A protocol for assessing indoor air quality in retrofitted energy efficient homes in Ireland

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ABSTRACT

In recent years there has been much emphasis on improving the energy performance of Irish buildings. Much of this impetus stems from our requirements to implement provisions in the Energy Performance Building Directive (EPBD, 2002/91/EC, 2010/31/EU), and international targets to reduce CO_2 emissions by 2020. In Ireland, residential buildings account for 27% of Ireland's CO_2 emissions after transport. As a large proportion of the Irish building stock has already been built home owners are encouraged to retrofit existing buildings to improve the energy rating. The impact of retrofitting residential buildings to improve energy rating on indoor air quality and comfort has largely been unexplored.

This study proposes to conduct an assessment of indoor air quality and occupant comfort in 60 retrofitted energy efficient homes. Thermal comfort and occupant behaviour in retrofitted energy efficient home will also be assessed using an occupant survey. This is the first time that a full study of indoor air quality in retrofitted energy efficient homes will be completed in Ireland, and represents one of very few such studies conducted internationally.

KEYWORDS

Indoor air quality (IAQ), Indoor air pollution (IAP), Energy efficient retrofits, Retrofitted energy efficient homes, Thermal comfort

1 INTRODUCTION

In recent years there has been much emphasis on improving the energy performance of European buildings and encouraging the design, construction and market uptake of energy efficient domestic and public buildings. Much of this impetus stems from the EU commitment to decarbonise the European energy system by 2025 (European Commission, 2014a). The buildings sector accounts for 40% of the total EU energy consumption, and reducing energy in this area is an EU priority and one of the main objectives of the Energy performance Buildings Directive (European Commission, 2014b). In response to this challenge the Irish Government has published a National Energy Efficiency Action Plan (NEAAP, 2012) which defines actions to improve energy efficiency across six areas, including the residential sector, which accounts for over quarter of the primary energy used in Ireland. The Better Energy Home scheme is just one of many initiatives listed in the NEAAP, aimed at improving energy efficiency in the residential sector. To date over €300 million, or 255,000 homes have availed of house hold energy efficiency improvement under initiatives such as the Better Energy Home, or The Warmer Home Scheme (Better Energy, 2014).

It is not clear how increased building air tightness will impact on levels of indoor air pollutants (IAP), such as particulate matter or gases released from occupant activities in the home (Crump et al., 2009 and Milner et al., 2014). In most developed countries the population is known to spend upward of 80% of their time within indoor environments (Kleipeis et al., 2001), and a substantial percentage of this time at home, as a result exposure at home is likely to play a significant role in human health. Pollutants such as particulate matter ($PM_{2.5}$) play a significant role in the development and exacerbation of respiratory and cardiovascular diseases (Brunekreef and Forsberg (2005), Castillejos et al., (2000), Host et al., (2008), and de Hartog et al., (2003)). Energy efficient measures have some obvious direct health benefits such as increasing indoor temperatures and occupant comfort (Howden-Chapman et al., 2007). There are few studies which examine the potential health burden due to exposure to indoor pollutants generated in the home, and only one related to standard Irish homes (Galea et al., 2013). There have been no studies which have evaluated the health benefits of energy efficient retrofits in Europe, partly because of the lack of data on indoor air quality (IAQ) in energy efficient homes (Crump et al., 2009, Derbez et al., 2014, Arvela et al., 2013) or in energy efficiency retrofits (Milner et al., 2014).

A recent UK study (Milner et al., 2014) used mathematical models to investigate the effect that reduced home ventilation as part of a household energy efficiency retrofit would have on deaths from radon related lung cancer deaths. Results from this study suggest that increasing building air tightness could increase radon concentrations by 57%, resulting in an additional annual burden of 4700 life years and (at peak) 278 deaths. Milner and co authors conclude that reducing uncontrolled building ventilation may have a negative impact on IAQ and health and caution that energy efficient improvements in the home needs careful management requiring a ventilation strategy. A study on IAQ in newly built French homes incorporating mechanical ventilation with heat recovery (MVHR) before and after occupancy, showed that concentrations of pollutants such as benzene, $PM_{2.5}$ and radon were low and other pollutants such as CO_2, and formaldehyde were comparable to concentrations in standard French homes. The MVHR units allowed for air exchange rates of 0.5 h-1 or higher, the authors caution that IAQ could become an issue if the MVHR units are not used correctly (Derbez et al., 2014).

