The Invisible Killer: High Indoor Pollution Meets Low Public Awareness in a Developing Metropolis

Yixin Sun[1], Dil Rahut[2], Budy P Resosudarmo[3], Jeanne Sorin[4], Daniel Suryadarma[2]

[1] University of Chicago, Booth School of Business
[2] Asian Development Bank Institute
[3] Australia National University
[4] University of Chicago

Correspondence: ysun9@chicagobooth.edu

Highlights

- Installed 308 indoor air quality monitors in homes in Jakarta, Indonesia; matched these households to outdoor sensors to track ambient outdoor pollution
- Indoor PM2.5 not only track closely with ambient outdoor levels – both far exceeding WHO recommended limits - but also exhibit dangerous pollution spikes that can reach 10 times ambient levels.
- These pollution patterns persists across the income distribution.
- On average, 71.2% of mean daily household PM2.5 concentrations can be attributed to outdoor air infiltration, while 28.8% originates from in and around the household.
- Survey results show households are aware of high outdoor pollution, but underestimate indoor levels

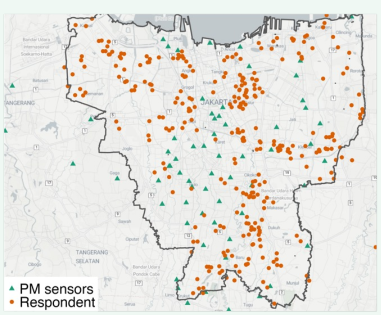
Motivation

Fine particulate matter (PM2.5) - particles less than 2.5 micrometers in diameter – is one of the biggest environmental health threats globally, and the vast majority of future mortality from air pollution will occur in low- and middle-income countries (Shaddick et. al 2020). While most air pollution measurement occurs outdoors, people spend much of their time indoors - creating a crucial gap in our understanding of true exposure levels, especially in developing cities that lack systematic indoor air quality data. Indoor measurements are essential, as they better capture both how people adapt to pollution and their actual exposure, particularly for PM2.5 particles that readily penetrate indoor spaces. While existing literature addresses household pollution from cooking and lighting fuels in rural low-income areas of developing countries, we focus on Jakarta, Indonesia - one of the world's largest metropolitan areas. Urban developing regions face distinct indoor air pollution sources and exposure patterns, requiring different policy solutions to match the context.

Methods

- Installed 308 indoor air quality monitors in homes in Jakarta, Indonesia (mapped in figure)
- For each household, collected hourly indoor air quality data for three months, between June-December 2024
- Match these homes to three closest outdoor sensors, utilizing 63 low-cost sensors to measure respondent-specific hourly ambient outdoor air quality
- Before installation, surveyed all households about pollution knowledge, beliefs, and practices, as well as household demographic variables

Fig. 1: Locations of Indoor Air Quality Monitors and Outdoor Sensors in Jakarta



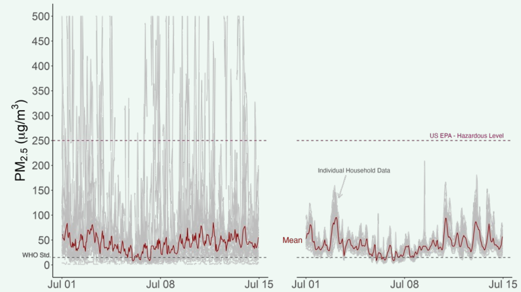
Takeaway

Given that ~70% of indoor PM2.5 exposure comes from outdoor sources, addressing transportation and industrial emissions at their source is critical for protecting public health in Jakarta. At the same time, monitoring of indoor spaces and public education campaigns are also needed to address the alarmingly high infiltration rates and residents' systematic underestimation of indoor air quality risks

Result 1: Jakarta's Indoor PM2.5 tracks high ambient outdoor pollution, punctuated by hazardous pollution peaks

Figure 2 shows hourly PM2.5 measurements over a two-week period. The red line represents the mean household level for each hour, which closely tracks outdoor concentrations. Both indoor and outdoor levels consistently exceed the WHO's recommended 24-hour exposure limit of 15 μg/m³. However, the individual household measurements (shown in gray) reveal frequent indoor pollution spikes that the mean obscures. These episodes can reach over 250 μg/m³ (classified as 'hazardous' by EPA standards) and spike to 10 times ambient levels. Such extreme concentrations likely stem from hyperlocal sources, which are prevalent in our sample: 98% of households cook with LPG cookstoves, households average 0.84 smokers, and 29% report nearby garbage burning within the past week.

