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Analysing Indoor Air Pollution: A Study on Pollutant Levels and Air Quality Assessment in Social Housing Properties

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Abstract

Amid growing concerns over Indoor Air Quality (IAQ), this paper presents a comprehensive analysis of pollutants to assess the environmental health in a few Case Study Buildings (CSBs). The main objectives were to evaluate the levels of key Indoor Air Pollutants (IAPs) (PM10, PM2.5, CO, CO2, TVOCs) and relative humidity across multiple social housing properties and to analyze how occupant behavior may affect IAQ. Utilizing quantitative measurements, the study investigates the range and exposure of the building occupants to IAPs. The methodology involves the systematic measurement of IAPs through the installation of data loggers, focusing on pollutant levels to evaluate air quality across multiple CSBs. Findings show fluctuation in pollutant levels, with some IAPs demonstrating consistently within the acceptable range while others exhibit sporadic spikes in pollutant concentrations. The results indicate that significant attention should be given to PM10, CO, and VOCs. This study underscores the importance of continuous monitoring and targeted interventions to mitigate poor IAQ and ensure healthier indoor environments for building occupants. Further research and implementation of effective measures are imperative to safeguard public health and well-being.

Keywords

Indoor air quality; Indoor air pollutants; Occupant health; Energy efficiency

1. Introduction

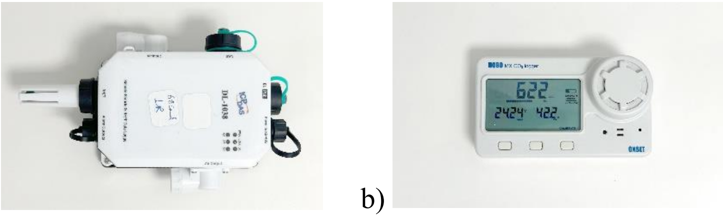
In recent years, there has been a growing awareness of the profound impact of IAQ on human health and well-being. The significance of this issue is underscored by studies indicating that indoor environments often harbor higher concentrations of pollutants compared to outdoor spaces, putting individuals at risk of various health issues (Chenari, 2016). This is concerning given that most people spend approximately 90% of their time indoors (Laumbach and Kipen, 2012). While IAQ assessments are crucial across all types of dwellings, special attention is warranted for social housing properties. Residents in these settings, already among the most vulnerable populations facing economic, social, and health inequalities (Baker et al., 2016), are further impacted by inadequate ventilation systems and maintenance protocols in their living spaces (Vardoulakis et al., 2015). Poor IAQ in residential buildings can lead to various adverse health effects, ranging from minor discomfort to severe respiratory issues and chronic illnesses (Mavrogianni et al., 2022). Several studies have linked exposure to indoor air pollutants with increased risks of respiratory infections, asthma exacerbations, allergic reactions, and even cardiovascular diseases (Beizaee et al., 2021). Prolonged exposure to high levels of pollutants like carbon monoxide can potentially lead to neurological damage and even death (Baeza-Romero et al., 2022). Low-income families may be more likely to experience poor IAQ due to substandard housing conditions and inadequate resources for addressing the issue (National Institute of Environmental Health Sciences, 2024)). Exposure to indoor air pollution, both short-term and long-term, can lead to a wide range of diseases (Koivisto et al., 2019). Therefore, the development of monitoring systems is crucial for IAQ control. Effective IAQ control necessitates determining the sources of air pollution (Tran et al., 2020). IAQ in residential buildings is significantly influenced by three primary factors (Marć et al., 2018; Peng et al., 2017): (i) outdoor air quality, (ii) human activities within buildings, and (iii) building materials, equipment, and furniture. Outdoor contaminant concentrations and building airtightness greatly impact IAQ due to the potential for indoor transportation of outdoor contaminants (Poupard et al., 2005). IAQ can be impacted by the materials used in the construction and furnishing of buildings. Many building materials, furniture, and household items emit volatile organic compounds (VOCs) that can contribute to poor IAQ (Wolkoff et al., 2018). Additionally, inadequate ventilation and poor maintenance of air filtration systems can exacerbate the problem by allowing these pollutants to accumulate in the indoor environment (Yadav et al., 2023). Furthermore, specific populations may be more vulnerable to the negative effects of poor IAQ. For example, children, the elderly, and individuals with pre-existing respiratory conditions such as asthma are at higher risk of health problems due to exposure to indoor pollutants (Hanssen et al., 2018).

