Do We Breathe the Same Air?

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ABSTRACT

91% of the world's population lives in areas where air pollution exceeds safety limits[1]. Research has focused on monitoring ambient air pollution, but individual exposure to air pollution is not equal to ambient and is thus important to measure. Our work (in progress) measures individual exposures of different categories of people on an academic campus. We highlight some anecdotal findings and surprising insights from monitoring, such as **a)** Indoor CO_2 concentration of 1.8 times higher than the permissible limit. Over 10 times the WHO limit of $PM_{2.5}$ exposure during **b)** construction-related activities, and **c)** cooking (despite the use of exhaust). We also found that during transit, the $PM_{2.5}$ exposure is at least two times higher than indoor. Our current work though in progress, already shows important findings affecting different people associated with an academic campus. In the future, we plan to do a more exhaustive study and reduce the form factor and energy needs for our sensors to scale the study.

CCS CONCEPTS

• **Human-centered computing** → *Ubiquitous and mobile computing design and evaluation methods*; *Interaction devices.*

KEYWORDS

air pollution; air pollution wearable; blue-collar

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1 INTRODUCTION

Ambient fine particulate ($PM_{2.5}$) is a significant risk factor for premature death, shortening life expectancy at birth by 1.5 to 1.9 years [1]. 99% of the people in countries like India, Pakistan, Nepal, and Bangladesh experience ambient exposures of $PM_{2.5}$ exceeding 75 $\mu g/m^3$ to 100 $\mu g/m^3$ [2]. Monitoring ambient air pollution is an active research area [3, 8, 9].

[1]https://www.who.int/health-topics/air-pollution

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Ambient and non-ambient particulate matter are not highly correlated [5, 13] and thus, it is essential to measure an individual's exposure to air pollution. Previous research on exposure monitoring by [11] in Europe involves a system which is bulky to carry around and lasts for only 6 hours in a single charge. [12] investigated the impact of exposure air pollution only on the elderly population of Baltimore, Maryland (U.S).

Our work aims to measure the $PM_{2.5}$, Humidity, Temperature, Total Volatile Organic Compound (TVOC) [10] and eCO_2 [6] via a low energy wearable sensor. We have done a pilot deployment measuring two air quality-related parameters ($PM_{2.5}$ and CO_2) for the following type of individuals associated with the campus:

(1) *Blue-Collar Workers*: These personnel work in construction-related activities and the kitchen.
(2) *White-Gold Collar Workers*: These includes administrative and research/academic personnel. Some of them stay on campus whereas some would visit the campus from the city during office hours.

We found that construction sites have $PM_{2.5}$ values between 400 $\mu g/m^3$-1000 $\mu g/m^3$. The concentration of CO_2 in indoor environment reaches a hazardous level of ≥1000 ppm. A sensor placed in a bus revealed that the $PM_{2.5}$ value outside the campus is at least two times higher than the inside.

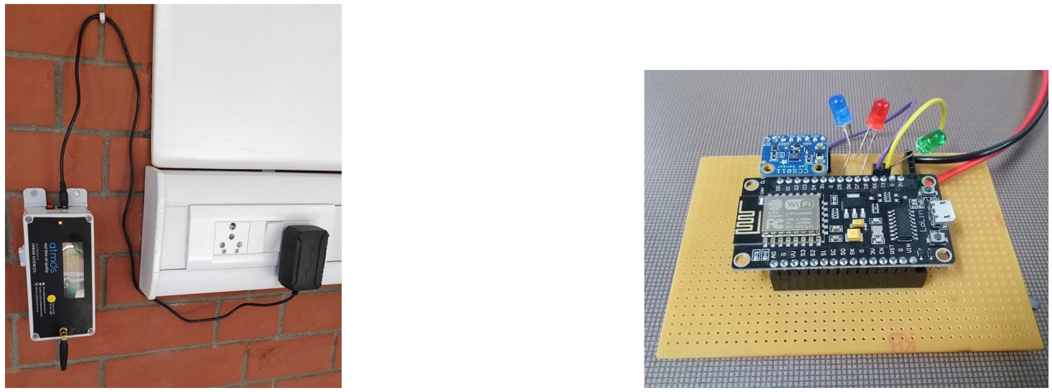
We observe that even in a highly localized environment, the exposure can vary significantly from the ambient concentration of air pollution. High temporal variance in exposure was observed when people are in transit, and air quality of meeting rooms deteriorate as number of people increases, thus creating an unhealthy environment.

