An Experimental Validation of an Indoor Radon Model that examines Energy Retrofit Buildings

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ABSTRACT

The modelling framework IAPPEM was redeveloped to predict indoor radon concentrations in dwellings that have undergone an energy retrofit, and have experienced a consequent air tightness change. The framework is flexible, and allows for simulations to be carried out under various pre-retrofit radon concentration levels, multi-zone building geometries, ventilation configurations and retrofit types. However, detailed real-time radon concentration and ventilation data is necessary for model validation, and such data is non-existent in the Irish context. The generation of these data, which allows for full model validation and testing, is the focus of the current study. The objectives of the current study are to (i) fully characterise the ventilation status of selected Irish dwellings, through measurement, and determine the real-time radon concentrations therein (ii) parameterise the model for these selected dwellings, and make comparative predictions of radon concentrations. The current study focused on measuring hourly radon concentrations, using real-time radon monitors, in dwellings that are representative of the buildings stock undergoing energy retrofit. Each dwelling was monitored for a week-long period to establish time-varying fluctuations in indoor radon concentrations and obtain data on the minimum and maximum range. In addition, air exchange was measured using the tracer gas decay method with CO_2 as the tracer. Air exchange comprised of eight selected hourly measurements per dwelling over each measurement week to ensure that the effect of meteorological variations was captured. The model will predict indoor radon concentrations based on local meteorological conditions, building characteristics and in-situ characterisation of radon entry rates derived from experimental measurements. The model's output will be compared with the hourly radon concentrations collected during the sampling period. Time-series analysis will be carried out, comparing experimental and predicted indoor radon concentrations.

KEYWORDS

Field data
Indoor radon concentrations
Dynamic radon entry rates
Ventilation in renovated buildings

1 INTRODUCTION

The negative impact on human health due to exposure to ionising radiation is well documented (WHO, 2009). In Ireland, radon gas is considered the greatest source of radiation exposure to the general population accounting for just over 55% of the average radiation dose (Connor et al., 2014). Radon gas (222Rn) is a naturally occurring odourless, colourless and tasteless gas; it arises as a product of Uranium (238U) decay, which is a radioactive material found in varying quantities in soil and rocks. Radon decays by emitting an α particle into a series of short-lived radioactive progeny, two of which are polonium (218Po and 214Po). If inhaled, the vast majority of radon is exhaled almost immediately. However, the short-lived decay products of radon can deposit on the bronchial epithelium and be exposed to alpha radiation (IARC, 2001).

Radon is the second highest leading cause of lung cancer, after smoking, in many countries. In an OECD survey of 30 countries, Ireland was found to have the eighth-highest average indoor radon concentration, accounting for up to 250 cases of lung cancer each year (WHO, 2009, Colgan et al., 2008). Darby et al. (2005) examined radon levels from 13 European case-control studies and the associated risk of lung cancer; the study found that for every 100 Bq m^{-3} increase in measured radon, there was an 8.4% (95% CI [3.0%, 15.8%]) increase in the risk of lung cancer.

The European Energy Efficiency Directive (2012) sets the policy roadmap for the period until 2020, and each Member State is required to reduce their energy consumption by 20% to meet the EU's greenhouse gas emission reduction commitments. In 2014, Irish buildings accounted for 35% of the total national energy consumption and approximately 59% of electricity consumption (SEAI, 2016). Retrofitting of the building fabric has been identified as one of the most cost-effective energy-efficiency improvements to achieve energy savings in the economy (Johnston et al., 2005).

In the Irish context, the scope for energy efficiency gains to be made through retrofitting of the existing building stock has been continuously identified within the National Energy Efficiency Action Plans (DCENR, 2014b, DCENR, 2009, DCENR, 2011a). To this end, the Irish National Energy Retrofit Programme aims to upgrade 1.2 million residential, public and commercial buildings by 2020 (DCENR, 2011b, DCENR, 2014a). However, recent research has shown that energy retrofitting of dwellings may lead to greater airtightness, and there is a possibility that radon concentrations may accordingly increase (Pressyanov et al., 2015, Fojtikova and Rovenska, 2014, Jiránek and Kačmaříková, 2014, Fojtíková and Navrátilová Rovenská, 2015).

Studies have reported that indoor radon concentrations are strongly associated with the geogenic radon potential, building material, construction type, foundation and the year of construction (Demoury et al., 2013, Drolet and Martel, 2016, Borgoni et al., 2014, Collignan et al., 2016). However, even dwellings located in the same area, with assumed relatively homogeneous radon potential, have reported localise heterogeneities exert a strong influence on indoor radon concentrations (Drolet and Martel, 2016).

Small pressure differences between the indoor and outdoor environments gives rise to the convective transport of radon gas into dwellings; various factors including the stack effect, wind interaction with the building fabric, heating and mechanical ventilation all contribute to the pressure differences (Nazaroff, 1992).