IAQ is greatly impacted by occupant behavior and environmental circumstances. Commonplace actions in communal housing, like using specific home goods, cooking improperly without enough ventilation as well as smoking indoors, can emit pollutants into the air (Zhou et al., 2022). These activities also expose residents to various dangerous compounds and worsen IAQ. A lack of knowledge and instruction on the consequences of these actions can make the problem worse. According to Mannan and Al-Ghamdi, 2021, smoking indoors releases toxic compounds that linger and seriously endanger the health of those who live there, and not only smoking but also lightning items such as candles or incense sticks or items generating fumes make it a notable factor in poor IAQ. Apart from obvious reasons such as smoking and cooking some more habits of occupants may affect the IAQ. Cleaning habits and poor ventilation have also been important factors in degrading IAQ, several cleaning products, highly fragranced products, and air fresheners all add to indoor pollution. When occupants choose these devices without sufficient ventilation, they unintentionally bring dangerous materials into their lives. Another essential component of IAQ is moisture management. It has been observed that certain behaviors such as drying clothes inside, increase the humidity within, especially without ventilation or less ventilation which consequently fosters the formation of mold (Daphne et al., 2020, Hermione et al., 2021). IAQ issues can be exacerbated by indoor overpopulation, as it can lead to an increase in carbon dioxide levels (Margaret et al., 2022, Biros et al., 2021). Regular monitoring of IAQ levels and occupant education on the importance of maintaining good IAQ are also crucial components of a comprehensive IAQ management strategy (Mendell et al., 2016). Improving IAQ in residential buildings requires a multifaceted approach that addresses both the sources of pollution and the ventilation systems. Effective source control measures can include minimizing the use of products that emit pollutants, proper maintenance of combustion appliances, and implementing moisture control strategies (WHO, 2010). Additionally, ensuring adequate ventilation through mechanical systems or natural ventilation can help dilute and remove pollutants from the indoor environment (Chenari et al., 2016).

This paper embarks on a thorough exploration of IAPs within various social housing properties, aiming to not only evaluate how the behaviors of occupants in different flats can affect the IAQ but also scrutinize potential exposure risks for residents.

2. Methodology

The study concentrates on measuring key pollutants such as Particulate Matters (PM_{10} and $PM_{2.5}$), Carbon Monoxide (CO), Carbon Dioxide (CO_2), and Total Volatile Organic Compounds (TVOCs), along with assessing temperature and humidity levels on an average of 24 hours across seven Case Study Buildings (CSBs). Measurements were taken during winter and pollutants such as CO, CO_2, TVOC, PM_{10}, $PM_{2.5,}$ and humidity were recorded using DL-1038 (Figure 1. a). HOBO MX1102A CO2 Monitor & Data Logger (Figure 1. b) were also used to measure the temperature, relative humidity, and CO_2 levels.



a) b)

Figure 1: a) DL-1038. b) HOBO MX1102A CO2 Monitor & Data Logger. (Source: The authors)

Data loggers were installed in the living rooms for 37 days starting from November 27, 2023, and were monitored at 15-minute intervals until January 2, 2024. Daily average readings of each pollutant were analyzed to assess IAQ and elucidate the impact of resident behavior on pollutant levels.

The research follows the IAQ guidelines and standards from organizations such as the World Health Organisation (WHO), Chartered Institution of Building Services Engineers (CIBSE), American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), and Leadership in Energy and Environmental Designs (LEEDs) rating system. Table 1 summarizes the IAQ guidelines and standards used to analyze the collected data.

Table 1: IAQ guidelines and standards

Pollutant	**Guideline Value**	**Source**
Carbon monoxide	6 ppm (24 hr average)	(WHO, 2021)
Carbon dioxide	1000 ppm	(ASHRAE, 2019)
TVOCs	300 $\mu g/m^3$ [1] (8 hr average)	(CIBSE TM40, 2020)
$PM_{2.5}$	15 $\mu g/m^3$ (24 hr average)	(WHO, 2021)
PM_{10}	45 $\mu g/m^3$ (24 hr average)	(WHO, 2021)
Relative Humidity	40-70%	(CIBSE, 2021)
Temperature (Winter) – Living Areas	22-23°C	(CIBSE, 2021)

[1] According to Arc's Guide to Reentry v1.1 (Pyke, 2020), a conversion factor of 3.767 is used to convert $\mu g/m^3$ to ppb to get a value approximately equal to 80 ppb.

2.1. The Case Study Buildings

The CSBs were constructed between the 1950s/1966s and have cavity walls and double-glazed windows and are located in an urban area in the London Borough of Newhan. The occupants included pregnant women, elderly and young people, and people who smoked (vaped), burned candles or incense sticks, used air fresheners as well as used household cleaning materials. In terms of occupancy, the majority of the flats were always occupied apart from one which was occasionally occupied. The number of occupants is as follows: 2 flats (Flat A and B) had 2 occupants, 3 flats (Flat C, D, and G) had single occupancy, 1 flat (Flat E) had 3 occupants, and 1 flat (Flat F) had 4 occupants. All CSBs were 1-bed, and 2-bedroom apartments most of which were located on the top and middle floors with facing North-South orientation, except from Flat C which was located underground and was facing East-West. All buildings had central gas heating systems and mechanical ventilation units to improve background ventilation, however, they were not used (for various reasons including noise and cold draft) by the tenants. Table 2 summarizes the key characteristics of each flat in the case study, including location, number of occupants, area (number of bedrooms), and orientation.

