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Practice Information Note

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Indoor Air Quality and Ventilation in Modern Airtight Homes

*In the second of her articles addressing prevalent issues of climate which affect the built environment in Scotland, **Professor Sue Roaf** has selected an investigation into indoor air quality and ventilation in modern airtight homes, prepared by **Gráinne McGill** of the Mackintosh Environmental Architecture Research Unit.*

The Mackintosh Environmental Architecture Research Unit (MEARU) was established in 1986 within the Mackintosh School of Architecture. MEARU 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.

Gráinne McGill received her degree in Architecture, Masters in Sustainable Design and PhD in Architecture at Queen's University Belfast. Her doctoral thesis examined the impact of energy efficient design strategies on indoor air quality, focusing particularly on new-build airtight UK social housing.

She has recently worked on a meta-study of the performance of heat recovery ventilation funded by Innovate UK and a range of building performance evaluation projects examining the indoor environmental quality and energy performance of new-build housing developments in Scotland. She is currently helping to organise a number of events for an AHRC funded multidisciplinary network on the Health Effects of Modern Airtight Construction (for more information- see www.hemacnetwork.com).

Introduction

Since the 1990s the push to reduce energy use in buildings has been escalating, driven latterly by the increasingly pressing global need to reduce levels of the greenhouse gas emissions from building that are so devastating to our climate. But the hasty adoption of new ways of doing things can often mean mistakes are made simply because of a lack of hands-on experience with the emerging systems being promoted. The viewing of 'innovation' as a good thing in the quest for better building can sometimes have unintended consequences, some of which can leave architects wide open to litigation. One of the most contentious areas amongst many involved in the building industry is the trend towards increasingly 'Airtight Buildings', often reinforced by emerging Building Regulations. In this article we address some of those 'Airtight' concerns and proffer advice on the subject gleaned from recent research, much of which was assimilated and undertaken for a doctoral thesis by Grainne McGill at Queen's University, Belfast[1]. What architects need is sufficient confidence in their 'water-tight' reasons for making related design detail decisions that even if they do fail they will have been deemed to have acted with due care and diligence and not held responsible for subsequent construction failures. We hope the following article will help them understand the issues involved, and point the way to reasonable and professionally competent solutions that will boost that confidence in the rapidly changing building markets of today.

The move to Airtight Buildings

Achieving a reasonable level of airtightness in a building is commonly seen as vital for two reasons to:

1) Reduce heat loss associated with natural infiltration through gaps in the building envelope
2) Stop draughts and help maintain comfortable interior conditions for the building occupants.

The continuous improvement of airtightness standards in modern new-build homes over the last two decades has resulted in practice from the ability to air-pressure test buildings in situ and in theory from the ability to model the thermal performance of buildings so highlighting the large impact rates of air infiltration have on the energy performance of buildings. The removal of natural air movement paths through building structures have gone hand in hand with the increased uptake of Mechanical Ventilation

[1] McGill, Grainne (2016). Indoor Air Quality in Selected New-build Airtight Dwellings: A UK Case Study, unpublished PhD, Queen's University Belfast.

with Heat Recovery (MVHR) systems to provide 'controlled movement of air' in and out of the building with the added benefit of recovering some of the heat lost en route by exiting air. Gone are the leaky structures essential for the coal fired heating of many homes right up until the 1970s, and in comes the mechanical systems of the sealed buildings in a step-change in ventilation solutions that has happened only in the last few years. MVHR systems are now promoted to be the preferred form of ventilation, viewed by many as standard in modern new-build homes post-2016[2] (Sullivan et al., 2012).

