnect between ventilation design and performance, and the “circle of blame” culture between designers, developers, clients and end-users. The need for policymakers to create regulations / mechanisms to protect and advise building occupants was highlighted. It was emphasised that although IAQ standards are available, these provide guidance only (i.e. they are not regulatory and are never measured or enforced). In particular, the significant differences between indoor air quality ‘liability’ in the domestic and non-domestic sectors was highlighted (i.e. in the non-domestic sector someone is responsible where-as in the domestic sector there is not), stressing the need for the joining up of legislation.

After lunch, the theme of liability continued, with Dr Mich Swainson (Building Research Establishment) revealing a rise in court cases in modern housing due to complaints of overheating. He suggested that the architectural profession has lost the art of design for

natural ventilation in dwellings and noted that windows are no longer viewed as part of the 'comfort provision'.

Dr Atze Boerstra gave a European perspective and presented findings from the Netherlands, demonstrating that the observed shortcomings of mechanical ventilation systems are not limited to the UK, suggesting the need for maximum ventilation noise level requirements in the building code and obligatory maintenance requirements for ventilation systems.

Following this, Prof Pawel Wargocki provided an overview of the relationship between ventilation and health, emphasising that although there is general agreement that increasing ventilation rates will reduce IAQ related health outcomes, ventilation is only a modifying factor and should not be used as a panacea for all IAQ problems. He noted that in order to establish an acceptable standard for ventilation, we need to first be aware of the level of exposure to air pollutants indoors and define a suitable standard for IAQ.

Finally, Prof Jan Sundell gave a global perspective and provided an overview of the history of ventilation in homes and health, outlining the significant increase in house dust mite proliferation associated with energy conservation strategies in Sweden, resulting from lower levels of ventilation. He stressed the fundamental need for large scale, multidisciplinary projects in the UK, to address the gap in knowledge on the relationship between ventilation and IAQ on occupant health.

The conference concluded with a presentation from Lynne Sullivan (Sustainable By Design), who explained that architects are currently flying blind in this area and emphasised the need for increased collaboration between architects, health care professionals and indoor air quality researchers to ensure that occupant health and wellbeing is a core priority during the design process.

The discussion session at the end of day touched upon a number of important factors, such as the need for increased consumer awareness, the lack of IAQ studies in the UK (and lack of funding), the unregulated nature of homes, the lack of defined standards for a home environment and the disconnection between health studies and monitoring studies. The lack of evidence on the relationship between IAQ and health was emphasised, particularly in comparison to the availability of data on ambient air quality and health.

On a practical level, a call was made for the development of best practice / design guides to provide information to architects and built environment professionals on source control and ventilation provision in modern airtight homes. The event concluded with a networking dinner.

Key priority research areas were identified:

- Large scale UK study to identify impact of IAQ on occupant health
- Source control and material emissions
- Microorganisms in homes

- Guidance for design and construction professionals
- End-user interactions (noise, awareness, control, occupant perception)
- Review of existing evidence of IAQ in modern airtight homes
- Effectiveness of ventilation systems in practice
- Intervention studies on susceptible groups (such as asthma / COPD patients)
- Relationship between house dust mite and airtightness levels in homes

Presentation slides and further information on the symposium event are available at www.hemacnetwork.com

## Photos from the symposium event

Networking Lunch

Reid auditorium, Symposium attendees

## Survey Responses

### Topic suggestions for follow-up workshop

- Strategies to improve ventilation regulations and guidance (including commissioning of ventilation technologies), and practical solutions to accommodate air circulation in homes
- Step change in design thinking – should we be designing airtight homes that require mechanical ventilation? Can mechanical ventilation ever be 'fail-safe'?
- Microbial growth in buildings: health impact, trends, monitoring, effect of building design and occupier activity
- Impact of end-user interaction on indoor air quality
- Development of suitable IAQ metrics and standards for measuring and monitoring IAQ. Quantification of ideal, comfortable, acceptable / unacceptable, dangerous and fatal levels
- Construction material emissions and their impact on health and indoor air quality in airtight buildings
- Development of simple ground rules - What are the key measures to implement into new buildings and main things to avoid?
- Building automation and indoor air quality

### Suggested outcomes from network activities

- Guidance / Code of Practice for architects and building services engineers on the key findings, especially common mistakes to avoid
- Increased public awareness of indoor air quality in homes
- Large scale, collaborative, interdisciplinary, and international bids (real game changers) to address evidence gap
- Investigation of the value, effectiveness and enforcement of regulations and standards
- Simple straightforward guidance, at level suitable to be targeted towards different groups: specifiers, owners, users etc.
- A database of material emissions and case studies of current materials used in low energy buildings
- Establishment of a calibrated assessment scale and methodology for measuring and reporting IAQ problems
- Regulatory change to improve ventilation provision

- A better understanding of the problem
- Quantification of the cost of poor IAQ to the health service and indirect costs to the UK economy

## The key problem that needs addressed

- Conflict between energy efficiency and sufficient ventilation - Does modern domestic architecture which addresses energy conservation imply risk to the humans in the houses? If so, what are the most likely risks and how may they be prevented?
- The disconnect between academia and practice
- Insufficient evidence (science linking cause and effect such that regulation can be meaningful is limited)
- Lack of funding, particularly for inter-disciplinary studies
- Poor dialogue between regulatory bodies and real world stakeholders
- Lack of understanding and awareness (particularly among residents) of the importance of ventilation and indoor air quality
- Need for IAQ standards (based on maximum pollutant concentrations)
- Inadequate ventilation provision in airtight homes
- Source control
- Lack of action - the 'head in the sand' attitude of professionals about health issues and indoor air quality

# Event 2: Workshop

The aim of the workshop was to elaborate on the findings from the symposium through smaller, more focused cross-disciplinary group activities; identifying complementary skills and expertise, exchanging knowledge and establishing potential areas for collaboration. The workshop was held on Wednesday 30th of November 2016 at the Glasgow School of Art.