Figure 2: Case Study Buildings (Source: The authors)

Table 2: Summary of Case Study Building Characteristics (Source: The authors)

Flat	Location	Number of Occupants	Number of Bedrooms	Orientation
A	Building A	2	1	North-South
B	Building A	2	1	North-South
C	Building B	1	1	East-West
D	Building A	1	1	North-South
E	Building A	3	2	North-South
F	Building A	4	2	North-South
G	Building A	1	1	North-South

3. Results and findings

3.1. CO_2 levels

According to ASHRAE, 2019, the safe limit for CO2 is 1000ppm. Figure 3 shows CO2 levels in case study buildings. The red line is the guideline for CO2 levels. The data below is an average of 24 hours which are numbered as day 1 to day 37, and on the y-axis, the levels of CO2 are mentioned in terms of parts per million(ppm). The detailed analysis of CO2 readings across the CSBs over 37 days reveals distinct patterns in IAQ. Flat C consistently maintained CO2 levels below the ASHRAE guideline limit of 1000 ppm, indicating effective ventilation or lower occupancy levels and ensuring satisfactory IAQ. Flat G and F exhibited fluctuations in CO2 levels, with occasional spikes, but most readings in Flat F were consistently above the guideline limit, suggesting significant challenges in ventilation or occupancy control. Flats B and E also displayed occasional exceedances of the guideline limit, indicating potential issues in ventilation or occupancy management. Flat D exhibited minor spikes during the initial days but was under the limit on most days after that. These flats experienced fluctuations in CO2 levels, with occasional spikes possibly attributed to increased occupancy or limited ventilation. In contrast, Flat A consistently surpassed the guideline limit, indicating significant ventilation or occupancy issues requiring urgent intervention. Its persistently elevated CO2 concentrations underscore the need for targeted measures to improve ventilation and reduce occupancy levels, ensuring a healthy indoor environment for occupants.

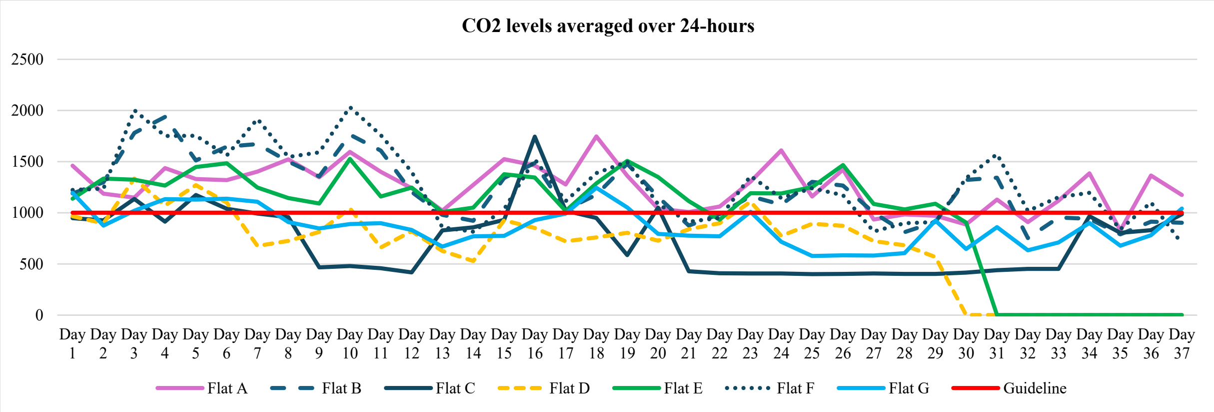


Figure 3: Daily average readings of CO_2 levels (Source: The authors)

3.2. CO levels

Carbon monoxide is one of the most harmful pollutants (United States Environmental Protection Agency, 2023). Higher concentration of CO is directly linked with high health risks. Many studies have shown that if CO levels rise too high in a room with no ventilation can result in fatal or even death. According to WHO, 2021, the safe limit for CO is 6 ppm which is an average of 24 hours. Figure 4 shows CO levels in CSBs, where the red line is the acceptable guideline for CO levels.

The findings reveal dangerously high CO pollution permeating Flats B, E, D, and A – facing extended durations exceeding 20 ppm daily averages by 3-20 times the safe limit. Specifically, Flat A suffered from sustained CO levels between 30-96 ppm from November 27th to December 14th. Additionally, extreme spikes reached up to 172 ppm on December 16th, indicating acute toxicity threats. In contrast, Flats C, G, and F only demonstrated occasional CO spikes above limits before recovering to alignment.