This shift towards extremely high levels of structural airtightness and mechanical ventilation to deliver adequate airflow has in part been driven by a shift to 'Passive House[3]' Standards developed in Germany in the 1990s to promote a simple palate of Insulation, High Performance Glazing, elimination of Infiltration and Cold Bridging and MVHR. This design mantra reflects the priority given during that decade to *Energy Efficiency*, rather than the more wide ranging design goals of the Multi-Comfort Home proposed by Saint Gobain[4] or the Danish Active House[5] where issues of sustainability and resilience are also taken into account. The latter promotes the use of 'adaptive envelopes' with natural ventilation, shading, thermal mass for energy storage and environmentally friendly materials. These are all models associated with a range of products to be traded, whether it is German MVHR systems, French plasterboard or Danish windows it is important that their benefits are understood and assimilated into good designs and that their weakness within the UK market context are also understood and avoided. One would not put a lightweight structure covered with roof lights in the Sahara desert nor rely solely on filtered mechanical ventilation for 'fresh air' in a very humid or dusty location.

There have been growing number of court cases in Europe and the UK related in particular to concerns around energy efficient buildings on indoor air quality and occupant health, particularly in housing[6]. Concerns expressed are often interlinked and associated mainly with the:

a) Effectiveness of mechanical ventilation systems in practice.
b) Potential for a build-up of air contaminants indoors.
c) Risk of overheating during the summer season – a rapidly growing problem.

Indoor air quality is now a hot topic in the Scottish media and in the UK, following the publication of a number of reports demonstrating the risk of poor indoor air quality in the home environment[7]. Architects have a profound influence on the quality of indoor air and have a responsibility to the building occupants to provide a safe and healthy indoor environment. It is important therefore to understand the risks associated with indoor air quality in new-build homes and take steps to address these where possible during the design process.

Why is indoor air quality a problem in modern homes?

There are particular features of modern airtight dwellings that make consideration of indoor air quality important. These are discussed below:

Increased airtightness

Improving airtightness levels is expected to play an important role in limiting energy loss through uncontrolled infiltration in UK homes. Poor levels of airtightness are claimed to be responsible for up to 40% of heat loss in buildings[8]. As homes become more airtight, less dependence can be placed on air permeability (leakage) to achieve adequate ventilation. Ventilation in homes can:

1. Supply fresh air / oxygen for breathing
2. Remove moisture from the home (from breathing, cooking, washing and showers etc) that can have health impacts eg. from the promotion of mould / fungal growth.

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[2] Sullivan, J. et al., (2012). Mechanical Ventilation with Heat Recovery in New Homes, Zero Carbon Hub and NHBC, Milton Keynes
[3] www.passivhaus.org.uk
[4] www.multicomforthouse.co.uk
[5] www.activehouse.info
[6] Sullivan, J. et al. (2012). Mechanical Ventilation with Heat Recovery in New Homes, Zero Carbon Hub and NHBC, Milton Keynes.
[7] Sassi, P. (2015). Indoor environment quality: legislation and regulations implemented in the United Kingdom, Proceedings of the 2015 Healthy Buildings Congress, Eindhoven. See: https://bh2015europe.files.wordpress.com
[8] Jaggs, M. and C. Scivyer (2009), A Practical Guide to Building Airtight Dwellings, NF 16, IHS BRE Press on behalf of the NHBC Foundation, Bucks, UK

3. Remove pathogens, gases and toxins
4. Removal of smells
5. Provide Direct comfort cooling or heating to occupants by convection
6. Provide Indirect comfort by heating or cooling the actual structure of a building
7. Cause discomfort if entering as uncontrolled draughts

Uncontrolled infiltration is not considered a good method of ventilation, but the tightening of building envelopes without adequate provision of ventilation has the potential to increase concentrations of indoor air contaminants, combustion gases, indoor humidity and associated mould growth, by preventing their escape.

Figure 1. Mould growth on the ceiling of a poorly ventilated bathroom (Source: MEARU – Mackintosh Environmental Research Unit, Glasgow School of Art)

Figure 2. Airtightness testing (Source: MEARU)

The nature of the ventilation paths through a building for all seven of the above functions is of crucial importance to both the health and comfort of its occupants, not least in airtight dwellings. The principle of 'build tight, ventilate right' is well known, first introduced in a popular Swedish marketing campaign and Building Code in 1980. However 'fresh air' is associated with health in the minds of many and apprehensions relating to the extremely high levels of airtightness sought in new-build dwellings remain.

