Indoor Air Quality and Thermal Comfort, in Irish Retrofitted Energy Efficient Homes

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ABSTRACT

Indoor air quality and thermal comfort was measured in 14 three-bedroom, semi-detached, cavity wall naturally-ventilated homes during the winter following an energy efficient retrofit. As part of the energy retrofit, homes received new windows and doors, an upgraded heating system, attic insulation, and wall vents, as well as pumped beaded wall insulation into three external walls.
Temperature and relative humidity (RH), as well as concentrations of total volatile organic compounds (TVOCs), $PM_{2.5}$, CO_2, and CO were measured over a 24-hour period in the main living area and main bedroom of each home. Concentrations of NO_2 and formaldehyde were measured in the living room only. Benzene, toluene, ethylbenzene, xylene, and NO_2 were measured over a three week period and radon was monitored over three months.
The average winter air change rate was 0.59 h^{-1}. The average PM2.5 concentrations during the winter period were 18.5 $\mu g/m^3$. The 24 hour average formaldehyde and TVOC concentrations were 19.4 ppb and 379.7 ppb respectively. The average 24 hour temperatures and humidity levels found in the living room and bedrooms in the retrofitted dwellings were 20.0 ºC and 19.1 ºC and 46.8 %RH and 50.4 %RH, respectively.

KEYWORDS

Indoor air quality, retrofit, occupant behaviour, thermal comfort

1 INTRODUCTION

In most developed countries,people are known to spend more than90% of their time indoors (Vardoulakis, 2009)and a substantial percentage of this time is in thedwelling; as a result exposure to pollutants in thedwelling is likely to significantly influence human health.Over the last number of years, more dwellings are being retrofitted to reduce energy usage to meet energy efficiency targets and as a method for reducing fuel poverty. There is still limited knowledge on the unintended consequences of retrofitting such as the impact of reducing ventilation rates in indoor air quality. While there have been studies that have assessed the impact of retrofitting on indoor air quality across one season(Broderick et al., 2017), there are few studies which have monitoredindoor air pollutants over six to twelve months after an energy efficient upgrade (Földváry et al., 2015, Coombs et al., 2016, Wells et al., 2015).Studies such asWells et al. (2015)have reported short term increases in $PM_{2.5}$ and formaldehyde concentrations immediately following a retrofit,but a long term decrease one year after the retrofit.

Pollutants such as BTEX, VOCs, and carbon monoxide have been known to vary seasonally, with winter having the highest concentrations(Elbayoumi et al., 2014). Concentrations of VOCs during the winter period can be three to four times than concentrations during the summer period (Schlink et al., 2004).Parameters such as CO_2,temperature and humidity can vary seasonally, studies such as Derbez et al. (2014) andFöldváry et al. (2015). Földváry et al. (2015) have reported differences in CO2, temperature, and humidity between winter and summer in energy efficient homes. Elements such as weather conditions, occupant behaviour, and outdoor concentrations can influence the concentrations of indoor air quality parameters(Schlink et al., 2010).

Methodology

The dwellings were monitored during the winter period following the retrofit. The dwellings recruited were constructed in accordance with the Irish Building Regulations(Building Control Act, 1990). The dwellings were of cavity wall construction and were built in 2000. The dwellings had a volume between 100 – 126 m^3 and had a D1 or D2 building energy rating. Indoor air pollutants and thermal parameters were monitored in the main living room and bedroom in each dwelling. A basic layout of the dwellings is shown below (Figure 1).

