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INDOOR AIR QUALITY IN HOMES

A case study of indoor and outdoor air quality in Hampshire, UK

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Background and Context

Extensive scientific research has established outdoor air quality as a significant risk to human health, leading to its recognition and regulation by governments [1]. In contrast, the importance of indoor air quality has received relatively little attention and is now increasingly recognised as a critical public health priority [2]. A recent study by the Department for Environment, Food and Rural Affairs (Defra, UK) reported that the UK population spends approximately 80-90% of their time indoors, making exposure to indoor air pollution a significant health risk [3].

Exposure to poor air quality can lead to a spectrum of adverse health outcomes. For example, airborne particulate matter, particularly PM2.5 (particle diameters of 2.5 μm or less), is known to trigger asthma attacks and exacerbations of Chronic Obstructive Pulmonary Disease (COPD) as well as heart disease, stroke, and lung cancer [3-5].

The sources of indoor pollution are diverse

Indoor air pollution results from internal sources and outdoor air entering buildings. However, indoor sources, e.g., as shown in Figure 1, are the dominant drivers of indoor air quality [3]. Domestic activities such as cooking and the use of wood-burners are key contributors to PM2.5 [6,7], while other activities such as cleaning, use of candles and smoking, home improvement projects, and even printers can also contribute significantly. While local authorities have been monitoring outdoor air quality and implementing action plans accordingly [8-10], indoor air quality has not received equivalent regulatory or monitoring attention and currently lacks a comprehensive assessment [2,3].

> **“Indoor concentration often exceeds the outdoor concentration”**

The University of Southampton recently reported an analysis of outdoor air quality based on sensor measurements across Hampshire [11]. The present investigation aims to analyse indoor air quality and compare it with outdoor air, which would help us understand:

- → The extent and severity of indoor air pollution;
- → Diurnal and seasonal trends that could inform targeted behavioural interventions and improved ventilation strategies for residential spaces.

Data were collected using EarthSense Zephyr air quality sensors [12] installed at four domestic locations across Hampshire, with each location equipped with an indoor and outdoor sensor. These locations were selected to capture a diverse range of environments: Southampton (urban), two separate locations in Winchester (semi-urban), and the New Forest (rural).

Monitoring was conducted for durations ranging from a few months to over two years at the different sites between January 2023 and October 2025. The collected data were analysed using statistical methods to characterise pollution trends.

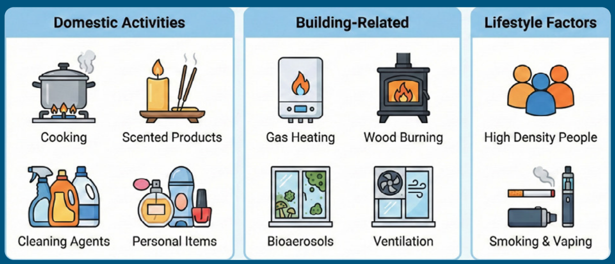

Figure 1. Different indoor pollutant sources.

Key Findings

Outdoor pollutant levels follow a predictable pattern

The hourly-averaged outdoor PM2.5 concentrations as a function of time are shown in Figure 2. The average annual outdoor PM2.5 concentration across all sites in Hampshire was ~7.3 μg/m³, which satisfies the annual average recommended limit of 20 μg/m³ by the UK Air Quality Standards Regulations 2010 [13] but is 46% higher than the World Health Organisation guidelines [14].

Seasonal patterns only vary moderately day-to-day, as shown by the shaded blue in Figure 2. Winter months have higher PM2.5 levels than spring and autumn, with summer having the lowest overall levels. Cold winter evenings provide the stable atmospheric conditions for air pollution to accumulate.

Note: Data from the Southampton outdoor sensor were excluded from the current analysis as it was situated in close proximity to a high-traffic roadway, resulting in significantly elevated readings. The readings from this specific sensor were deemed unrepresentative of the local background level, which are known to be generally consistent across Hampshire [11], and were consequently removed from the present analysis. These remaining readings varied less than 10% across all study locations.