Nine workshop sessions were identified in total, based on the key research priorities identified from the symposium event.

The purpose of the event was to identify specific challenges faced within each topic and stimulate ideas for funding opportunities. Session chairs were identified with specific relevant expertise, to help guide the sessions and ensure the discussions remained focused. The aim of each workshop session was to develop a research question and suitable methodology in an 'abstract' form, to be pitched to all attendees in the afternoon for feedback and discussion. To ensure that the discussions remained focused, numbers were limited to 15 participants per session.

The workshop brought together 46 participants from both professional and academic communities to discuss the state of knowledge in the field and identify and research opportunities. In particular, the significant involvement of industry professionals (ventilation suppliers, housing associations, architects, clinicians and consultants) and policy makers (Scottish Building Standards Division) helped to increase awareness and knowledge of the potential health effects of modern airtight construction and facilitated the transfer and exchange of knowledge between research and practice.

The event resulted in the submission of three multi-disciplinary funding proposals based on specific gaps in knowledge that were identified through the session discussions.

# Workshop Programme

| | |
|---|---|
| 10:30 | Registration, tea and coffee |
| 11:00 | Introduction and Overview |
| 11:30 | Parallel workshop sessions (1 hour 30 minutes)<br><br>**Prof Jan Sundell**, *Tsinghua University Beijing*<br>Cross sectional study on children's health and IEQ<br><br>**Dr Catherine Lawrence**, *University of Strathclyde*<br>Airtightness and House Dust Mite Proliferation in Scottish Homes<br><br>**Prof Graham Devereux**, *University of Aberdeen*<br>Intervention studies for susceptible groups<br><br>**Ian Mawditt**, *Fourwalls* & **Dr Mich Swainson**, *BRE*<br>Effectiveness of ventilation systems |
| 13:00 | Lunch |
| 14:00 | Parallel workshop sessions (1 hour 30 minutes)<br><br>**Prof Tom Woolley**, *Rachel Bevan Architects*<br>Source control and material emissions<br><br>**Prof Cath Noakes**, *University of Leeds*<br>Microorganisms in homes<br><br>**Prof Rajat Gupta**, *Oxford Brookes University*<br>End-user interactions<br><br>**Dr Sani Dimitroulopoulou**, *Public Health England*<br>Evidence Review: IAQ & ventilation in modern airtight homes<br><br>**Chris Morgan**, *John Gilbert Architects*<br>Guidance for design and construction professionals |
| 15:30 | tea and coffee |
| 15:45 | **Presentation pitches: Outcomes from workshop sessions** |
| **17:30** | **Discussion** |
| 18:00 | Close |

# Summary of workshop discussions

## Cross sectional study on children's health and IEQ

This session kicked off with a presentation from Prof Jan Sundell, which provided context and rational for the workshop session and an overview of the purpose of the proposed study. A study proposal was presented (Phase 1: Cross-sectional study, Phase 2: Case-control study), based on previously completed studies undertaken by Prof Sundell and colleagues in China, Denmark, Korea, Texas, Sweden and Singapore. Some findings of these studies were also presented, including risk factors identified for asthma and allergies among children (such as the presence of DEHP and the use of water-based paints). A case was made for further investigation, to identify why children in English speaking countries (such as the UK, New Zealand and Australia) have higher incidences of asthma and allergies than non-English speaking countries.

The discussion that followed highlighted some perceived barriers to the development of large scale studies of IAQ and health in a UK context, including a lack of collaboration between architecture, engineering and medical groups and difficulty of acquiring funding for multidisciplinary studies that fall between the remits of specific research councils (AHRC, EPSRC and MRC). Suggestions to overcome these included the development of a funding proposal for a cross-sectional doctoral training centre, establishment of coordinated university studentships or approaching multiple research councils to suggest the topic as a research agenda, with a specific multidisciplinary focus.

A study proposal was discussed in detail, including the focus on asthma onset (rather than asthma exacerbation), the importance of a randomised sample, justification for the focus on children (as opposed to adults), suitable measurement protocols and analysis techniques, and possible participant recruitment strategies. Suggested next steps included the identification of a suitable research team (UK wide) and refinement of the questionnaire and proposed methodology for a UK context.

## Airtightness and house dust mite proliferation in Scottish homes

The session chair, Dr Catherine Lawrence, initiated the discussion with a short presentation outlining the rational for a study to identify whether housing design (particularly airtightness and ventilation levels) might have an influence on House Dust Mite (HDM) proliferation in a UK / Scottish context, emphasising the need for a multidisciplinary consortium to investigate this effectively. Through the discussion, it was suggested that this might include a second stage to investigate whether improvements of ventilation provision could lead to a reduction of HDM (through an intervention style study), with physical measurements of indoor environmental conditions.