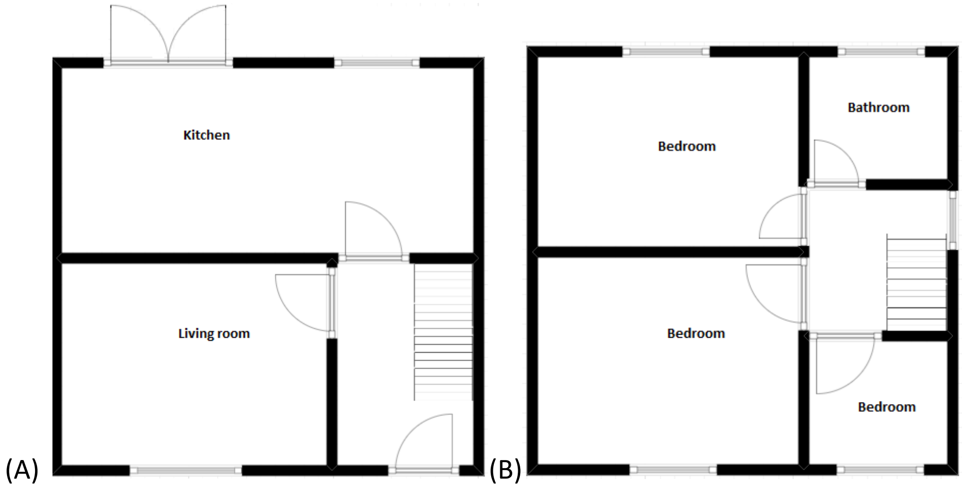

Figure 1: Schematic showing typical layout of the 3 bed roomed semi detached dwellings. (A) Downstairs (B) Upstairs(Broderick et al., 2017)

A TSI SidePak AM510 Personal Aerosol Monitor fitted with a PM2.5 impactor was used to collect and log real-time data on airborne PM2.5 The monitor was set to log at 1 minute intervals to allow assessment of peaks and daily variability in exposure to be determined. Carbon monoxide levels were measured using EL-USB-CO carbon monoxide loggers. A Graywolf IQ 610 was used to monitor CO, CO2, total volatile organic compounds (TVOCs), temperature (Wet bulb and Dry bulb), and relative humidity (%RH). Carbon Dioxide levels were monitored using Telaire 7001. A Graywolf TG 502 was used to monitor total volatile organic compounds (TVOCs), temperature (Wet bulb and Dry bulb), and relative humidity (%RH). Average indoor nitrogen dioxide levels were measured using NO2 passive diffusion tubes supplied by Gradko Environmental. NO2 was monitored in the main living room only. Total Volatile Organic Compounds (TVOCs) concentrations were collected using a GrayWolf IQ-610 photoionisation detector. Average BTEX levels were measured using BTEX Passive Diffusion Tubes supplied by Gradko Environmental. BTEX levels were monitored in the main living room and bedroom. Formaldehyde measurements were made using a GrayWolf FM-801 formaldehyde meter. Formaldehyde was monitored only in the main living room. Air exchange rates were determined in the living room of each house by using CO2 as a tracer gas and measuring the rate of decay over a one hour period (Cui et al., 2015). Air change rates were expressed as h^{-1}.

The comfort vote was measured at two times during the 24 hour monitoring period; in the morning and in the evening. The comfort vote is a subjective occupant thermal scale going from "-3" (cold) to "+3" (hot), with "0" as "neutral". The occupants completed a short comfort survey, whichalso incorporated the level of activity, location in the dwelling, and what the occupants were wearing at the time.

Retrofit specifications

The dwellings were upgraded over the summer periods of 2015 and 2016. Each of the dwellings received pumped insulation (using extruded polystyrene beads) (Figure 2), 300 mm thick attic insulation (mineral rock wool). The dwellings had the windows and doors replaced with more energy efficient models. Each of the dwellings had the boiler upgraded to a 90% efficient boiler with heating controls (modulating condensing balanced boiler). Background vents with covers were installed in the dwellings and extract fans with humidity control were installed in the kitchen and bathroom.

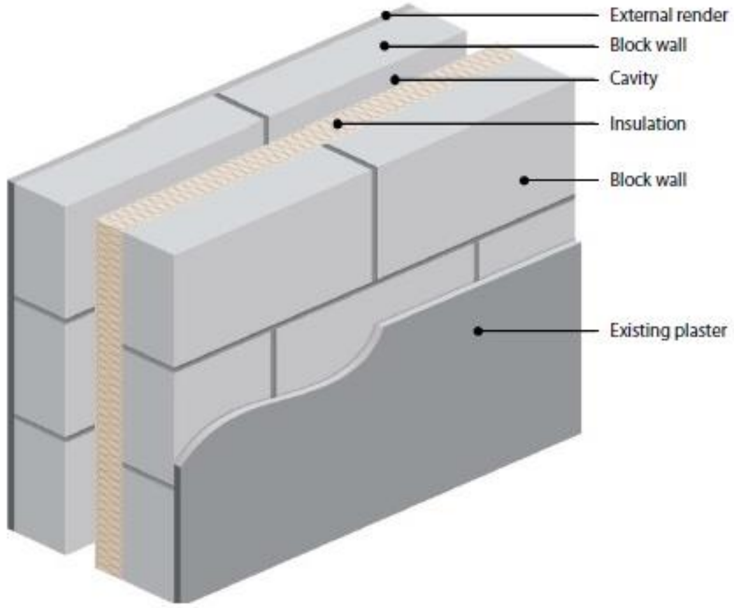

Figure 2: Schematic showing cavity wall(NSAI, 2014)

Data Analysis

The statistical package SPSS (version 23) was used to calculate 24 hour means, standard deviations and ranges for each variable.

