Collecting Long-term Indoor Environmental Quality Data in Highly Energy Efficient Irish Dwellings

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ABSTRACT HEADING

Current building regulations are designed to ensure that buildings, including newly built and retrofitted residential dwellings, are more energy efficient. This has raised concerns and practical challenges in relation to maintaining acceptable indoor environmental and air quality. However, there are minimal data available regarding long-term indoor air pollutant concentrations in low-energy residential buildings. The majority of studies to date have focussed on using the traditional research approach that uses research-grade equipment; however, this approach has limitations in the ability to obtain longer-term measurements. The current study uses customer-grade sensors with the capability of remotely transmitting information to conduct a longitudinal monitoring campaign. These sensors have been installed in four rooms per dwelling in highly-energy efficient Irish dwellings; two habitable rooms (living room and bedroom) and two wet rooms (kitchen and bathroom). The sensors collect indoor environmental and air quality data; temperature, humidity, CO_2*, VOCs, radon and air pressure. The sensors will be collecting data continuously for 18 months, two winter periods (heating season) and a summer period. While data collection is still ongoing, a cumulative of 43,120 days' worth of data has already been collected. This paper presents the data from a sample of 20 randomly selected dwellings. The initial findings highlight a considerable distribution of data within dwellings, demonstrating the ability of long-term monitoring campaigns to capture indoor air pollutant fluctuations. Data analysis is still ongoing and is focusing on identifying temporal trends in indoor environmental quality, accounting for factors including occupants' activities, building characteristics, seasonal variations, and the effectiveness of the ventilation system (natural vs mechanical ventilation systems).*

INTRODUCTION

The potential negative impact of building energy conservation measures on Indoor Air Quality (IAQ) is widely acknowledged. Indoor air pollutants are of particular concern, as occupants spend more than half of the time spent indoors in residences, with elderly and children spending up to 100% of their time in dwellings. It is therefore essential to understand how energy-saving strategies impact upon indoor air quality and the well-being of occupants.

Cony Renaud Salis et al. (2017) reported the challenges in reviewing these criteria as currently there are insufficient data available in low-energy residential buildings. Typically, only aggregated pollutant concentrations (average, min, max) are summarised, which lack enough detail for individual buildings. To appreciate the complexities of the indoor built environment, there is a requirement for sufficiently large datasets to capture the range of influencing factors on air quality such as; building characteristics, meteorological conditions, ventilation type and control system, occupant behaviour.

Traditional research approaches rely upon research-grade equipment and repeated visits to each location, which places resource constraints (both equipment and personnel) on administering large-scale monitoring campaigns. The

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recent improvements in customer-grade (low-cost) IAQ sensors means that there is an opportunity to collect large-scale data without the traditional constrictions.

The current research is continuously accumulating indoor environmental quality measurements over two heating seasons and a cooling season in low-energy residential buildings. This provides a complex comparison that incorporates occupant satisfaction, thermal comfort, indoor air quality and potential for mould growth.

METHODOLOGY

McGrath et al. (2019) evaluated various criteria to consider when selecting customer-grade (low-cost) sensors for longer-term monitoring campaigns compared with a traditional research project. After considering the criteria in the context of the current study, the WavePlus (Airthings, Oslo, Norway) was selected; measuring temperature, humidity, CO_2, VOCs, radon and air pressure. These devices connect to a hub (Airthings, Oslo, Norway), which remotely sends the data to online servers where it can be remotely downloaded. These devices can operate via a sim-card, reducing the dependence on WIFI and risks associated with occupant interference. The first sensors were installed in October 2019, and the deployment continued until June 2020. These sensors will continuously transmit data until May 2021. In addition to the sensor data, detailed contextual information and occupant satisfaction data have been collected, as well as a photographic survey within each of the residential dwellings, which will be utilised to provide statistical analysis once all the data has been collected.

To date, 85 highly energy-efficient Irish dwellings (a designed energy performance below 75 kWh/(m^2*yr) have been recruited to participate in the study. Sensors were deployed in four different rooms in each dwelling; two habitable rooms (living room and bedroom) and two wet rooms (kitchen and bathroom), capturing IAQ data for rooms that operate supply or extract ventilation. Forty-eight dwellings are equipped with Mechanical Ventilation Heat Recovery throughout the dwelling, while the remaining dwellings have natural ventilation in the habitable room and intermittent extract ventilation in the wet rooms.

RESULTS

To date, the sensors have collected a cumulative of 110,000+ days' worth of data, and an additional estimated 30,000 days' worth of data will be collected prior to the conference. Although data are collected from four sensors in each dwelling for six different pollutant metrics; the following results only focus on a single room, the bathroom, for ease of comparison. The results for on providing a sample of the data to demonstrate the potential for longer-term monitoring.