Previous studies have modelled indoor radon concentrations in the residential microenvironment (Revzan and Fisk, 1992, Sherman, 1992, Man and Yeung, 1999, Fang and Persily, 1995, Keskikuru et al., 2001, Milner et al., 2014, Riley et al., 1999, Diallo et al., 2013). However the majority of these studies focussed either simulating the sub-slab gravel layer had on radon entry rates into buildings. Milner et al. (2014) investigated the impacts of indoor radon concentrations as a consequence of increasing the airtightness of the English housing stock; however, this study only assumed a steady state radon entry rate and did not account for dynamic radon entry rates into dwellings.

Collignan et al. (2012) reported dynamic radon entry rates that results in a high temporal variability of radon concentrations in residential buildings; factors that influence radon entry rate include wind speed, moisture content, pressure differences and radon concentration in the soil (Keskikuru et al., 2001, Riley et al., 1999, Andersen, 2001).

In response to the National Radon Control Strategy (NRCS, 2014), the modelling framework IAPPEM (McGrath et al., 2014a, McGrath et al., 2014b) was redeveloped during the EPA project UNVEIL: UNderstanding VEntilation and radon in energy efficient buildings in IreLand (2015-HW-DS-4). The model predicts radon concentrations in dwellings that have undergone an energy retrofit, and have experienced a consequent air tightness change. The framework is flexible, and allows for simulations to be carried out under various pre-retrofit radon concentration levels, multi-zone building geometries, ventilation configurations (i.e. vent size/type) and retrofit types (e.g. cavity filling and external insulation). However, detailed real-time radon concentration and ventilation data is necessary for model validation, and such data is non-existent in the Irish context. The generation of these data, which would allow full model validation and testing, is the focus of the current study.

2 METHODOLOGY

Site Selection

Irish dwellings were recruited through existing local authority contacts, that are representative of those referred to in NSAI S.R. 54:2014 Code of Practice: Methodology for the energy efficient retrofit of existing dwellings (i.e. bungalow, semi-detached, terraced dwellings) (NSAI, 2014). Dwellings were selected where radon levels are both above and below the 200 Bq m^{-3} Irish reference level, as pre-determined from passive radon monitoring carried out by the EPA.

Outdoor temperature and pressure data for the measurement dates were obtained from the Informatics Research Unit for Sustainable Engineering (IRUSE) at the National University of Ireland Galway, which maintains a full record of weather conditions in Galway, Ireland (53.280148, -9.059237).

All residential dwellings were located within approximately 3 km of National University of Ireland Galway.

Airflow and Air Tightness measurements

Air exchange rate measurements were carried out for each dwelling using the CO_2 tracer gas decay technique. Air exchange comprised of eight selected hourly measurements per dwelling over each measurement week to ensure that the effect of meteorological variation was captured. The CO_2 tracer gas decay measurements involved releasing CO_2, from a sealed cylinder, into the room, until concentrations exceeded 3500 ppm. A GrayWolf probe (GrayWolf Sensing Solutions; Shelton, CT, USA) was used for gas detection at one-minute intervals.

Air tightness testing was conducted in accordance NSAI Certification I.S. EN ISO 9972:2015 - Thermal Performance of Buildings – Determination of Air Permeability of Domestic Buildings – (Single or Single & Multi) Fan Pressurisation Method. A single measurement per dwelling was carried out, as weather variations over the course of the experimental period will induce pressure differentials of far less than 50 Pa, which is the design pressure for air-tightness testing.

Field Measurements and Data Collection

In order to obtain representative values for radon entry rates into Irish dwellings, the methodology developed by (Collignan and Powaga, 2014) to characterise radon potential in existing dwellings will be employed. The methodology involves a blower door test to maintain the dwelling at successively different depressurization levels that heighten the convective radon flux into the dwelling. In steady state conditions, the radon flow leaving the building through the blower door corresponds to the radon entry rate.

Hourly radon concentrations were measured with a continuous radon monitor, a Rstone Continuous radon gas sensor (Radiansa Consulting S.L., Girona, Spain), for a week-long period to establish time-vary fluctuations in indoor radon concentrations and obtain data on the minimum and maximum range.

Data analysis, model validation and simulation

The model will predict indoor radon concentrations based on local meteorological conditions, building characteristics and in-situ characterisation of radon entry rates derived from experiments. The model's output will be compared with the hourly radon concentrations collected during the experimental campaign. Time-series analysis was carried out, comparing experimental and predicted indoor radon concentrations.

3 RESULTS

As the experimental monitoring campaign is still ongoing only initial results are available to present within in paper. The initial results focus on data collected from 26 days monitoring within a single dwelling. The data was designed to capture the variability in radon concentration over an extended period.