It is essential that consideration is given to ensure that adequate ventilation is included in the retrofit, to maintain thermal comfort parameters and to remove air pollutants generated indoors. The National Standards Authority of Ireland has provided a code of practice for the energy efficient retrofit of dwellings (National Standards authority of Ireland, 2014). Natural ventilation and wall or window trickle vents are the most common form of ventilation in Irish homes and may not be adequate for higher levels of building air tightness. Impacts of increasing the energy efficiency of households are largely positive; along with reducing energy use, helping to meet National and EU Energy targets, the building retrofit should make the home more comfortable for the occupant as it will improve indoor temperature, and reduce moisture. However there are some concerns that increasing building air tightness may have a negative effect on IAQ, which in turn could affect health.

1.1 Objectives

The objectives for this study are to characterise indoor concentrations of a number of priority pollutants, and to access occupant comfort before and after homes undergo an energy efficient

retrofit. The impact of energy efficient retrofitting on indoor air pollutant concentrations, occupant comfort and energy consumption will be examined.
A questionnaire will be design and administered to the owners of the energy efficient retrofitted homes to investigate the perceived benefits of retrofitting and to explore the possibility of co-benefits from retrofitting.

2 METHODOLOGY

60 homes that are planning a household energy efficient retrofit will be recruited in collaboration with Sustainable Energy Authority of Ireland (SEAI), Energy Agencies and Local County and City Councils for the main study. A pilot study will be completed in winter 2014 and will include 12 homes. As part of the retrofit homes will have the levels of insulation will be increased, windows and doors will be replaced, and the boiler will be upgraded to at least 90% efficiency as a minimum. Homes will be recruited to participate in the study using the following selection criteria:

a) Families, 1 or 2 adults with children, occupants will be non- smoking.
b) Three bed semi-detached houses (100 – 126 m2) with Building Energy Ratings (BER) of less than D1, constructed of either hollow block or cavity wall insulation,
c) Homes which are planning to undergo energy efficient retrofit of up to B1 or B2 BER over the period September 2015 – September 2016,
d) Hollow block homes planning a retrofit upgrade to include new windows, and either external or internal insulation, and
e) Cavity wall block homes planning a retrofit upgrade to include new windows, and either internal or cavity wall insulation.

2.1 Pilot Study

The pilot study will include 12 homes that will be monitored before and after an energy efficient retrofit during the winter period of 2014 to assess worse case scenario for the generation of indoor pollutants and maximum energy use in the home. Homes will be selected for inclusion in the study by construction type as illustrated below (Figure 1).

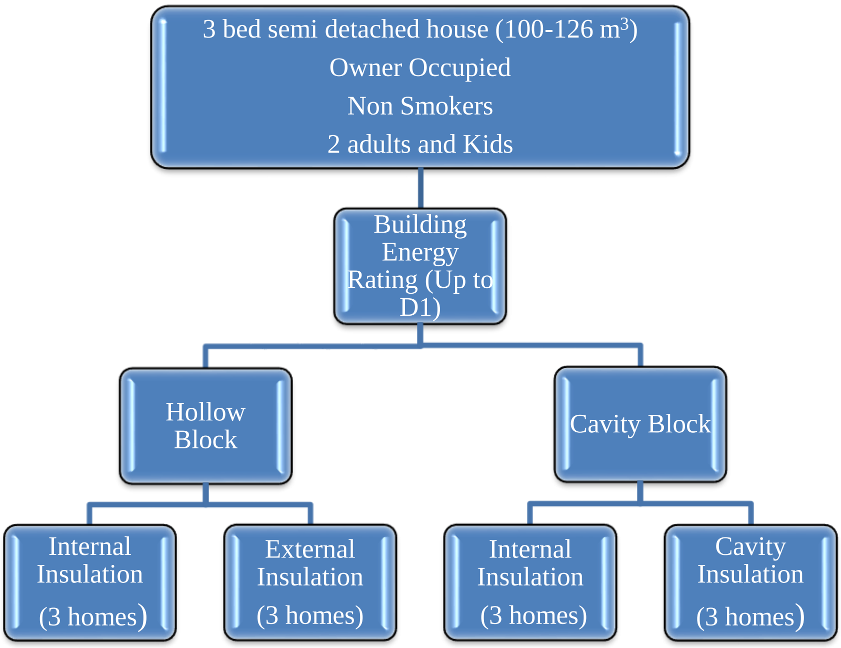

Figure 1: Breakdown of construction types and number of homes to be monitored in each group.