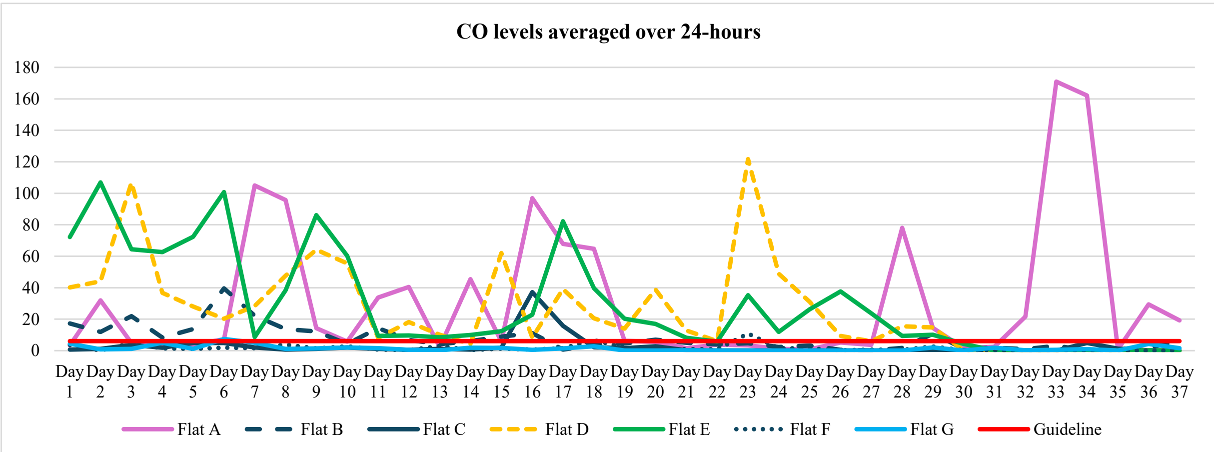


Figure 4: Daily average readings of CO levels (Source: The authors)

3.3. TVOC levels

TVOC are a group of chemicals that can be released into the air from various sources, including cleaning products, paints, and building materials. High levels of TVOC in indoor environments can lead to negative health effects, such as eye irritation, headaches, and respiratory problems. Therefore, it is important to monitor the TVOC levels in indoor spaces to ensure occupant safety and comfort. According to CIBSE, the recommended limit for TVOC is 80 ppb. In Figure 5, the data displays TVOC levels in the CSBs over 37 days. The red line represents the recommended guideline limit.

The research findings show that all flats experienced recurring spikes above 80 ppb, often reaching alarming levels up to 10-20 times the limit, requiring closer inspection. Specifically, Flat C had periodic elevations ranging from 500-4000 ppb, including an extreme spike hitting 2019 ppb. Similarly, Flat D showed consistent ranges of 500-1500 ppb with spikes up to 2019 ppb. Even more critically, Flats F, B, and A had numerous TVOC measurements between

1000-5000 ppb. Flat F had a maximum of 4610 ppb at one point and Flat A reached 4860 ppb, representing extremely dangerous indoor pollution levels from volatile organic compounds.

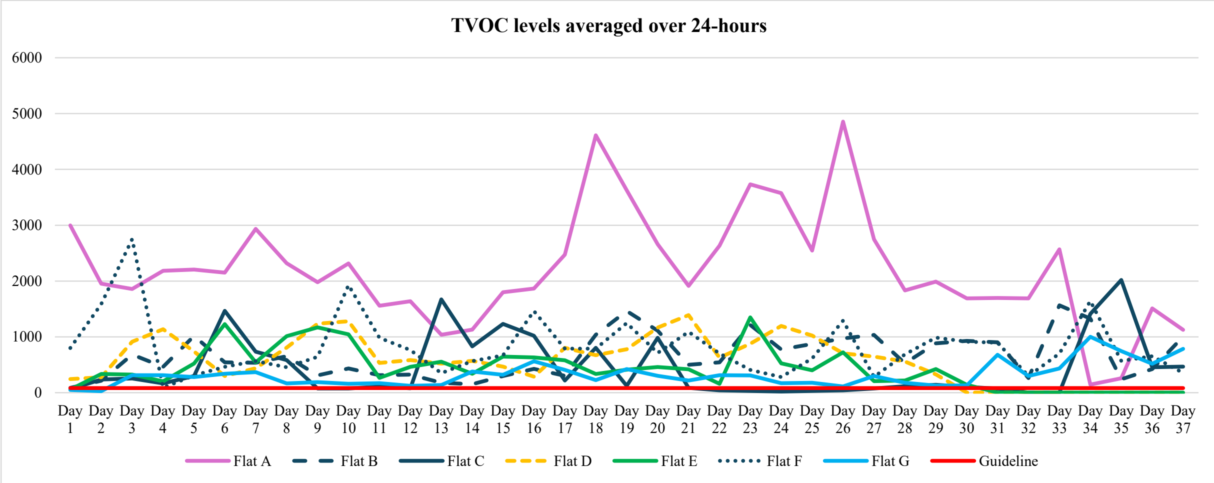


Figure 5: Daily average readings of TVOC levels (Source: The authors)