It was noted that a link between environmental conditions and health would not be established by the proposed study design, however it was suggested that future studies

might investigate whether there is any association between HDM concentrations and asthma prevalence. Many elements to this study were deliberated, including discussions on a suitable sample size, methods for collecting dust samples (such as survey company or administration of dust collection kits), collection of environmental data (RH and temperature), confounding factors (such as cleaning regimes, surface materials, lifestyle etc.), analysis and interpretation of results (based on WHO sensitisation level for HDM) and the potential impact of the findings.

Proposed next steps included a collation of information from other European countries, to identify whether there is sufficient evidence to suggest a link between building weatherisation strategies and increased proliferation of HDMs, and whether there is proof of concept that increased ventilation levels might lead to a reduction of HDM concentrations in Scottish homes.

### Intervention studies for susceptible groups

The focus of this session was to explore opportunities for intervention studies for susceptible groups (e.g. patients with COPD, asthma, cystic fibrosis). The session initiated with a brief introduction by the chair, Prof Graham Devereux, who put forward a number of key questions to focus the discussion. These included the following: i) Is there enough evidence to do intervention studies at the moment, ii) Are we trying to prevent disease or ameliorate people with established disease, iii) What susceptible groups are we going to look at, iv) What are the likely outcomes (design of the study), v) What interventions would we want to do, vi) Can we use large datasets?

The discussion that followed raised a number of important issues, such as the difficulty of acquiring funding for longitudinal studies that focus on primary prevention, the range of confounding factors (such as lifestyle, smoking habits, medication, co-morbidities, outdoor pollution) and the need for large datasets, the potential effectiveness of interventions (such as moisture control or improved ventilation) and the importance of choosing suitable IAQ markers (e.g. patient specimens or pollutant concentrations).

A study was proposed to investigate whether interventions to improve ventilation and indoor air quality in the home environment might reduce the rate of exacerbations in COPD patients living in modern homes. This might include an initial large scale survey, followed by a case control study (those who exacerbate and those who don't), which would involve investigation of the home environment and patients lifestyles.

### Effectiveness of ventilation systems

The aim of this workshop was to stimulate ideas for projects on the effectiveness of ventilation systems in homes. The session was chaired by Dr Mich Swainson (BRE) and Ian Mawditt (Fourwalls). The session kicked off with a discussion on what is meant my 'effective' ventilation, which is defined in Approved Document Part F as, *"a measure of how well a ventilation system works in terms of delivering supply air to the occupants of a building".* It was suggested during the discussion however that effectiveness should include other

elements, such as cost (energy performance), comfort, noise, usability, robustness and the effectiveness of removing (or diluting) pollutants and moisture. It was noted that ventilation rates are often expressed volumetrically (e.g. ach), which was considered to be too simplistic as does not consider effectiveness in terms of IAQ or occupancy requirements.

A number of questions were proposed for future investigation, including i) Who should be accountable to ensure ventilation effectiveness, ii) Should there be a competent person or mandatory independent inspection to test ventilation systems post-completion, iii) Do we have enough information on key elements of ventilation failure (design, installation, commissioning, operation, maintenance) or do we need more studies, iv) Do other countries have the same issues, v) How effective are filtration technologies in domestic setting?

A study was proposed to develop a depository / database of best practice UK case studies on effective ventilation in modern airtight homes, supported by physical data on performance (as built) and end-user experiences.

### Source control and material emissions

This workshop, chaired by Prof Tom Woolley, explored the importance of source control to reduce indoor air pollution in homes, with a particular focus on control of material emissions. Questions deliberated included the following, i) Can ventilation remove or significantly reduce emissions successfully, ii) What material emissions are of most concern (e.g. VOCs, formaldehyde, flame retardants, radon etc.), iii) What evidence is there of higher concentrations of hazardous emissions in air-tight buildings (and resulting health problems), iv) What can be done to mitigate emissions (using materials), and v) What guidance / standards exists on specifying low emission materials and how can it be applied.

It was noted that even if the general public could be convinced on the importance of source control, there is a lack of guidance available on specifying low emission materials and a lack of supply due to a breakdown in the UK natural building material supply chain in recent years. The importance of adopting the precautionary principal was stressed, and the need to raise awareness of source control among architects, manufacturers and built environment professionals through university programmes and targeted reports.

A study was proposed to investigate the emission rates of typical UK construction materials in environmental chambers under different scenarios and conditions.

### Microorganisms in homes

This workshop, chaired by Prof Cath Noakes, explored the increasing awareness that buildings can influence our exposure to a range of microorganisms indoors, which can have both positive and negative influences on health. The session focused on the relationships between building design, indoor environmental parameters, occupants and the presence of microorganisms in housing.

A range of topics were discussed, including i) Sources of microorganisms in housing (e.g. occupants, HVAC, building fabric), ii) Methods and challenges in sampling/detection of microorganisms (e.g. air samples, sequencing), iii) Confounding factors (geographic location, occupant behaviour, household demographics, seasonal variations etc.), iv) Health effects of microorganisms in housing, v) Influence of design and occupant behaviour on presence of damp and mould in housing (and impact of airtightness strategies), and vi) The microbiome of the built environment (relationships between design, ventilation, location and microbial ecology, including development of antimicrobial resistance).

A study was proposed to bring together expertise from architecture, engineering and microbiology to evaluate how building design may influence the presence of microorganisms in the home and the development of antimicrobial resistance.