Indoor air quality guidelines

Each of the dwellings indoor air quality and thermal parameters were compared to international guidelines.

Results

Table 1and Table 2summarise a sample of the IAP measurement data collected during the winter period following a retrofit. The majority of the post retrofitwinter IAP concentrationswere found to be within WHO guidelines. The average winter air change rate was 0.59 h^{-1}. Data for radon, NO_2, and BTEX are pending. The $PM_{2.5}$ concentrations of 18.5 µg/m3 were similar to those found in French dwellings during the winter period (16.9 µg/m3)(Derbez et al., 2014). Formaldehyde concentrations (19.4ppb) were similar to those found in Swedish homes during the heating season (17.0 ppb) (Langer and Bekö, 2013). Concentrations of TVOCs were found to be higher in the current study compared to French dwellings (Derbez et al., 2014). The temperatures found in the living room and bedrooms in the retrofitted dwellings were similar to those found in renovated UK homes by Hong et al. (2009) (20.02ºC in the living room, 19.1ºC in the bedroom and 19.7ºCin the living room and 18.2ºCin the bedroom, respectively).

Table 1: Post retrofit winter 24 hour mean temperature and relative humidity

	(N=14)		
Winter	Mean	SD	Range
Temperature (living room)	20.2	2.0	18.0 – 23.5
Temperature (bedroom)	19.1	1.9	16.2-23.2
RH (living room)	46.8	9.5	30.2 – 55.6
RH (bedroom)	50.4	3.6	33.8 – 55.3

Table 2: Post retrofit 24 hour winterIAP concentrations

Pollutant	(N=14)		
Winter	Mean	SD	Range
PM2.5 (µg/m3) [1]	18.5	3.6	11.8 – 23.4
CO2 (ppm) [1]	726.5	93.5	557.0 – 842.5
CO (ppm) [1]	0.7	0.4	0.1 – 1.4
Formaldehyde (ppb) [1]	19.4	5.8	10.8 – 29.7
TVOC (ppb) [1]	379.7	108.4	206.2 – 547.5

[1] 24 hour averages

Thermal comfort

Post retrofit, the majority the occupants (n=13) were satisfied overall with the comfort during the winter period in their dwellings. 21 % (n=3) occupants reported that their dwellings were draughty during the winter period after the retrofit due to issues with the vents located in the living room. The comfort vote during the winter monitoring was between “neutral” and “warm” in the cavity wall dwellings.

Discussion

Previous studies have shown that air change rates decreased in the dwellings that had their three walls filled with insulation and windows and doors changed(Shrubsole et al., 2012).The increase in temperature in the dwellings may have been due to the increased insulation and the upgraded more efficient boiler. Heat loss in the dwellings can be decreased through increased cavity wall insulation.Byrne et al. (2016) reported a heat loss reduction in dwellings of between 21 to 66 % in cavity wall homes and a 37% to 77% reduction in externally insulated wall dwellings. Due to the lower outdoor temperatures during the winter period, dwelling occupantsin this study tended to limit the amount of time for which windows and doors were open during the monitoring period. The occupants reported cleaning and using aerosols products such as cleaning sprays and odour masking sprays, which, when combined with lower ventilation rates during the winter period, can lead to increases in pollutant concentrations.

5 CONCLUSIONS

This study aimed to assess the impact of retrofitting dwellings on indoor air quality, thermal comfort, and ventilation. The results indicate that the concentrations of pollutants and thermal parameters were in line with previous studies, however the findings of this study cannot be generalised to other homes due to the limited sample number. As the data presented is only a sample of the IAP monitored, and studies have shown that pollutant levels can vary following the retrofit, these dwellings are currently being monitored during the summer period.Future studies on energy efficient dwellings should investigate indoor air quality in dwellings over the different seasons so as to ensure that energy retrofit programmes do not have a negative impact of health. This study provides valuable data which can be used in health impact assessments to assess the impact retrofitting has on health and can also aid in the progress of indoor air quality metrics.

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