Some home owners are concerned that ‘fresh air’ is excluded as air is delivered via dirty ducts of mechanical systems, some like to simply throw open a window to purge a stale room, others are worried about growing costs of installing and operating such systems and others with their potential to fail at the construction and operational phases. UK house builders are particularly concerned as to whether or not these strategies would result in a healthy indoor environment[9].

Reduction of Ventilation Rates

Evidence suggests that even once the expensive mechanical ventilation (MV) systems have been installed in many new build homes, they are not meeting recommended ventilation rates in practice. This has been shown to result from a number of different reasons, such as the poor performance of ventilation systems, obstructions to vents (such as trickle vents obstructed by blinds/ curtains), occupant interference (such as closing trickle vents or turning the mechanical ventilation system off) and/or inadequate ventilation provision at the design stage. In some cases, measured airtightness levels may go beyond design expectations, potentially resulting in the need for retrospective ventilation provision to meet desired air change rates.

Dependence on Mechanical Ventilation systems

In homes with MV without heat recovery, during the heating season there is often a trade-off between ventilation levels required to maintain good indoor air quality and control of ventilation to reduce heat loss and energy consumption. However, if ventilation levels are reduced below recommended levels this could have a detrimental impact on occupant health. Poor ventilation rates have been associated with a number of health issues, including asthma, allergies, sick building syndrome symptoms and infections[10].

Figure 3. Mechanical extract fan turned off by building occupant (Source: MEARU)

The increasing use of mechanical ventilation systems in housing signifies a step-change in the UK construction sector. In theory, if installed and operated correctly MVHR systems have the potential to improve the quality of indoor air by reducing exposure to particles through filtration of incoming supply air and the provision of continuous background levels of ventilation, irrespective of outdoor climate conditions. However dependence on MV systems to provide adequate levels of background ventilation involves inherent risks if systems fall short of the required standards.

Construction Materials and Techniques

Building materials can contain many chemicals known to be harmful to occupants, including phthalates, halogenated flame retardants, formaldehyde and Volatile Organic Compounds. Chemicals commonly found in the indoor environment include carcinogens, endocrine disrupters, neurotoxins and mutagens. ‘Red Lists’ for building materials are available that outline particular chemicals to look out for when specifying materials and products.

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[9] Davis, Harvey, 2008, Zero Carbon: What Does it Mean to Homeowners and Housebuilders (NF9), NHBC Foundation, Bucks.

[10] Wargocki, P. et al. (2002). Ventilation and health in non-industrial indoor environments: report from a European Multidisciplinary Scientific Consensus Meeting (EUROVEN), *Indoor Air*, 12:113-128

There are temporary exceptions for numerous Red List items due to current limitations in the materials economy. Refer to the Materials Petal Handbook for complete and up-to-date listings.

The project cannot contain any of the following Red List materials or chemicals:[20]

- Alkylphenols
- Asbestos
- Bisphenol A (BPA)
- Cadmium
- Chlorinated Polyethylene and Chlorosulfonated Polyethlene
- Chlorobenzenes
- Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs)
- Chloroprene (Neoprene)
- Chromium VI
- Chlorinated Polyvinyl Chloride (CPVC)
- Formaldehyde (added)
- Halogenated Flame Retardants (HFRs)
- Lead (added)
- Mercury
- Polychlorinated Biphenyls (PCBs)
- Perfluorinated Compounds (PFCs)
- Phthalates
- Polyvinyl Chloride (PVC)
- Polyvinylidene Chloride (PVDC)
- Short Chain Chlorinated Paraffins
- Wood treatments containing Creosote, Arsenic or Pentachlorophenol
- Volatile Organic Compounds (VOCs) in wet-applied products[22]

Figure 4. Living Building Challenge Red List (www.living-future.org)

Modern construction methods may also impact on indoor air quality. For example, the transition from solid, site built construction to more lightweight, pre-fabricated systems has the potential to reduce the sink area for pollutant absorption as the overall mass of the materials involved in the build may be reduced significantly. Furthermore, energy efficient design strategies that increase interior temperatures may exacerbate the degradation of indoor air quality by consequently increasing the emission of Volatile Organic Compounds.