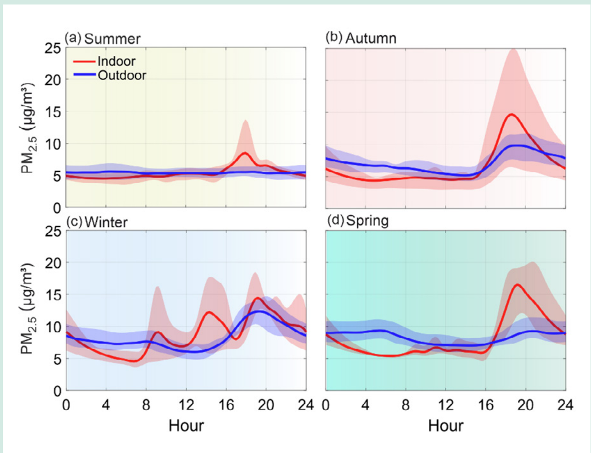

Figure 2. Hourly average PM2.5 concentrations as a function of time. The blue-shaded region shows the variability in measured outdoor concentrations across sites. The larger, red-shaded regions indicate variability across homes, demarcating the minimum and maximum indoor concentrations depending on occupants’ behaviour.

Indoor pollutant levels are more variable and differ from outdoor levels

The present study shows that the hourly average indoor PM2.5 concentration ranged from 4 to 25 μg/m³ (Figure 2) across the homes, showing a large variability. Also notable is that the indoor concentration often exceeds the outdoor concentration, particularly in the evenings and with distinct seasonal patterns. One of the homes kept a record of their wood burning activity, during which times we often observed short-lived large concentration peaks of ~ 1000 μg/m³, which is over 100 times larger than the average, posing serious exposure to occupants. These illustrate how indoor levels can vary, driven by the range of building ventilation and indoor sources (occupants' behaviour).

Spring & Autumn: While indoor levels are low during the day, a sharp increase occurs in the evening, jumping from daytime concentration of ~5 μg/m³ to nearly ~15 μg/m³, which is nearly 66% larger than the outdoor concentration of ~9 μg/m³ (see Figure 2b). In these months, when evenings turn cool, people likely close windows to trap heat while simultaneously starting indoor activities (e.g., dinner, heating), also trapping pollution inside.

Winter: Indoor concentrations are highest in the winter (Figure 2c), driven by high outdoor levels as well as increased indoor activity and reduced ventilation with windows closed to conserve heat. In addition to evening peaks, additional peaks occur during the day due to people being home more, increased seasonal cooking activities, more heating demand (gas heating/wood burning), and other activities such as smoking, which would accumulate pollutants indoors.

Summer: This is the cleanest season for indoor air (Figure 2a) with consistently low concentrations (~4.2 μg/m³) and, crucially, below the outdoor level for most of the day. Warmer weather encourages ventilation (open windows). This creates a high air exchange rate, preventing indoor pollutants from accumulating. Even when evening activities occur (a small peak around 18:00), the pollution is quickly flushed.

Indoor sources dominate pollution levels in the evenings

Figure 3 shows the diurnal (24-hour) cycle of the **indoor-to-outdoor ratio (IO)**, averaged over the study period, highlighting when indoor levels exceed ambient conditions. When **IO < 1**, the air inside is **cleaner** than the air outside and when **IO > 1**, the air inside is **more polluted** than the air outside. In the evening, the indoor levels are consistently greater, driven by occupant activity. The shaded range indicates that this can sometimes be as much as 100% more polluted inside than outside. The good news is that lifestyle choices can reduce this ratio, with some homes experiencing much lower indoor levels than others.

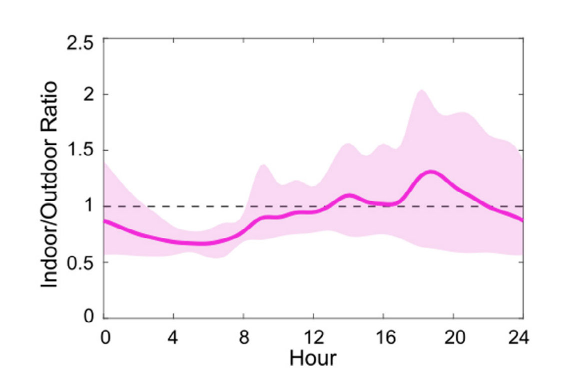

Figure 3. The ratio of indoor and outdoor concentration of $PM_{2.5}$ as a function of the time of day.