3.4. PM_{10} levels

PM_{10} is a common air pollutant that can have harmful effects on human health. To address this issue, WHO 2021 has set a guideline for PM_{10} levels on a 24-hour average of 45ug/m^3. Any PM level that exceeds this limit within 24 hours is considered poor air quality. In Figure 6, we can see a comparison of PM_{10} levels in various CSBs. The red line represents the guideline for PM_{10} levels. After analyzing the PM_{10} data from all monitored flats, some units consistently exceeded the specified threshold of 45 μg/m^3. However, Flats C, F, G, and B consistently maintained concentrations below this limit throughout the observation period, indicating good air quality. On the other hand, flats E, D, and A frequently recorded PM_{10} levels exceeding the limit, indicating poorer air quality conditions in these units. Based on the provided data, we can conclude that Flats C, F, G, and B are committed to maintaining satisfactory IAQ levels for their residents by consistently adhering to the PM_{10} limit. These flats stand out as examples of good practices in ensuring healthy living environments.

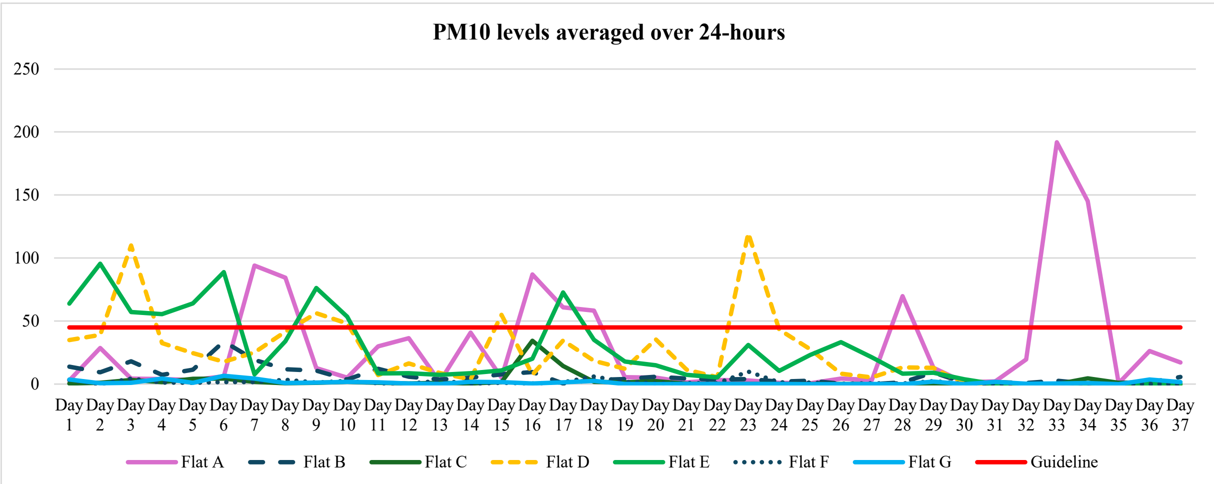


Figure 6: Daily average readings of PM_{10} levels (Source: The authors)

3.5. $PM_{2.5}$ levels

PM_{10} and $PM_{2.5}$ are said to be co-related to each other but still, there is a vast difference in terms of their acceptable safe limit guideline inside the room. According to WHO 2021, the guideline for $PM_{2.5}$ on a 24-hour average is 15ug/m^3. In Figure 7, $PM_{2.5}$ is compared in CSBs for 37 days. The red line is shown as a guideline for $PM_{2.5}$ levels. Upon meticulous examination of the $PM_{2.5}$ data, it's evident that none of the monitored flats surpassed the prescribed threshold of 15 μg/m^3 throughout the entire observation period. Even though some flats, such as Flat G and Flat A, sporadically recorded slightly elevated $PM_{2.5}$ levels on certain days, these instances were still well within the acceptable range and did not breach the established limit. Notably, Flat F consistently exhibited exceptionally low

$PM_{2.5}$ concentrations, with values consistently below 1 µg/m^3, showcasing excellent IAQ maintenance. Overall, all monitored flats maintained $PM_{2.5}$ levels within acceptable limits, indicating effective measures in place to ensure IAQ remained conducive to health and well-being throughout the monitoring period.