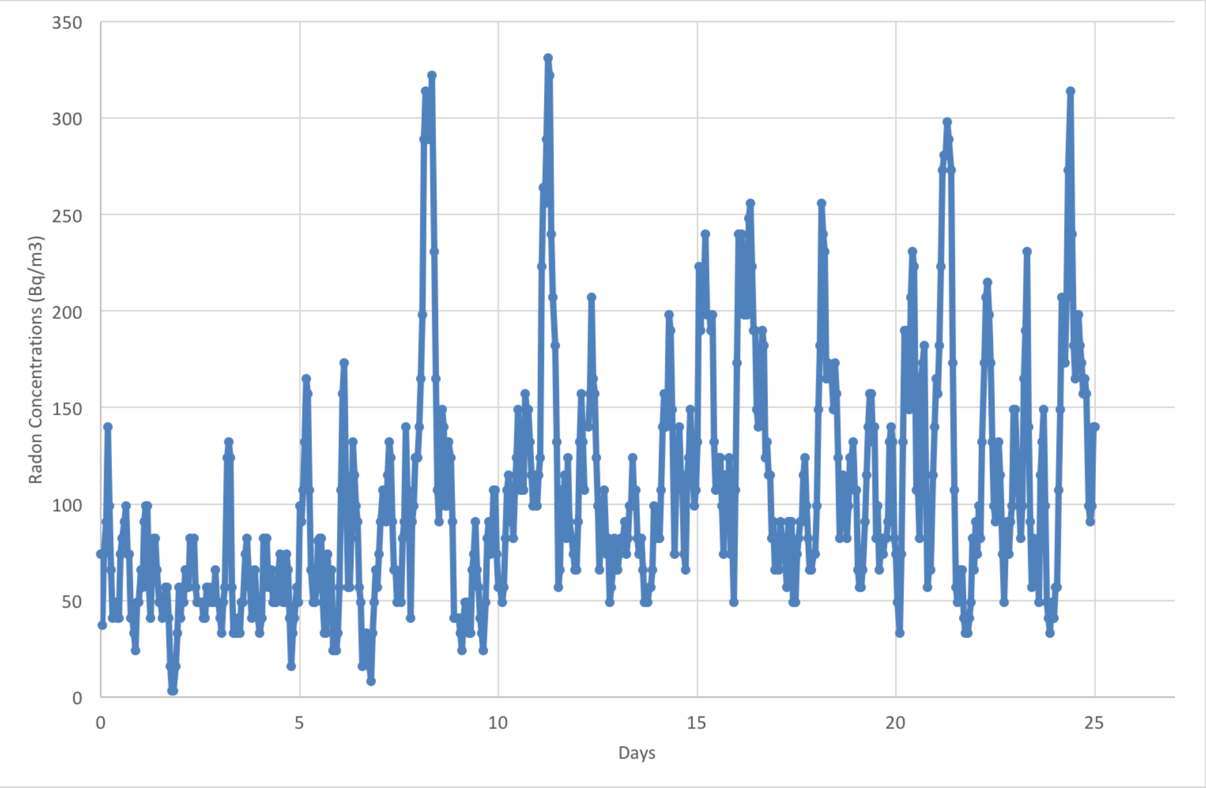

Figure 1. Time-series data from 26 days from hourly measurements.

Figure 1 illustrates the high temporal variability of the indoor radon concentrations in an unoccupied room. Table 1 summarises the mean, minimum and maximum for temperature, radon concentrations, pressure values and humidity over the 26 days. The results demonstrate that variations occur for the indoor pressure and radon concentration, while the indoor temperature remains relatively consistent over the sampling period.

Table 1. Summaries the data obtained from 26-day sampling in one residential dwelling.

Radon Concentration	Min	Max	Mean
Radon Concentration (Bq/m^3)	3	331	105
Relative Humidity (%RH)	44	60	55
Pressure (mbar)	973	1017	1002
Temperature (Celsius)	21	27	23

4 CONCLUSIONS

The current study focuses on measuring hourly radon concentrations, using real-time radon monitors, in dwellings that are representative of the building stock undergoing energy retrofit. Each dwelling was monitored for a week-long period to establish time-varying fluctuations in indoor radon concentrations and obtain data on the minimum and maximum range. In addition, air exchange was measured using the tracer gas decay method with CO_2 as the tracer. Air exchange comprised of eight selected hourly measurements per dwelling over each measurement week to ensure that the effect of meteorological variations was captured.

The remaining work focuses on the model predicting indoor radon concentrations based on local meteorological conditions, building characteristics and in-situ characterisation of radon entry rates derived from experimental measurements. The model's output will be compared with the hourly radon concentrations collected during the sampling period. Time-series analysis will be carried out, comparing experimental and predicted indoor radon concentrations.

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