Figure 1 shows the time-varying patterns in CO_2 concentrations in a single bathroom that operates with intermittent mechanical ventilation, over a month-long period. The typical nature of intermittent mechanical ventilation requires the occupant to activate the extraction unit, which combined with meteorological conditions (temperature and wind speed fluctuations) are attributed to the large fluctuations in CO_2 over time. The variations highlight the potential limitations of conducting short-term monitoring campaigns, and as a result, missing the longer-term fluctuations in indoor environmental quality.

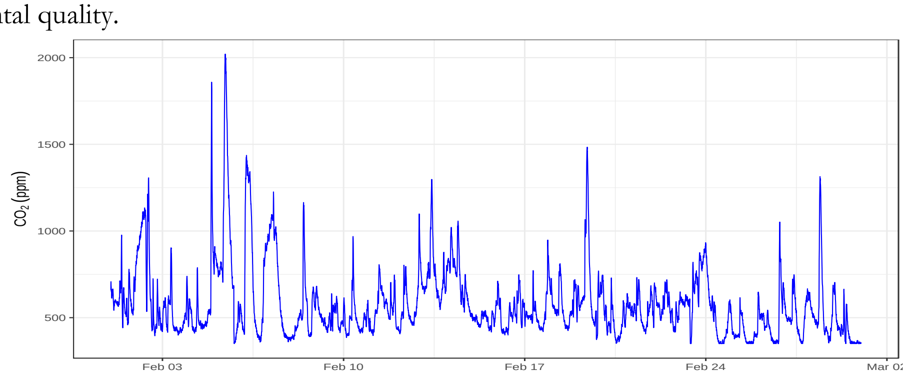

Figure 1. The data from February 2020 highlighting the variation in CO_2 concentrations in one selected dwelling.

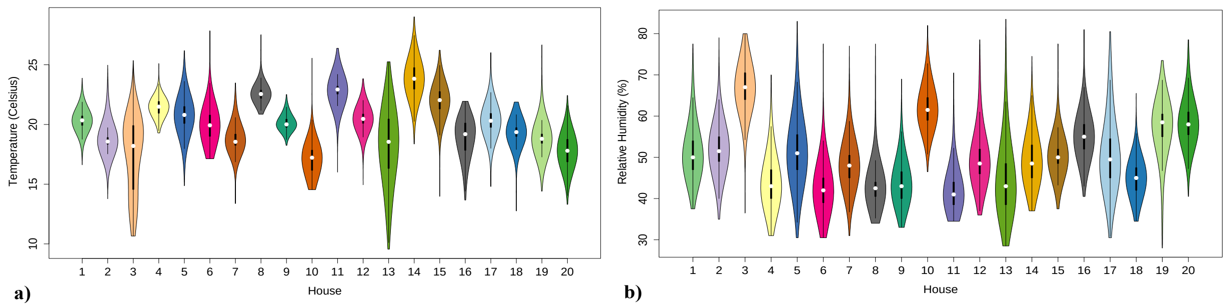

Figure 2. Violin plots showing the distribution of data across the 20 dwellings for (a) temperature and (b) humidity.

Figure 2 shows violin plots for both the temperature and the humidity values for 20 dwellings; violin plots show the probability density of the data at different values, the thickness of the shape corresponds to the values at that interval. In addition to a spread of the median values across the different dwellings; there are also varying distributions associated within each dwelling, e.g. Houses 3 and 13 have considerably greater distribution for the temperature values.

In 16 out of the 20 dwellings, the hourly average exceeded 70% relative humidity on at least one occasion. The four homes that did not exhibit exceedance of the reference level all had MVHR units installed; however, the homes that showed the highest percentage of time (compared with the monitoring duration) exceeding the reference level were all also operated by MVHR. House 3 exhibited exceedance of the reference level 27% of the time; however, the second-highest ranked dwelling only showed exceedance of the reference level 2.9% of the time. One explanation is the age of the building; House 3 had only recently been completed and it is possible that the house still had higher residual moisture content from the construction period compared with the other dwellings.

Nine of the bathrooms showed an exceedance of an hourly-average temperature value of 24°C on at least one occasion. However, only two of those homes showed values above that reference level for more than 1% of the time. It can be noted that, in contrast with the humidity values, the top four ranked dwellings that showed exceedance of the reference temperature level had a mixture of MVHR and natural ventilation.

CONCLUSION

While data acquisition is still ongoing, and a further 5 months' worth of data are still to be collected, the initial findings are promising. The preliminary data highlights the spread of data within each dwelling and enforces the concept that long-term measurements are needed to accurately capture details surrounding the indoor built environment. The current methodology demonstrates that customer-grade sensors have the capability to remotely capture longer-term fluctuations in indoor air pollutants. The humidity data recorded highlights the impact of the age of the dwelling but also the importance of occupancy interaction with the system. However, further analysis is still required to factor in varying room dimensions and additional building characteristics.

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