### End-user interactions

The focus of this workshop was to identify opportunities for multidisciplinary projects investigating the influence of end-user interactions on indoor air quality in the home environment. The session was chaired by Prof Rajat Gupta, who initiated the discussion with a presentation providing evidence of interactions and experiences of end-users from recently completed building performance evaluation studies. He noted that end-users can influence indoor air quality and ventilation in a building (through behaviour), and that indoor environmental conditions can also have an impact on the end-user (in terms of comfort, productivity and health).

The discussion that followed raised some important concerns regarding the usability and responsiveness of mechanical ventilation systems, the potential psychological implications of (perceived) lack of control, the complexity of occupant behaviour with regards to lifestyle choices, social factors, habits and values, the inherent challenges associated with trying to change behaviour through improving awareness, the lack of effective noise standards for ventilation systems and the complexities of setting noise standards for ventilation systems in airtight homes.

A number of possible strands for future work were identified, including i) an evaluation of ventilation habits and behaviours in low energy UK houses, and ii) an investigation of the potential psychological impact of increased isolation from the exterior environment in airtight homes. Some interventions were proposed, such as providing users with data on indoor pollutant concentrations, or additional information / training on indoor air quality and ventilation.

### Evidence review – IAQ and ventilation in modern airtight homes

This workshop, chaired by Dr Sani Dimitroulopoulou, discussed the available evidence on the quality of indoor air and ventilation in modern airtight homes. Sani kicked off by providing a quick update on recent indoor air quality initiatives in the UK (including the development of indoor air quality guidelines by NICE), emphasising the importance of new research to evaluate the impact of energy efficient design strategies on IAQ.

The structure of the discussion was based on a research paper published by Prof Pawel Wargocki and colleagues (2013) on a proposed research agenda for achieving IAQ and supporting health in highly energy efficient buildings. This paper outlines a number of research needs on issues including, i) Impact of user behaviour with respect to control of IEQ, ii) Development of new methods of monitoring IAQ, iii) Definition of ventilation requirements and the parameters defining these, iv) Definition of pollutants of concern in highly energy efficient homes, v) Comparison of user expectations and health risks relating to IAQ in new energy efficient, retrofitted and traditional homes, vi) Examination of the impact of non-building related variables, and vii) Development of improved and simplified toxicological characterization of pollutants.

The findings of a number of recently completed UK studies were discussed, including potential solutions to improve IAQ in airtight homes; such as IAQ labelling systems for UK building products, improved ventilation legislation, increased public awareness, changes driven by insurance claims / liability, innovations in ventilation technologies and education / training of the UK construction sector. Suggested next steps included the collation of evidence on IAQ and ventilation in UK homes. It was stressed that there is a fundamental need to work together to propose (and deliver) solutions to address these challenges from a multidisciplinary perspective.

### Guidance for design and construction professionals

The aim of this workshop, chaired by Chris Morgan (John Gilbert Architects), was to establish ways to engage, educate and empower architects to consider IAQ during the design process, through the development of guidelines and/or best practice guides. It was noted that whilst it is clear that more research is required to establish a strong consensus on ventilation standards, there are some simple design strategies that can be implemented to support the achievement of good IAQ in homes.

Topics explored through the discussion included, i) The regulatory context and the lack of guidance on IAQ for architects, ii) Concerns regarding the treatment of current minimum ventilation standards in UK building regulations as target levels, iii) The focus of the guidance (e.g. new-builds and/or retrofits, airtight / non-airtight, targeted at clients, designers, specifiers and/or end-users), and iv) The potential adoption of guidance through certification schemes / bespoke IAQ plans. Suggested next steps included the exploration of funding options and the establishment of a suitable multidisciplinary team (including architects and IAQ specialists) to inform the development of the IAQ design guidelines for airtight homes.

## Survey Responses

### Feedback from project pitches

*Characterising materials by their emission in to air would be difficult sine these vary with time and the physical conditions in the room*

*This is important, but this group will not fix this - we may raise awareness and promote labelling, but we need to understand better the health risks associated with off-gassing in airtight homes*

Source control and material emissions

*This could be combined with the cross sectional study and used as a later stage investigation. May be worth doing a pilot study in the short term as part of the AMR call*

*Interesting research possibilities on microbiome. Need to harden up on objectives and methods - is the interest viruses, bacteria or fungi? All are of interest medically but in different ways.*

Microorganisms in homes

*We need the medical evidence to illustrate the human and monetary cost of the problem - top priority*

*Evident that consumer does not understand the need for ventilation let alone how to do it. Therefore it has to be legislation driven to protect health rather than a desire solution.*

Evidence review: IAQ & ventilation in modern airtight homes

*This is an area that I personally think needs to be more fully investigated*

*It seems to me that a significant problem is people not realising the importance of ventilation. People will always undermine the performance of any "system" if unwanted, hence second priority.*