Our current work though in progress, already shows important findings affecting different people associated with an academic campus. In the future,we plan to do a more exhaustive study and reduce the form factor and energy needs for our sensors to scale the study.

2 SENSING INFRASTRUCTURE

We monitored $PM_{2.5}$ and equivalent CO_2. The PM sensor had a sampling rate of one second, and it communicates to the network using a GSM/GPRS connection. The data from the sensor is stored on a remote database as well as a memory card. The memory card data is a good backup when the onboard microcontroller fails to connect to the network. The indoor placed CO_2 sensor had a sampling rate of 1 second and communicated via WiFi using a microcontroller (ESP32). The data was sent using an HTTP POST request and stored in a local server as a CSV file.

We can broadly categorise our monitoring into two categories:



(a) $PM_{2.5}$,PM_{10} monitoring

(b) CO_2 monitoring

Figure 1: Air quality monitoring deployment in campus

(1) **Static Monitoring** We used five $PM_{2.5}$ and one CO_2 sensor for static sensing. The CO_2 sensor (Figure 1b) was placed in an office where two to ten people frequently meet. The $PM_{2.5}$ sensors (Figure 1a) were placed at **a)** Kitchen Mess to monitor pollution exposure of mess workers, **b)** construction site to monitor the pollution exposure due to construction activities, **c)** two sensors were placed at entrance gates of the campus (to monitor vehicular pollution from the highway) and **d)** another sensor was placed in the open space near a canteen to monitor ambient $PM_{2.5}$ levels.

(2) **Mobile Monitoring** A $PM_{2.5}$ sensor was placed on a bus for two days to monitor the pollution exposure of individuals during transit. The bus travels to and from the campus.

3 PRELIMINARY RESULT

We now discuss some insights and results from static monitoring followed by mobile monitoring.

Construction Site: The air pollution monitor placed in the construction site showed $PM_{2.5}$ value as high as 1000 $\mu g/m^3$ during welding activity with a 24-hour mean of 154 $\mu g/m^3$, more than six times the WHO mandated air quality standard [2]. The monitoring was done between September 2019 to November 2019. We had observed that while the construction workers wear helmets to protect their head and eyes, but, they do not have any protection for their nose. Thus, our key takeaway from construction monitoring is to *introduce interventions such as mandatory masks for filtering*. We plan to take this matter with the concerned authorities.

Entrance Gate: The air pollution monitor placed in the entrance gate with frequent vehicular movement reported a 24-hour mean $PM_{2.5}$ value of 87 $\mu g/m^3$, more than three times the WHO mandated air quality standard. The monitor at the temporarily closed entrance gate reported a 24-hour mean $PM_{2.5}$ value of 42 $\mu g/m^3$. The data collection period was October 2019 to January 2020. Given the proximity to the highway, the entrance is expected to be more polluted compared to the rest of the campus. Possible interventions could include *educating the guards on the gates about air pollution, and to encourage campus car owners to regularly get car emissions checked.*

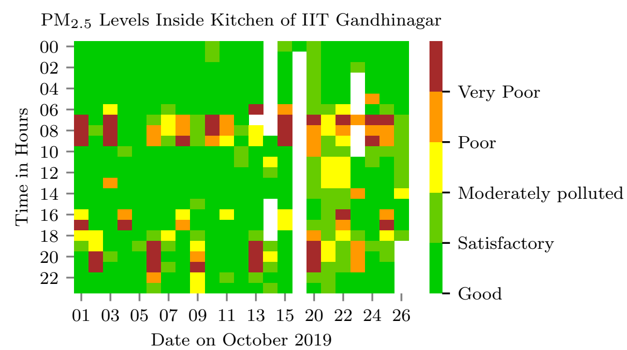


Figure 2: $PM_{2.5}$ levels inside the kitchen mess. White regions indicate missing data. The colour scale is as per Indian air quality standards.