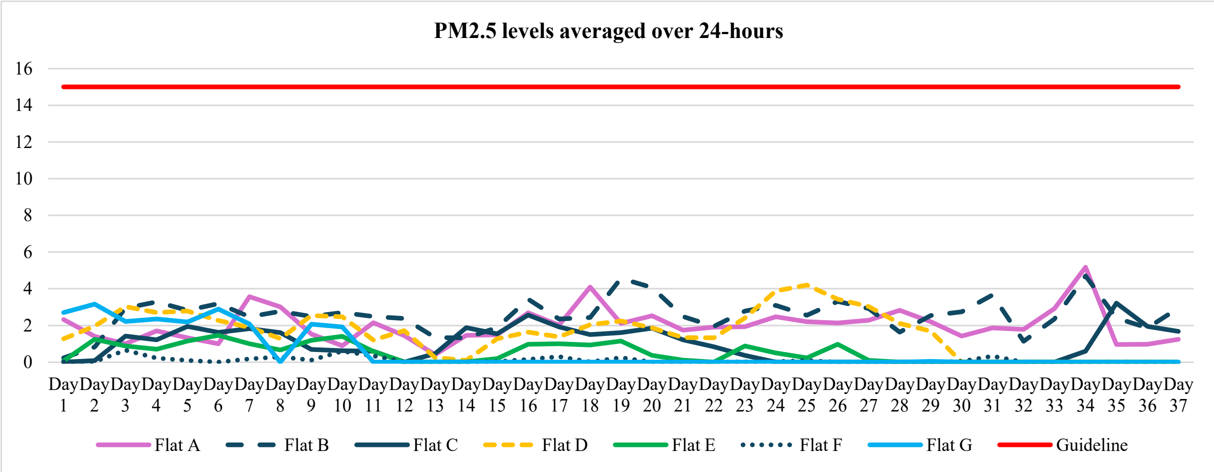


Figure 7: Daily average readings of $PM_{2.5}$ levels (Source: The authors)

3.6. Humidity levels

Humidity is the concentration of water vapor present in the air. It depends on the temperature and pressure present in the air. High humidity levels can create a risk for excess moisture and condensation that potentially leads to mold while low levels can rapidly spread viruses like cold and flu. Therefore, CIBSE 2021 has given a guideline for minimum and maximum limits of humidity levels present in the air which is 40% as the minimum safe limit and 70% as the maximum safe limit. In Figure 8, the graph shows the humidity levels for all 7 CSBs throughout 37 days. The red line shows the guideline for relative humidity. The analysis of humidity levels across seven residential flats over 37 days reveals varied conditions experienced by occupants. Flat C generally maintained humidity levels within an acceptable range, fluctuating between 61.84% and 69.36%, consistently below the target limit of 70%. Similarly, Flat G exhibited relatively stable humidity levels ranging from 51.83% to 58.49%, ensuring comfortable living conditions throughout the observation period. In contrast, Flat F experienced diverse humidity levels between 55.09% and 70.97%, occasionally approaching or exceeding the target limit, particularly on Days 9, 10, 13, 17, and 25, yet overall conditions remained within an acceptable range for occupants. Flat B consistently maintained humidity levels below the target limit, fluctuating between 45.71% and 56.59%, ensuring comfortable living conditions for its residents. Likewise, Flat E showed relatively stable humidity levels ranging from 46.84% to 63.85%, remaining below the target limit throughout the observation period. Flat D recorded humidity levels between 52.49% and 66.78%, occasionally nearing the target limit but generally within an acceptable range. However, in Flat A, humidity levels fluctuated between 61.24% and 73.47%, occasionally exceeding the target limit, particularly on Days 29 and 37, potentially bordering on discomfort during peak periods. Despite fluctuations, most flats maintained acceptable humidity levels, with Flat A potentially requiring further monitoring and adjustments to ensure consistent comfort levels.

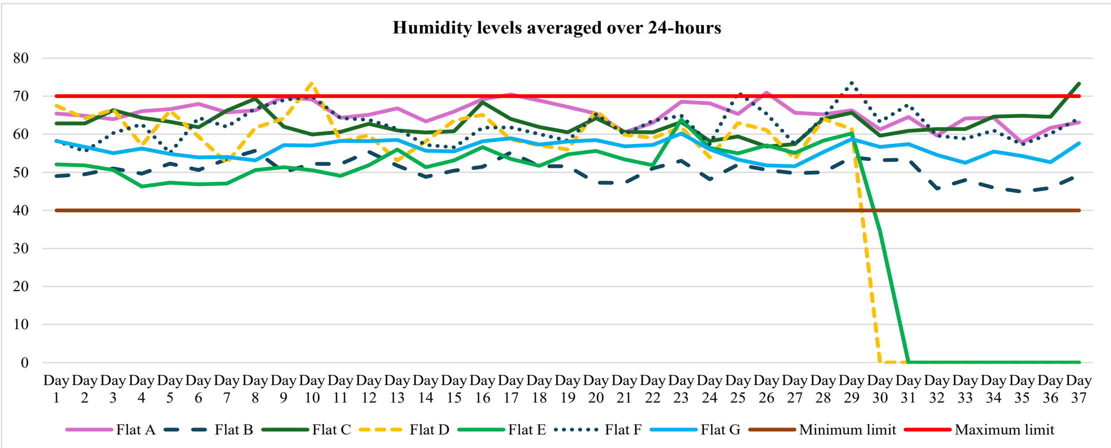


Figure 8: Daily average readings of Humidity levels (Source: The authors)