The concentration of air pollutants indoors and levels of ventilation required depend in part on the relative volume of the space. In the UK, new-build homes are being built substantially smaller than in the rest of Europe. This may have significant implications on the quality of indoor air and cooling provision in new-build dwellings.

MVHR systems

The incorporation of MVHR systems in airtight dwellings should help to reduce heating demand while maintaining comfortable conditions and acceptable levels of ventilation and air quality indoors. This must be envisaged in the presence of risk factors, particularly in a social housing context, such as design and installation standards, occupant understanding and operation, maintenance and servicing in practice, and the effect of these on the overall performance of the systems.

Poor MVHR Design and Installation Standards –

Particular risks include: lack of sound attenuation, extensive use of flexible ducting, poorly sealed and insufficiently insulated ducts, inadequate mounting of ductwork, inappropriate placing of extract and supply grilles, inadequate air distribution between rooms and inaccurate commissioning. These risks are exacerbated by the lack of third party performance testing post completion. For information on best practice relating to the installation of MVHR systems, see the recently published NHBC Standards 2016 (Chapter 8.3: Mechanical Ventilation with Heat Recovery).

Figure 5. Duct bend un-insulated in cold roof (Source: Eco-Energy NI)

Occupant Understanding and Operation - Given the vulnerability of MVHR systems to inadequate operation and/or interference from building occupants, it is fundamentally important that households have a clear understanding of how the ventilation systems operate and their importance in an airtight construction. Particular risks include occupants turning the systems off, tightening the vents, or operating the ventilation system on the lowest setting (holiday mode), on boost mode continuously or on summer bypass mode during the winter season.

Figure 6. Trickle vent closed (Source: MEARU)

Maintenance and Servicing –

In mechanically ventilated homes, the performance of the ventilation system in practice is dependent largely on the quality of maintenance and upkeep of the system throughout the life of the building. A significant problem in a social housing context is the inability of maintenance staff to gain access to homes with MVHR systems to carry out essential repairs and maintenance (such as cleaning filters). Often filters require changing every 4-6 months, depending on location and activities within the home. The impact of inadequate maintenance on system performance however is substantial, resulting in problems with noise, reduced airflow, contamination of the supply air and increased energy consumption.

Recommendations to 'Design Right' for Ventilation

A) Communicate Information effectively to occupants: It is important to convey information in suitable format to ensure occupants are aware of the importance of ventilation and can operate the ventilation strategies effectively in their home. This may be achieved through provision of a bespoke, illustrated Home Starter Guide in combination with detailed hands-on demonstrations. Where installed, the benefits of heat recovery ventilation should be clearly communicated to occupants, to reduce the risk of deactivation due to concerns of energy consumption.

B) Design Suitable ventilation strategies: Is the dwelling located beside a busy road? What level of airtightness is likely to be achieved in practice? What maintenance is required for the chosen strategy and what are the likely costs? What level of complexity is appropriate for the building occupants? These are all questions that should be considered when deciding on a suitable ventilation strategy. For example, natural ventilation may not be particularly suitable for an airtight dwelling located beside a noisy, heavily polluted road.

Ventilation Control strategies: Control interfaces for mechanical ventilation systems (where installed) should be designed and positioned in a way to facilitate and promote occupant use and engagement. Interfaces should be user-friendly and located in the main living space or conjoining corridor and not positioned in a cupboard beside the ventilation unit. Automatic boost ventilation (activated for example by a cooker/shower switch or RH sensor) may be considered to ensure effective removal of excess moisture and pollutants indoors, in addition to manual controls. Boost mode switches should ensure automatic deactivation after a defined period of time, to eliminate the risk of continuous operation.