Recommendations and strategies

Be aware of indoor activities that may create pollutants

A surprising revelation from this study was that indoor concentrations of PM2.5 often exceed outdoor levels. We recommend residents to carry out a simple check of their homes to spot common pollution sources (e.g., Figure 1), particularly those occurring in the evenings.

Make use of targeted ventilation to reduce the build-up of air pollution

- → A variety of indoor activities can lead to increased pollution, like wood burning, cooking, heating, cleaning, home improvement projects and various hobbies. Increasing ventilation and opening windows for 10–15 minutes during and immediately after can significantly reduce the build-up of indoor pollutants, especially in the evenings. During cooking, use extractor fans, ensuring the pollutants are flushed outdoors rather than just recirculating inside.
- → In all seasons, it is generally beneficial to bring fresh air inside by opening windows when outdoor pollution is lowest. This also resonates with the recent expert guidance [15,16], emphasising that good ventilation is necessary to maintain good indoor air quality. However, for homes near busy roads, be mindful to open windows during off-peak traffic times, as outdoor air can carry traffic-related pollutants.

Limit the indoor sources in your homes

The high variance in indoor levels, particularly in Autumn/Winter (Figure 2b,c), suggests that some homes are heavily polluting themselves while others are not. Occupants are suggested to reflect on which indoor activities are truly necessary. Healthy indoor air starts with informed choices at home. With effective ventilation and awareness of indoor air pollution sources, indoor air quality can be better than ambient conditions.

References

1. Blake, E., & Wentworth, J. (2023). Urban outdoor air quality. Parliamentary Office of Science & Technology, UK Parliament. **https://doi.org/10.58248/PN691**
2. González-Martín, J., Kraakman, N. J. R., Pérez, C., Lebrero, R., & Muñoz, R. (2021). A state–of–the-art review on indoor air pollution and strategies for indoor air pollution control. Chemosphere, 262, 128376.
3. Lewis, A. C., et al. Indoor Air Quality. Indoor Air Quality, Public version, Department for the Environment, Food and Rural Affairs, 1 Nov. 2022, p. 142,
4. Chen, T., et al. (2021). Acute respiratory response to individual particle exposure (PM1.0, PM2.5 and PM10) in the elderly with and without chronic respiratory diseases. Environmental Pollution, 271, 116329.
5. Kumar, P., Singh, A. B., Arora, T., Singh, S., & Singh, R. (2023). Critical review on emerging health effects associated with the indoor air quality and its sustainable management. Science of The Total Environment, 872, 162163.
6. Chakraborty, R., Heydon, J., Mayfield, M., & Mihaylova, L. (2020). Indoor Air Pollution from Residential Stoves: Examining the Flooding of Particulate Matter into Homes during Real-World Use. Atmosphere, 11(12), 1326.
7. Kuye, A., & Kumar, P. (2025). Particulate matter exposure from different heating stoves and fuels in UK homes. Scientific Reports, 15(1), 21394.
8. Southampton City Council (2024). **https://www.southampton.gov.uk/ our-green-city/council-commitments/clean-air/improving-air-quality/**
9. Winchester City Council (2024) **https://www.winchester.gov.uk/environment/air-quality**
10. New Forest District Council (2024). **https://newforest.gov.uk/airquality**
11. Vanderwel, C., Simmonds, O., & Peng, Z. X. (2024). Identifying regional air quality trends from sensor network data: An analysis of PM2. 5 measurements in Hampshire.
12. EarthSense (2024). **https://www.earthsense.co.uk/**
13. Air Quality Standards Regulations (2010) **https://www.legislation.gov.uk/uksi/2010/1001**
14. World Health Organization. (2021). WHO global air quality guidelines: particulate matter (PM2. 5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization.
15. Royal College of Physicians. A breath of fresh air: responding to the health challenges of modern air pollution. (2025).
16. Committee on the Medical Effects of Air Pollutants. Response to the Air Quality Expert Group (AQEG) report on Indoor Air Quality (2025).

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Find out more

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