End-user interactions

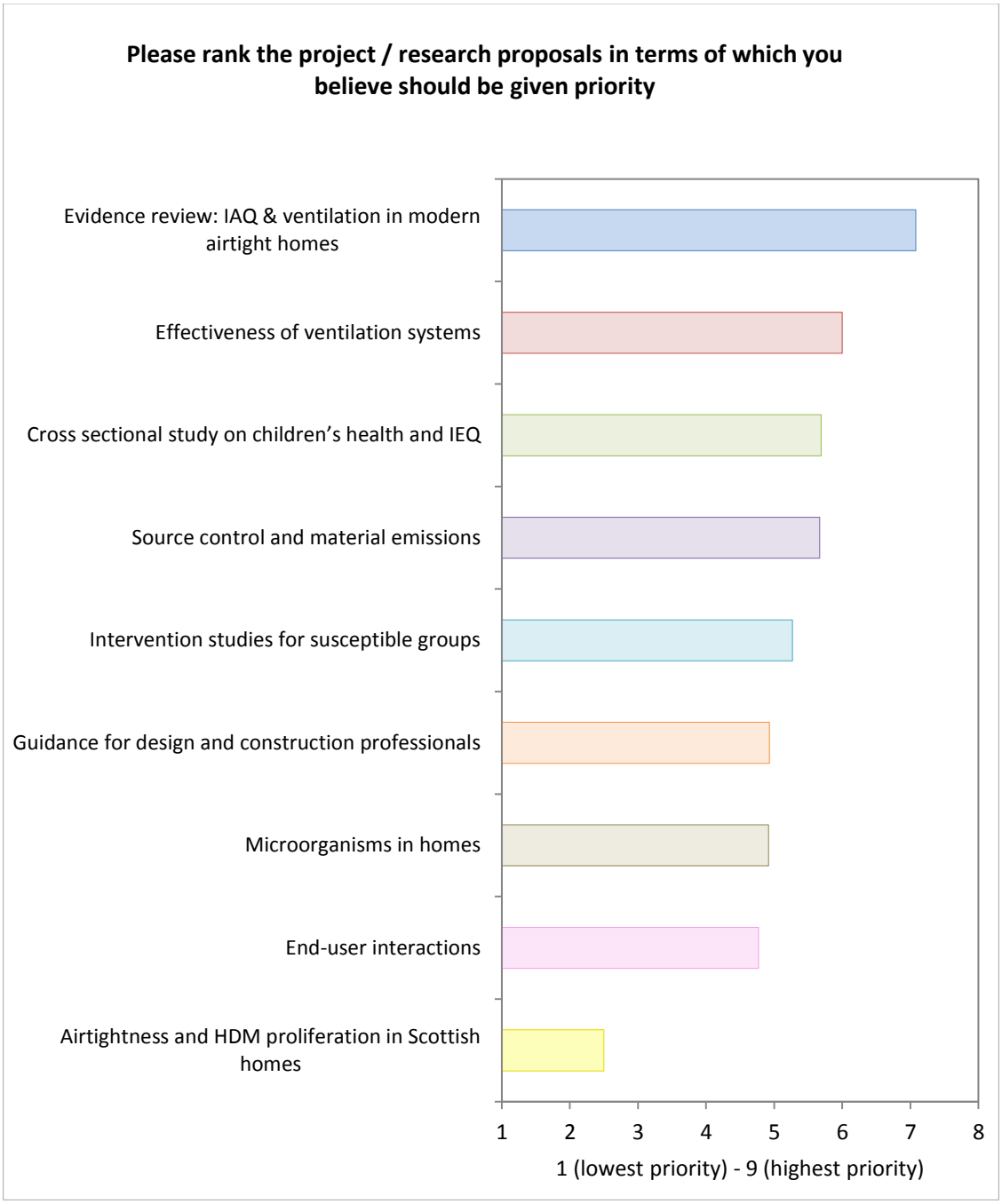
*Very interesting discussion, guidance is very necessary, big cap in architecture education, also practical on-site guidance.*

*Essential to get information out to various participants in construction; this should include client guidance [briefing] and End User Guidance - simple to understand.*

Guidance for design and construction professionals

## Ranking of proposals

Participants were asked to rank the presentation pitches of project proposals in order, based on those they believed should be given priority. The results are presented below.



## Photos from the workshop event

Session participants: Guidance for design and construction professionals


Session chair presentation: Microorganisms in homes

# Event 3: Sandpit

The aim of the sandpit event was to determine key research needs and identify opportunities for funding applications for cross-disciplinary projects, building on the outcomes of the previous activities. The sandpit was held on Tuesday 25th April 2017, at the Glasgow School of Art. The event was followed by the annual UK Indoor Environments Group conference on 'Indoor Environments and Health in Buildings', which is a networking event for a multidisciplinary audience of academics, policy makers and industry experts with an interest in improving indoor environments for health and wellbeing.

Six sandpit sessions were supported in total, following on from the outcomes of the workshop event and discussions during the steering group meeting, held in February 2017.

The purpose of the event was to refine proposals for multidisciplinary projects to be submitted as joint funding applications. Participants worked in small groups (<10 people) to brainstorm and refine ideas.

An informal agenda was devised, which covered the following activities:

- Introduction and overview
- Define the scope and the problem
- Ideas generation
- Identify aims and objectives
- Development of project proposal
- Outline of research bid
- Presentation development

At the end of the day, groups were asked to present their project ideas to participants for feedback, and submit a short summary of their research proposal with details of the research question, aims and objectives, and possible next steps. The event brought together 41 participants from the UK, Ireland, the Netherlands, China, Belgium, Austria, and Denmark.

The sandpit resulted in the development of six project proposals, which will now be taken forward by the groups and advanced as funding applications.