Plan for Maintenance: It is important to adequately consider maintenance requirements of mechanical ventilation systems at the design stage, including the adequate provision of space around the ventilation unit, access (particularly in a social housing context), complexity and frequency of maintenance required (filters, ducts, grilles etc.), and the associated costs. It is recommended to devise service checklists as a matter of course, to help ensure that the performance of the MVHR system does not deteriorate over time. Servicing contracts could be devised with MVHR suppliers/installers, to help break cycle of *'fit a fan and walk away'*.

Figure 7. Inadequately maintained filters (Source: MEARU)

Quality Control of ventilation: Greater attention to performance testing is required, including third party testing of flow rates, noise levels and electrical consumption of ventilation systems in practice. Designers need to be aware of conditions of warranties for MVHR systems, as warranties may be void where deviations from design occur on site.

Figure 8. Testing of airflow rates (Source: Gráinne McGill)

Source control: It is important for architects to be aware of the presence of toxic chemicals and communicate this knowledge to clients when specifying building materials and products. Source control is often the most effective strategy to improve indoor air quality in a home environment. Strategies might include the following:

- Provide a dedicated, well ventilated indoor drying space/ low energy system to reduce moisture build-up from naturally drying clothes indoors during the heating season
- Use hygroscopic surface finishes (such as clay or natural plaster based materials) to improve indoor moisture control
- Limit ingress of pollutants from outdoor sources through filtering of supply air or in naturally ventilated buildings, position ventilators/openable windows (where possible) at least 10m from external pollution sources
- Control indoor contaminants through the design of permanent walk off mats, a central vacuum system and/or shoe removal space
- Where ventilation ducts are installed, ensure these are sealed during construction to reduce the risk of contamination
- Use radon-resistant construction techniques
- Ensure adequate venting and sealing of connected garages to reduce ingress of pollutants into the home
- Specify non-toxic, durable and low-emitting building materials and finishes that can be cleaned using non-toxic methods
- Mixed mode solutions require clearly visible mechanical controls used to encourage the occupant to run the home in passive mode (windows open) with the mechanical systems off for various seasons or times of day and week, or mechanical mode when most effective (winter conditions).

Once potential sources of indoor air pollutants have been considered, there are a number of strategies that can be employed to improve the effectiveness of ventilation at removing indoor air contaminants, including:

- Provide adequate separation of intake and exhaust grilles
- Ensure all combustion appliances are adequately vented and specify carbon monoxide sensors for all floors
- Recommend a pre-occupancy flush (continuous purge ventilation) when construction work is completed (at least 48 hours) to reduce exposure to VOCs
- Ensure cooker hoods are vented to outside (not recirculated)

Enhanced passive ventilation: In naturally and mechanically ventilated homes, opportunities for effective passive ventilation should be maximised through careful consideration of local air pressure differences, prevailing wind direction, building form and orientation, positioning of openings, local topography and surrounding buildings. Importantly the move back to the inclusion of small opening areas for windows in kitchens, bathrooms and bedrooms – as was normal in homes before the 1990s – will enable the occupants to leave small areas open so removing moisture and contaminants without overly compromising energy efficiency, particularly after an event like cooking or washing. A major problem in modern homes is that windows are so large that they discourage occupants from naturally ventilating a home.

Post occupancy evaluation: Evaluating the quality of indoor air and ventilation post-occupancy is an important method to establish the concentration of air pollutants indoors and evaluate the effectiveness of the design process in providing a healthy indoor environment. This may also be applied to evaluate how occupants use the building in practice and detect particular sources of pollutants in order to devise strategies to remove these or control where possible.

Figure 9. Pollutant monitoring in a home (Source: MEARU)

Overall, there appears to be a general lack of awareness and attention to indoor air quality among UK building professionals. This may be attributed to perceived costs associated with indoor air quality strategies, confusion in assigning professional responsibility, the accentuated focus on energy goals and/or lack of awareness of the problem due to insufficient monitoring and evaluation. However, to ensure that occupant health is not disregarded in the drive towards energy efficiency, consideration of indoor air quality in modern new-build homes is essential and the architectural profession needs to take seriously the challenge of 'building tight and ventilating right'.