Kitchen Mess: The monitor placed at the kitchen reported $PM_{2.5}$ value between 350 $\mu g/m^3$ to 400 $\mu g/m^3$ during cooking activity as shown in Figure 2. Even though the cooking occurs at the same time every day, certain days are more polluted compared to others. This can be explained by the difference in the cooked items (fried items would be more polluting), or, incorrect or no usage of the exhaust fan. An important caveat with monitoring cooking exposure is that our sensors can pickup humidity (or steam) as particulate matter. We ruled out this possibility in our experiments by monitoring the co-located humidity sensor. The 24-hour mean $PM_{2.5}$ value stands at 122 $\mu g/m^3$, nearly five times the WHO mandated air quality standard. The monitoring at the kitchen mess started on October 2019 and continues till date. Possible interventions could include *educating the mess cooks about air pollution exposure and encouraging them to use exhaust fan while cooking. Given the regular cooking timings, the exhaust fans could also be automatically run as*

[2]https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

per a schedule

Canteen: Given that the canteen is in an open space facing a major river, the monitor placed here reported a 24-hour mean $PM_{2.5}$ value of 44 $\mu g/m^3$. It reflects the ambient air pollution value of the campus is highly correlated to the air quality monitor placed the temporarily closed entrance gate. The data collection period is September 2019 to January 2020. The location of the canteen having high footfall suggest that in the future *urban campuses could be planned considering the population exposure and places with high footfall should ideally be less polluted.*

We can not place a large number of sensors in the campus given the sensor and maintenance cost. Thus, we used inverse distance weighting (IDW) interpolation as shown in Figure 3a to estimate the air quality at unmonitored locations. The motivation of this work is to give the campus residents a fine spatial resolution campus air quality map to optimise their activities as per the air quality. The figure shows that the pollution level at the construction site is much worse then other. There is a deviation of up to 110 $\mu g/m^3$ between the construction site and the ambient air quality levels.

Indoor CO_2 concentration: The CO_2 sensor installed in a closed meeting room showed insightful statistics. The sensor circuit was activated at 10:25 AM inside the room when only one person was present inside. Figure 4 shows the different events and the corresponding CO_2 levels. The CO_2 were roughly twice the recommended values for an indoor environment and would likely reduce cognitive function[3]. This result shows that closed room meetings can be unhealthy in terms of air quality, and *it is important to monitor the HVAC systems at a fine granularity to ensure a highly conductive environment.*

Air pollution monitoring at bus: Figure 3b shows the pollution level at the route which was taken by bus. The data reported by the sensor fixed on the bus shows that the air quality level outside the campus is much higher than inside. As the bus reached the city centre, $PM_{2.5}$ value would cross 120 $\mu g/m^3$. This data is based on only two supervised trips the bus made between the campus and the city. With some back-of-the-envelope calculations, we find that even a 2 hour commute involving high exposure could increase even the daily mean exposure by about 8%. We postponed further monitoring until competent authorities certify us about the safety of our monitoring system for permanent installation in the bus. *Given the cost of installing and maintaining sensors, mounting sensors on fixed-route buses offer advantages: i) they measure the exposure inside a vehicle (highly apt to measure for a large population); ii) can give a finer spatial context owing to mobility.*
Table 1 shows 24 hour mean $PM_{2.5}$ value for different location of the campus.

4 CONCLUSIONS

One would typically assume people inside a "small" community to be similarly exposed to air pollution. In this work, we monitored different categories of workers inside an academic campus, and found that the exposure can vary very significantly even inside a campus, based on the activities and other factors such as proximity to roads. Different people would need different interventions to reduce their exposure. This work shows the importance of high-fidelity spatial monitoring and suggests the importance of wearable or personalised exposure monitoring.