3.7. Temperature

The guideline levels for temperature are different in summer and winter. Here considering winter, the guideline for temperature is 22-23°C for living room. Temperature is important as this determines the thermal comfort of a room. Occupant behavior plays an important role in measuring indoor temperature as it is directly related to the usage of heating devices in a room. Here in Figure 9, the temperature for 7 CSBs is shown in 24-hour average data. In considering the guideline for temperature, it is equally important to consider minimum and maximum limits. Therefore, the dark red line in Figure 8 shows the maximum guideline and the light red line shows the minimum guideline for temperature dew point. The detailed analysis of temperature readings across seven case study buildings over 37 days reveals varying levels of thermal comfort experienced by occupants. Flat C consistently maintained temperatures within the comfort range of 22 to 23 °C throughout the observation period, with occasional fluctuations but overall satisfactory conditions. Similarly, Flat G also exhibited mostly stable conditions within the comfort range, although minor deviations occurred on Day 6. Fluctuations in temperature readings were observed in Flat F, with frequent exceedances of the upper limit of the comfort range, particularly evident on Days 1, 3, 6, 7, 11, 12, 19, and 20, indicating potential discomfort due to warmer conditions. In contrast, Flat B displayed relatively stable conditions within the comfort range, with occasional deviations such as on Day 30. Flat E also maintained conditions within the comfort range for the most part, with minor fluctuations observed on Days 6 and 30. Similarly, Flat D generally experienced satisfactory thermal comfort levels, although slight deviations were noted on Day 6. However, Flat A consistently recorded temperatures below the lower limit of the comfort range, notably on Days 30 and 31, indicating potential discomfort due to cooler temperatures. Despite occasional deviations in some flats, most occupants likely experienced acceptable thermal comfort levels, with deviations in Flat F and Flat A warranting further investigation into factors such as insulation and heating/cooling systems to ensure consistent comfort across all flats.

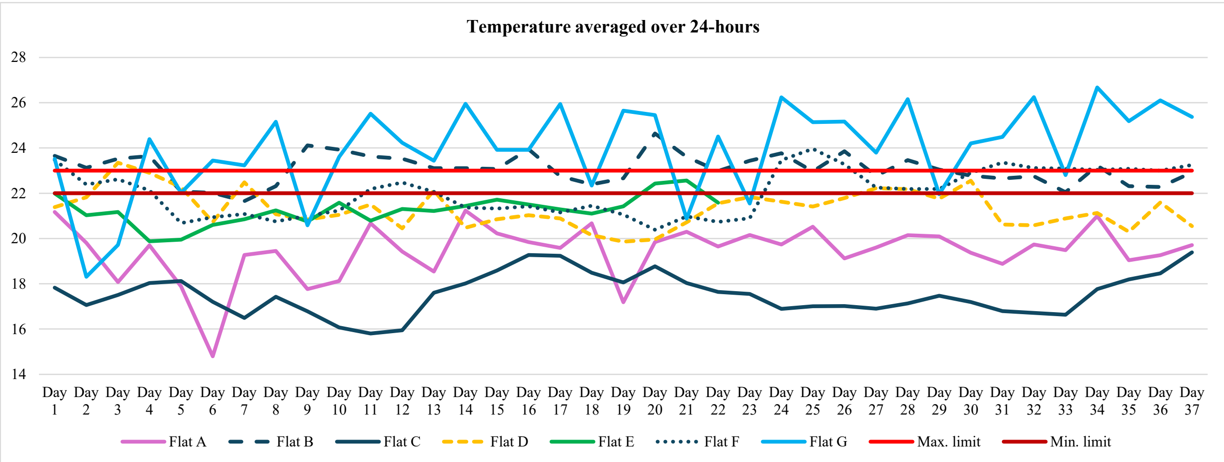


Figure 9: Daily average readings of Temperature levels (Source: The authors)

4. Discussion and conclusion

The investigation into the IAQ of seven residential flats has unveiled elevated levels of pollutants, posing potential health risks to the occupants. The findings from this study present a disconcerting scenario, with each residential unit exhibiting varying degrees of IAQ deficiencies that warrant immediate intervention and remediation strategies. Alarmingly, none of the monitored flats managed to maintain acceptable levels across all key pollutants, including CO_2, CO, TVOCs, PM_{10} and $PM_{2.5}$, and humidity and temperature deviations.