# Sandpit Programme

| | |
|---|---|
| 10:30 | Registration, tea and coffee |
| 11:00 | **Introduction and Overview** |
| 11:30 | Parallel Sandpit sessions |
| Session 1 | Chair: **Jan Sundell**<br>Cross Sectional Study of Children's Health and Homes |
| Session 2 | Chairs: **Pawel Wargocki and Sani Dimitroulopoulou**<br>Changing Nature of Pollutant Exposure in the Home Environment |
| Session 3 | Chairs: **David Waddington and Jack Harvie-Clark**<br>Ventilation Noise Levels and Occupant Perception in Airtight Homes |
| Session 4 | Chair: **Tom Woolley**<br>Chemical Emissions of UK Residential Construction Materials: Lessons from Europe |
| Session 5 | Chairs: **Ian Mawditt and Mich Swainson**<br>State of the Art of UK ventilation: RH as a metric for ventilation performance |
| Session 6 | Chair: **Anthony Seaton and Tim Sharpe**<br>Solutions / New Perspectives (Open call) |
| 13:00 | Lunch |
| 14:00 | **Parallel Sandpit Sessions (continued)** |
| 16:10 | Tea and coffee |
| 16:30 | **Research Proposal Presentations and Discussion** |
| 17:30 | Close |

## Photos from the sandpit event

Workshop session: Ventilation Noise Levels and Occupant Perception in Airtight Homes

Workshop session: Changing Nature of Pollutant Exposure in the Home Environment

# Recommendations

## Research

In order to stimulate change, there is a fundamental need to establish an evidence base on the associations between IAQ, ventilation and health in UK homes. To achieve this, large scale multidisciplinary studies are required to determine cause and effect. In the UK, there are currently very little data available on indoor pollutant exposures in homes (and associated factors), in comparison to the availability of data on ambient conditions. This needs to be addressed as a matter of priority, to establish baseline data on indoor exposures in the home environment and determine risk factors for occupant health, particularly for more susceptible groups such as respiratory patients, children or the elderly.

To achieve this, there is a need to prioritise collaborative research that considers, simultaneously, the multitude of factors at play (including IAQ exposure, health data, occupant behaviour, building characteristics and indoor environmental conditions). A number of such research projects were proposed by the network through the funded network activities, as outlined below. It is hoped these can be implemented to increase understanding of the problem from a UK perspective and to inform future building regulation requirements.

Overall, to achieve significant progress and accelerate research capacity in this field, there is a need to increase the availability of funding in the UK through enhanced investment at a governmental level (for example through cross-council initiatives).

## Proposed research projects in development

### *1) Cross sectional study of children's health and the home environment*

The UK has one of the highest prevalence of asthma sufferers in the world. In Scotland, 368,000 people are currently being treated for asthma, including 72,000 children. Last year, annual statistics from the National Records of Scotland revealed asthma death rates in Scotland were at their highest for more than a decade. Despite extensive research in this field, the aetiology of asthma and allergic disease is poorly understood; partially due to the lack of standardisation in methodology and case-definition in epidemiology studies, therefore limiting the value of temporal and spatial comparisons. Previous studies have identified a history of atopic disease within the family as a risk factor for asthma development. However the impact of environmental factors, particularly the home environment, is less understood.

The aim of this study is to explore the role of the home environment on the aetiology of childhood asthma in Scotland. The context of the proposed research is existing evidence of higher allergy levels in UK, Australia, and New Zealand; and a current impetus to address air pollution in the UK. The study will replicate a methodology employed by Prof Sundell and colleagues in previous studies in Sweden, USA, and China, using

standardised questionnaires developed as part of the ISAAC study, to identify the prevalence and severity of asthma, rhinitis and eczema in children.

*2) Assessment of chemical emissions from UK residential construction materials*

This project considers indoor environment in the domestic sector and aims to investigate volatile organic compound (VOC) emissions from common building materials. The project includes the review of UK and European legislation and standards relating to indoor air pollution and an assessment of the relevant existing measurement methodologies and protocols. A number of dwellings representing a range of standard UK construction types will be selected for a monitoring pilot, to establish VOC concentrations and the potential health effects on the building occupants.

The study will identify methodologies, protocols and construction materials for a larger study to acquire data on typical UK construction and related in-situ emissions, which can then be translated into practical guidance for architects, designers and specifiers to facilitate identification and specification of low-emitting building materials.

*3) Influence of ventilation design on the prevalence of anti-microbial bacteria in homes*

This project (funded by the AHRC: AH/R00207X/1) will investigate how contemporary housing design affects the indoor microbiome, and what the effects of this might be on anti-microbial resistance. In the early 19th century, the way that houses were designed led to considerable improvements in public health, largely as a result of improvements in sanitation, but also access to fresh air and sunlight. In recent years however, commercial interests and building legislation have largely dictated design issues. During this time the ways that buildings have been designed and constructed has changed significantly, mainly as a response to issues of climate change. Improved thermal performance and increasing airtightness has been able to isolate the building from the external environment. Whilst this will have benefits in terms of reduced carbon dioxide emissions, lower running costs and better comfort, it is becoming increasingly clear that levels of ventilation and consequent standards of indoor air quality (IAQ) are reducing and there is emerging evidence that this might have negative health impacts. Whilst there are a number of dimensions to IAQ, one area that has not been researched is the prevalence and nature of microorganisms. People - especially vulnerable groups such as the old and very young - spend a great deal of time in the home, and so any change to the indoor microbiome may significantly affect occupants' health. There is a concern that isolation from the outside environment may reduce diversity and result in proliferation of harmful microorganisms, including those that have antimicrobial resistance.