2.2 Types and locations of sensors

Within each participating home, samples will be collected in the area of the home where the occupants mainly use i.e. the main living room and the main bedroom.

a) A TSI SidePak AM510 Personal Aerosol Monitor fitted with a PM2.5 impactor will be used to collect and log real-time data on airborne PM2.5. The monitor will be set to log at 1 minute intervals and will allow assessment of peaks and daily variability in exposure to be determined.
b) Average indoor nitrogen dioxide levels will be measured using NO_2 Passive Diffusion Tubes (DIF100RTU-R/A) supplied by Gradko Environmental. NO_2 will only be monitored in the main living room.
c) Carbon monoxide levels will be measured using EL-USB-CO Carbon monoxide loggers
d) Radon gas levels will be measured using passive radon detectors, supplied by the Radiological Protection Institute of Ireland.
e) Total Volatile Organic Compounds and BTEX concentrations will be collected using a GrayWolf IQ-610 photoionisation detector.
f) Formaldehyde measurements will be made using a GrayWolf FM-801 formaldehyde meter. Formaldehyde will be monitored only in the main living room.
g) Temperature and Relative Humidity levels will be measured during both winter and summer, using Telaire 7001 Monitors and HOBO Data loggers and Thermo hydrographs.
h) Surface samples of dust mites will be collected from representative flooring and bed surfaces, using an SKC Carpet Tester suction sampling kit, comprising a polycarbonate filter cassette, connection to a Flite 2 High-volume sampling pump. The mites will be enumerated by microscopic analysis of the polycarbonate filters, using a protocol developed at the London School of Tropical Medicine.
i) Air exchange rates will be determined in the kitchen, living room and bedroom of each house using tracer gas analysis.

2.3 Questionnaire

A questionnaire will be designed and administered that will investigate the co-benefits of energy efficient retrofitting using previous studies in this area (Howden-Chapmen et al., 2014, Cox, 2005, Walker et al., 2014). Co-benefits of energy efficient retrofitting can include improved health and well being, energy cost savings, mould and damp reduction in the homes, and improved indoor air quality (Chapman et al., 2009). Jacob and Nutter, (2003) noted that co-benefits in energy efficient buildings such as improved comfort, better indoor air quality and enhanced noise protection may have the same monitory order of magnitude as energy-related benefits.

2.4 Data Analysis

The data obtained from before and after the retrofit will be compared to investigate the differences in levels of air quality between the dwellings. Independent samples *t* test and one-way ANOVA tests will be used to determine the differences before and after the retrofit and between the different construction types.

Thermal comfort will be assessed using the predicted mean vote (PMV) model with zero representing thermal neutrality on a scale from -3 to +3. However, although zero is the ideal scenario, anywhere from -0.5 to +0.5 is acceptable. The PMV model uses a combination of metabolic rate, clothing insulation, air temperature (dry bulb), mean radiant temperature, operator temperature, air speed, and relative humidity to determine thermal comfort (ISO EN 7730, 2005). The data for the PMV model will come from an occupant activity diary and from measurements taken from the house.

The relationship between IAQ and occupant behaviour will be assessed. Sharmen et al., (2014) suggested that occupant lifestyle and comfort can have a significant impact on the heating energy consumption in an apartment. Geurra-Santin (2013) found that although the overall energy consumption of energy efficient homes was less, this can lead to a rebound effect where the occupants tend to favour higher temperatures and less ventilation.

The rebound effect is when energy savings as a result of energy efficient improvements are negated by increased levels of energy consumption (Herring and Sorrell, 2009, Hens et al., 2010). The rebound effect will need to be taken into account when determining occupant behaviour relating to energy consumption. Factor analysis will be used to identify any underlying occupant behaviour factors that can potentially predict energy consumption and IAQ. Factor analysis will be used to investigate any possible correlation between occupant behaviour variables.

3 RESULTS AND CONCLUSIONS

The impact of increasing the energy efficiency of households are largely positive, along with reducing energy use, meeting EU Energy targets, the building retrofit should make the home more comfortable for the occupant as it will improve indoor temperature, and reduce moisture. However there are some concerns that increasing building air tightness may have a negative effect on IAQ, which in turn could affect health. Preliminary project results and proposed project methodologies will be presented here. This project aims to evaluate the impact of energy efficient retrofits on indoor air quality and occupant comfort.

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