Flat A emerged as a critical concern, exhibiting multiple IAQ issues that require immediate attention. The persistent elevation of CO_2 levels above the guideline limit indicates inadequate ventilation. Moreover, the dangerously high CO concentrations, ranging from 30-96 ppm with extreme spikes up to 172 ppm, pose severe health risks. The alarming TVOC level of 4860 ppb, up to 20 times the recommended limit, could be attributed to the occupant's activities like candle burning, air freshener use, and vaping. Furthermore, PM_{10} levels frequently exceeded the guideline, potentially linked to vaping. Flat A's occupant behavior, such as not using extractor fans in the kitchen and bathroom, and the potential for poor insulation or heating systems, as evident from temperature readings below the lower comfort limit, exacerbated the air quality concerns. Flat D experienced significant challenges in maintaining acceptable IAQ levels. High CO levels, exceeding the safe limit several times, could be attributed to insufficient background ventilation, a broken extractor fan in the kitchen, and the occupants' reluctance to use bathroom fans due to energy consumption concerns. PM_{10} levels also frequently surpassed the guideline, potentially due to the same factors. The open kitchen layout, combined with three occupants, may have contributed to the elevated pollutant levels. Addressing the ventilation issues and encouraging the use of extractor fans is crucial for improving air quality in this flat. IAQ in this flat B was compromised by dangerously high CO levels, exceeding the safe limit. The locked kitchen window, preventing proper ventilation, could be a significant contributing factor. As this flat houses a vulnerable elderly occupant, swift action to improve ventilation and mitigate CO exposure is essential to safeguard their health and well-being. While most parameters of Flat E were within acceptable limits, this flat experienced frequent exceedances of the PM_{10} guideline, indicating poorer air quality conditions. The presence of three occupants, including an elderly individual, underscores the importance of addressing the PM_{10} issue through ventilation improvements and source control measures. Flat F exhibited several air quality concerns, potentially related to recent renovations, including new kitchen tiles and fresh painting, combined with a higher occupancy of four individuals, including a pregnant woman. TVOC levels reached up to 4610 ppb, well above the recommended limits, posing potential health risks, especially for vulnerable occupants. Additionally, temperature and humidity levels frequently exceeded the recommended ranges, indicating a need for improved climate control and ventilation strategies. Among the monitored flats, Flat G demonstrated relatively acceptable IAQ, maintaining TVOC levels below the recommended limit and stable humidity levels within an acceptable range. However, occasional CO spikes above the safe limit suggest the need for further monitoring and potential ventilation improvements. Flat C consistently maintained CO2 levels below the guideline limit, indicating effective ventilation or lower occupancy levels. However, periodic TVOC spikes, with levels reaching up to 4000 ppb, suggest the presence of intermittent sources that require investigation and mitigation strategies.

Weather conditions played a pivotal role in the fluctuating levels of pollutants. Peaks in pollutant levels were often recorded during colder days when occupants likely kept windows closed, reducing ventilation and trapping pollutants indoors. Conversely, on milder days, lower pollutant levels were observed, correlating with increased natural ventilation. This was also observed during the site visits when occupants opened the windows during milder days and in some cases for thermal comfort reasons. There were also direct links between wind speed and concentration of IAPs particularly for TVOCs, and CO_2, however, the assessments were not conclusive for other IAPs. Figure 10, shows an example of the correlation between some IAPs (CO_2) and wind speed in the CSBs.

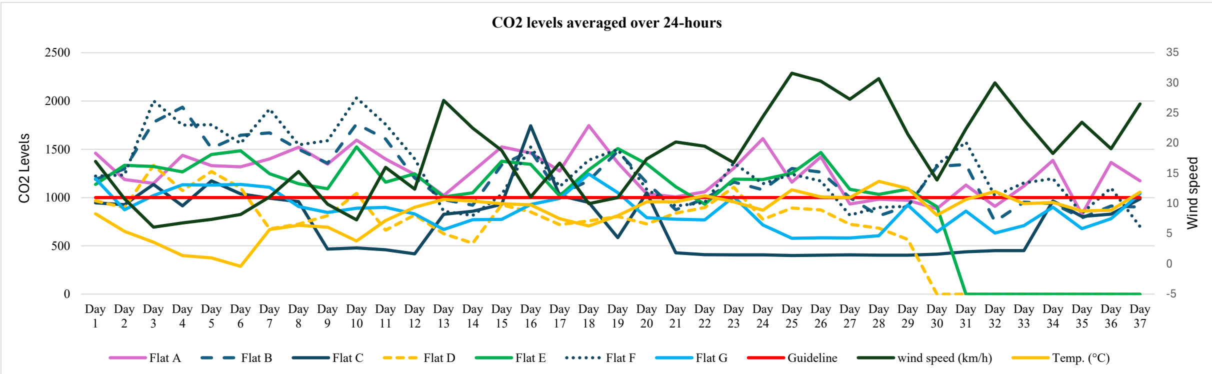


Figure 10: Correlation between the external temperature, wind speed, and IAPs (Source: The authors)

The analysis highlights the varying degrees of IAQ challenges faced by each residential unit, influenced by factors such as occupancy patterns, ventilation practices, and potential pollutant sources. Comprehensive remediation efforts tailored to the specific circumstances of each flat are crucial to safeguard occupant health and ensure a comfortable living environment. These efforts may include ventilation system upgrades, source control measures, occupancy management strategies, and collaborative efforts among building owners, occupants, and relevant authorities to implement best practices, regular monitoring, and education. Further research is required to assess the correlation between indoor/outdoor air pollutants, the effects of occupant behavior on IAQ, as well as possible application of fuzzy logic techniques (Versaci et al., 2022) on data analysis.

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Ethics approval

The authors have received ethics approval from the ethics committee of the University of East London, for the interviews and surveys that were conducted by the authors.

Conflict of interest

The authors declare that there is no competing interest.

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