This study aims to close this gap in knowledge by undertaking an assessment of contemporary housing to determine the ventilation characteristics and relate this to the presence and nature of microorganisms in the home, with the specific aim of identifying factors that would impact on the presence and proliferation of anti-microbial resistant microorganisms. It anticipated that this could lead to changes in the way that we design

buildings, in particular ventilation provision, and the project will aim to address this through a programme of academic, industry and public dissemination.

### 4) *Changing nature of pollutant exposure in the home environment: New-build versus retrofit home environments and risks*

Over the last decade, significant improvements have been made to the thermal performance of dwellings, particularly the airtightness of building envelopes. It is now well evidenced that increasing airtightness is likely to increase the concentration of air pollutants indoors. However much less is known regarding the changing nature of these pollutants in modern housing.

For instance, in modern airtight housing, tobacco smoke has been largely eradicated. There is also less influence of ambient pollution. The introduction of new chemicals in the indoor environment is exceeding the ability of regulators to effectively evaluate these in terms of their potential risk to human health. How might this new cocktail of pollutants influence the health of building occupants? Given that airtightness is continually improving in the UK, this information will be crucial to ensure the protection of occupant health in future housing.

This study will identify if/how the type of pollutant exposure in homes has changed, and investigate how this new cocktail of pollutants might influence occupant health. Are there any new pollutants emerging? What are the new risks? Is there a difference between pollutant levels in retrofitted and new-build homes? The study will benchmark exposure in new-build and traditional retrofitted dwellings, while establishing a mechanism to connect measured pollutants with associated sources and processes (e.g. lifestyle, culture, materials etc.). The results can be used to propose solutions to manage the problem.

### 5) *Ventilation noise levels and occupant perception in airtight homes*

Noise can be a significant constraint to the use of modern ventilation systems, as there is a tendency for residents to turn off noisy equipment in their home, partly due to acoustic disruption but also linked with associated energy cost concerns. Without adequate ventilation in modern airtight dwellings, air quality can have a significantly adverse effect on the health of the occupants. This most often occurs at night time when people are settling to sleep, resulting in adverse impacts on IAQ.

The aim of this project is to overcome noise as a barrier to the use of mechanical ventilation systems in modern airtight homes. An initial pilot study will investigate occupant perception of ventilation noise in a social housing context, which will be followed by physical measurements in selected homes to inform a larger study. The aim of the larger study is to establish which noise characteristics of ventilation systems are best suited for sleep.

### 6) *State of the art of UK ventilation: moisture as a metric for ventilation performance*

The topic of IAQ and ventilation effectiveness in dwellings is very broad. Multiple pollutants and their associated sources, and the wide range of resident preferences/activities make assessment of IAQ complex. It is now common for metabolic $CO_2$ to be regarded as a general indicator for the quality of indoor air and ventilation effectiveness. Increasingly domestic ventilation systems offer demand control functions, modulating on RH and $CO_2$ amongst other inputs. But is this making things more complicated than they need be? Does it offer long term reliability, what is the longevity both in life and accuracy of small NDIR $CO_2$ sensors?

Bio effluents and moisture have, for some time, been considered the main pollutants in homes, and control of these pollutants remains to be the basis for established background ventilation rates in building performance standards. Controlling ventilation rates based on only $CO_2$ instead of moisture content (typically using relative humidity as the metric), may mask non-metabolic moisture generation. This approach is common in non-domestic buildings, but in dwellings may result in some spaces being ineffectively ventilated, possibly leading to potential health and building fabric problems.

The aim of this proposed study therefore is to understand what control inputs are needed for effective demand control and whether these can provide a robust means of achieving good IAQ in buildings. Is complex sensors required or can we effectively regulate systems based on RH and temperature (e.g. using indoor and outdoor vapour pressure data)? This will be achieved through a review of ventilation performance and effectiveness in domestic environments where data of $CO_2$ and moisture content can be compared and correlated with occupancy, activities and external conditions. Where information is available for other indoor pollutants this will also be included in the assessment. The study will seek to determine whether $CO_2$ provides a useful proxy over and above moisture, or whether moisture content on its own is an adequate proxy for effective ventilation control throughout the year.

### 7) *A pilot investigation into relationships between ventilation and health status of people with chronic obstructive pulmonary disease (COPD) in contemporary airtight homes*

In the UK about 1 million people over the age of 60 have Chronic Obstructive Pulmonary Disease (COPD). Although the effects of outdoor air pollution on COPD are well established, the effects of indoor air pollution on COPD especially in the elderly remain unknown. There are increasing concerns that whilst new building regulations introduced to combat climate change make houses more airtight and thermally efficient, the construction materials and lack of ventilation may adversely affect indoor air quality and could be detrimental to the health of vulnerable groups, such as elderly people with COPD.

In this pilot study we will use a postal survey of elderly people (≥65years) with COPD to investigate associations between levels of ventilation predicated on building design and respiratory health. In a more detailed study of 50 elderly people with COPD,

measurements will be made in the home of airtightness, ventilation provision, actual ventilation and indoor air pollution and related respiratory health.