Fig. 2: Hourly Indoor and Outdoor PM2.5 at Household Level, Sample from July 1-14, 2024



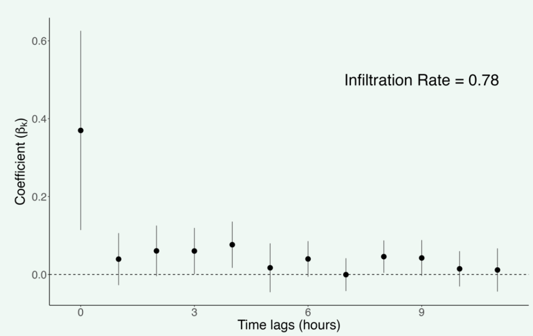
Result 2: The rate at which outdoor PM2.5 penetrates homes is 3-5 times higher than US measurements, resulting in ambient air contributing 71.2% of household concentrations.

Methods: To identify the sources of indoor pollution, we analyze how outdoor PM2.5 infiltrates homes. We estimate infiltration using a distributed lag panel regression that measures how indoor PM2.5 changes when outdoor PM2.5 increases by one unit. The regression analyzes data at the monitor-hour level. For each residence *i* in hour *t*, we model how indoor PM2.5 varies with current and previous hour measurements of outdoor PM2.5:

$$Indoor_{it} = \alpha + \sum_{k=0}^{11} \beta_k \times Outdoor_{i,t-k} + \mu_i + \phi_w + \nu_h + \varepsilon_{it}$$

To isolate outdoor PM2.5's contribution to indoor levels, we control for several factors using fixed effects: household-specific differences (μ_i), weekly PM2.5 trends (ϕ_w), household-specific average variation in PM2.5 within the day (ν_h). We include 11 lags to capture how outdoor pollution from previous hours influence current indoor levels. The infiltration rate is the sum of these coefficients: $\sum_{k=0}^{11} \beta_k$.

Fig. 3: Outdoor-to-indoor Infiltration Rates in Last 12 Hours

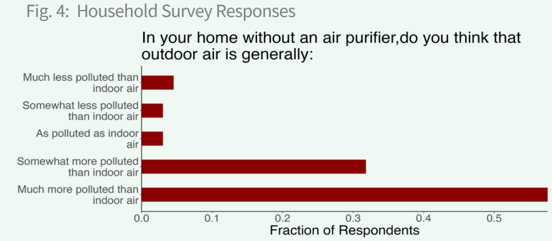


Results: PM2.5 penetrates from outdoors to indoors rapidly, primarily within the first hour and tapering off by hour 10. Our regression analysis, which focuses on mean relationships, estimates an infiltration rate of 0.78—notably 3-5 times higher than U.S. studies (Lunderberg et al. 2023). Using these mean-based estimates, along with average outdoor and indoor concentrations of 41.71 and 43.1 μg/m³, we attribute 71.2% of household PM2.5 to ambient air infiltration and 28.8% to sources inside and around the home.

Result 3: Households are aware of high outdoor air pollution, but underestimate indoor levels

Our monitor data from Figure 2 demonstrates that indoor PM2.5 not only matches ambient levels but frequently exceeds them during pollution episodes. However, household perceptions reveal a striking misconception: 89% of respondents believe their indoor air is less polluted than outdoor air. This widespread underestimation of indoor pollution exposure suggests households may be unaware of the risks from both infiltrating outdoor pollution and local indoor sources.

Fig. 4: Household Survey Responses



References

Lunderberg, David M., Yutong Liang, Brett C. Singer, Joshua S. Apte, William W. Nazaroff, and Allen H. Goldstein. 2023. "Assessing Residential PM2.5 Concentrations and Infiltration Factors with High Spatiotemporal Resolution Using Crowdsourced Sensors." Proceedings of the National Academy of Sciences 120 (50): e2308832120. https://doi.org/10.1073/pnas.2308832120.

Shaddick, G., M. L. Thomas, P. Mudu, G. Ruggeri, and S. Gumy. 2020. "Half the World's Population Are Exposed to Increasing Air Pollution." Npj Climate and Atmospheric Science 3 (1): 23. https://doi.org/10.1038/s41612-020-0124-2.