[3]https://www.yaleclimateconnections.org/2016/07/indoor-co2-dumb-and-dumber/

Table 1: Air Pollution level in different parts of the campus and a bus. Note that Entrance Gate 2 was temporally closed during monitoring and is located amidst dense green cover. The Open Space area is at the heart of the academic area of the campus. These two locations report much less pollution compared to the other pockets of the campus

Location	24h Mean $PM_{2.5}$ (μ g/m^3) Value
Construction Site	154
Entrance Gate 1	87
Entrance Gate 2	42
Kitchen Mess	122
Open Space (near Canteen)	44
Bus	95

5 FUTURE WORK

We plan to do a more exhaustive study and reduce the form factor and energy needs for our sensors to scale the study. We have developed our prototype of the wearable air quality sensor (Figure 5) that measures a) $PM_{2.5}$, b) humidity, c) Total Volatile Organic Compound (TVOC) and d) CO_2. Our next step is to address the challenge of the energy need of the device. The location of our campus is such that we often face outage on the GSM/GPRS connection. We plan to change the communication medium to LoRA [4]. Implementation of these changes will make the monitoring wearable least susceptible to failures.

Once we develop such a wearable, we would plan to conduct studies by measuring the exposure of different campus residents. We also plan to study the exposure of other kinds of blue-collar job workers.

Even a modest decrease of 10$\mu g/m^3$ can reduce PM-related mortality by about 3% [7]. Thus, we plan to introduce some of the discussed interventions.

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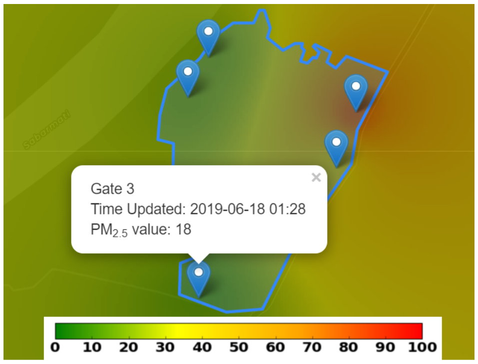
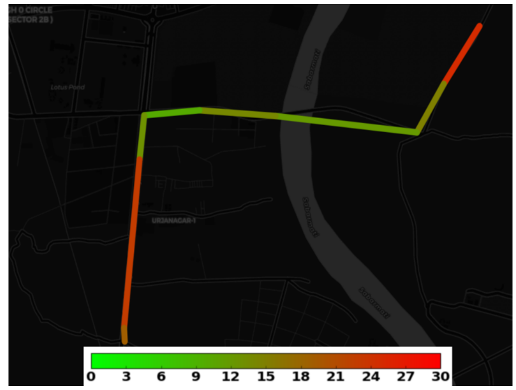


(a) Interpolated air quality level on the campus in $\mu g/m^3$



(b) Air Quality Level in $\mu g/m^3$ on the route taken by the bus

Figure 3: Campus and bus route air quality levels

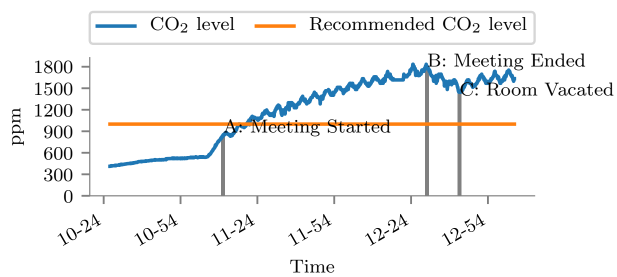


Figure 4: CO_2 value at different times and event of the day in a meeting room

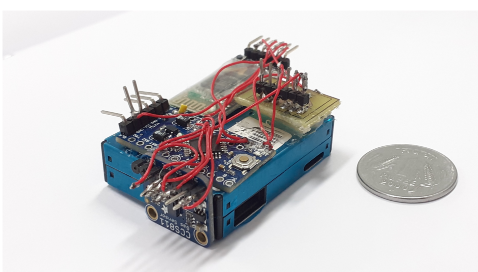


Figure 5: Prototype of our wearable air quality monitor

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