### 8) Ventilation and house dust mite proliferation in high density student accommodation in Scotland

This study will investigate the impact of ventilation and resulting indoor environmental conditions on the levels of house dust mites in modern airtight high density, non-serviced student accommodation in Glasgow. The hypothesis is that modern, poorly ventilated student residences will have higher levels of moisture and more stable environmental conditions than well ventilated residences, resulting in higher levels of house dust mites and greater risk of adverse health effects. Student accommodation has been selected as a building typology with small room sizes and a tendency to be intensively occupied. Measurements of HDM levels and environmental conditions will be monitored simultaneously in selected accommodation over a 12-month period, to investigate the impact of seasonal and temporal changes in ventilation and environmental conditions on HDM proliferation. Occupant behaviour (particularly occupancy and cleaning and heating regimes) will be measured through use of an occupant diary.

The study will help to i) Establish concentrations of HDM in student accommodation in Glasgow, ii) Identify key design variables and risk factors associated with HDM proliferation, iii) Evaluate the impact of seasonal and temporal changes on HDM levels, iv) Identify associations between ventilation effectiveness and HDM levels. The findings will be used to develop strategies to improve the quality of the indoor environment in student accommodation and reduce the risk of HDM proliferation, while providing an evidence base for future work to investigate the potential implications on occupant health.

### *9) Bedroom ventilation and asthma exacerbation among school children*

It is known that there are diurnal changes in the physiology in asthma patients in which airways become constricted overnight, with a consequence of an increase in asthma attacks during this period. Sufferers are known to experience some relief through opening windows during asthma events. At the same time, there is increasing evidence of poor ventilation rates in bedrooms of modern airtight buildings with limited ventilation provision. The aim of the study is to compare ventilation rates and concomitant effects (moisture, temperature and pollutants), with the frequency of asthma events and lung function of children with asthma living in modern homes.

We know patients with asthma are susceptible to their environmental conditions and that poor ventilation is an important factor. The hypothesis is that improved levels of ventilation in bedrooms overnight will lead to reduced incidences of asthma and improved lung function rate. There are a number of components that determine levels of ventilation. However, window opening has the single biggest effect. Comparing

windows open and closed gives a clear measure with which asthma events and lung function can be compared.

*If you are interested in finding out more information about the proposed research projects, please contact the Session Chairs or the Network Organisers.*

## Policy and legislation

Current legislation in the UK recognises the importance of lethal indoor air pollutants, such as carbon monoxide, and mandates specific actions accordingly. Thermal comfort is also well recognised, which has resulted in concerted action through fuel poverty and domestic energy efficiency initiatives and policies. In comparison, indoor air quality is poorly considered and has not received the same level of attention. As such, indoor air quality actions are significantly lacking.

Given the current focus on energy efficiency policies and the governmental target to build one million new homes by 2020, there is a significant need to raise the agenda of indoor air quality to ensure the delivery of homes that protect building occupants and do not create or exacerbate health problems.

To achieve this, the following should be considered:

1) Introduction of guidelines and/or standards for home IAQ, including measures to apply and regulate these where possible (for example through rating systems, IAQ certification schemes etc.)

2) Improvements to UK building regulations and enforcement (particularly regarding ventilation provision in airtight homes)

3) Greater regulation of emissions from building products and materials (and consumer products in the home)

4) Investment in public campaigns to raise awareness of the significance of IAQ in terms of occupant health

5) Greater investment in funding to support cross-disciplinary collaborative research

6) Clear provision of responsibility (and liability) of IAQ in domestic sector

## Practice

The gap between design expectations and as built performance has been well documented, including the poor delivery of mechanical ventilation with heat recovery systems (MVHR) in the UK housing sector (particularly in social housing) and the inadequate performance of trickle vents in contemporary homes. Substantial evidence is now starting to emerge regarding the potential health risks of exposure to emissions from building materials and products in the home environment, and the need to ensure source control in airtight homes (in addition to ventilation requirements as set out in the building regulations).
Yet, the UK construction industry has been slow to react. Below is a summary of recommendations to help improve knowledge and awareness of IAQ among built environment professionals.

- Provision of housing design guidance for architects and suppliers on source control, to include facilities to assist the sourcing of low emitting, non-toxic materials and products
- Improved training and education on the design, construction, operation and maintenance of ventilation provision for airtight housing, including potential risks and how to avoid these

A step change in thinking may be required, to stimulate the development of innovative, new solutions to significantly improve ventilation provision in housing whilst maintaining acceptable standards for comfort and energy efficiency.

# Next Steps

The HEMAC committee and project partners hope to take the project proposals forward as multidisciplinary collaborations, to increase awareness and understanding of the problem in a UK context and identify novel solutions towards healthy and energy-efficient new homes.

In addition to the project proposals outlined in this report, the authors will now seek funding to increase the capacity of the network, inform the development of research proposals and/or projects and disseminate its findings to non-academic audiences, through a series of planned activities (as outlined below).

## Public consultations

- Consultations with respiratory patients (such as COPD, asthma, cystic fibrosis patients), to inform on-going project proposals involving susceptible groups
- Development of a home user-guide for building occupants of airtight dwellings to provide information and advice on the type and sources of indoor air pollutants and on ventilation strategies

## Professional guidance

- Development of a design guide / best practice guide on IAQ and ventilation in airtight homes, to provide practical guidance to design professionals and specifiers.
- CPD event for practicing architects, to support the development of new skills and specialisms on IAQ and ventilation among the architectural profession

## Policy engagement

- Delivery of a policy roundtable event, to bring together actors from various sectors (including housing, health and the built environment), to deliberate how to work together to ensure the delivery of homes that protect building occupants from exposure to air pollution, whilst maintaining standards for comfort and energy efficiency.

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