T3.4 Impactanalyse luchtkwaliteit

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AMSTERDAM INSTITUTE FOR ADVANCED METROPOLITAN SOLUTIONS

T3.4 Impactanalyse luchtkwaliteit

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Samenvatting

Het werkpakket 3.4 had als doelstelling de verificatie en validatie van verwachte emissiereducties en gezondheidseffecten d.m.v. tijdreeksanalyse van de concentraties van luchtvervuiling in en rond de bouw hubs en -plaatsen. Gedurende het project zijn er een aantal onderzoeksopties afgevallen, aangezien noch de bouwlocaties noch de bouwhubs volledig in operatie waren. Uiteindelijk zijn er vier separate onderzoeken uitgevoerd - elk met een eigen doelstelling.

In het eerste onderzoek zijn onder supervisie van WUR/MIT luchtkwaliteit meting gedaan rondom bouwplaats Cordeel. Dit voornamelijk om strategieën te ontwikkelen voor het bereiken van luchtkwaliteitsnormen door middel van het plaatsen van goedkope luchtsensoren in bouwprocessen. De lessen uit dit onderzoek zijn te vinden in bijlage 1. Het tweede onderzoek is uitgevoerd door MIT/WUR, en was gericht op het analyseren van de luchtkwaliteit rondom biobased en modulaire bouw. Dit onderzoek vond plaats op Switi in Amsterdam. De resultaten van dit onderzoek worden hieronder in het Engels samengevat. Het derde onderzoek, tevens uitgevoerd door MIT/WUR vond plaatst in Rotterdam bij de bouwplaats Post, met het doel om dezelfde metingen en analyses rondom een conventionele bouwplaats uit te voeren. Een vierde onderzoek is uitgevoerd onder de supervisie van WUR/TUD, ondersteund door MIT, en gaat in op de vergelijking tussen bouwplaatsen SAWA, Switi, en Post. Het resultaat van dit onderzoek zit in bijlage 2.

De resultaten hebben een aantal implicaties voor metingen en meetstrategieën, en voor beleid. Voor de meetstrategieën is de hoofdconclusie dat er veel praktische barrières zijn voor effectieve en gegronde metingen in de bouw. Dit heeft te maken met veiligheid (is het veilig om te meten op de bouwplaats?), toegang tot bouwplaatsen (heeft de bouwplaats de capaciteit voor het ondersteunen van onderzoeksactiviteiten?), en onzekerheid met betrekking tot de bron van emissies in de stedelijke context. Het laatste punt zou overkomen kunnen worden met meer en betere metingen - echter zouden de middelen die hiervoor nodig zijn veel hoger uitkomen dan binnen dit project mogelijk is.

Er zijn drie aanbevelingen voor beleid op basis van de 4 uitgevoerde onderzoeken.

- Elektrificatie van bouwplaatsen is voor nu de beste manier om de luchtkwaliteit te verbeteren. Veel van de gewonnen verbetering in luchtkwaliteit door modulair en biobased bouwen, wordt nu namelijk significant verminderd door de, door diesel aggregaten aangestuurde, hijskranen. Hierbij moet worden benoemd dat de strategie om een diesel aggregaat in te zetten voor het generen van de elektriciteit natuurlijk geen goed alternatief vormt. Daarnaast is de mogelijkheid tot elektrificatie bij modulair en biobased bouwen groter vanwege de minder energie intensieve bouwactiviteiten, ondanks dat voor beide bouwtechnieken elektrificatie mogelijk kan zijn.

- Er is duidelijk verschil tussen biobased and conventionele bouw. Aan de hand van Ultra Fine Particles (UFP) en Black Carbon (roet) metingen kan worden geconcludeerd dat er minder luchtvervuilding plaatsvind door de bouw bij Switi dan bij Post. Daarnaast is het bouwprocess van Switi sneller dan bij Post, door de inzet van prefab en CLT, waardoor de vervuiling minder lang wordt gegenereerd op de locatie.
- Inzetten op meer metingen rondom de bouw is nodig. Vooral metingen die het gehele bouwprocess kunnen doorgaan. Bouwprocessen zijn vaak langer dan een jaar - zeker voor hoogbouw. Door de grote verschillen in aanpak van de bouw, waaronder variatie in materieel, verschil in snelheid van de bouw, verschil in activiteiten, ligging in de stedelijke context, en veel andere variabelen is het vaak (te) complex om tot een volledig valide beeld te komen van hoe emissies van de bouw effect hebben op luchtkwaliteit, laat staan de gezondheid. Echter is er vanuit een aantal kennissessies met partners van het project opgehaald dat er wel degelijk belang bestaat bij de bouwbedrijven om inzicht te generenen in de emissies - er bestaat simpelweg geen infrastructuur en er is niet afdoende kennis om dit effectief te doen.

Air Quality Monitoring Around Construction Sites

Ambitions

Despite the large ambitions at the start of the project, we need to acknowledge that the shortened timeline and the lack of directly available construction hubs and sites greatly impeded the research. In advance of the project, the goal was to verify and validate the emissions predicted by the model of the total WP3. Unfortunately, due to a lack of data and a lack of operational construction hubs, this was not possible. Our initial proposal was developed as illustrated in Figures 1, 2, and 3. We compare a conventional construction process with an optimized (biobased, prefab at construction hub) process. We aimed to collect data along the routes of the construction vehicles, and with stationary sensors at the construction hubs and sites. This would lead to a clear A to B comparison of air quality.

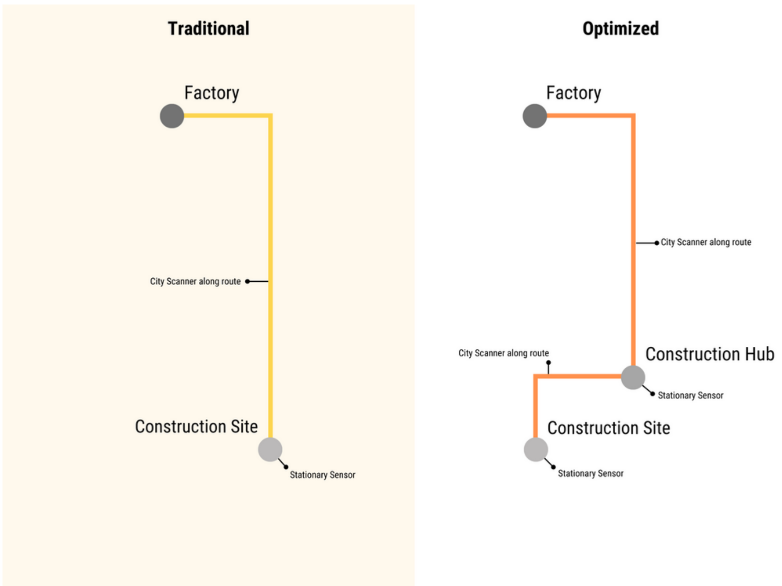


Figure 1: Schematic diagram of the research setup

Figure 2: Diagram of the proposed setup, multiple construction sites and hubs were evaluated and subsequently ruled out as they did not meet the requirements for either conventional or biobased construction processes.

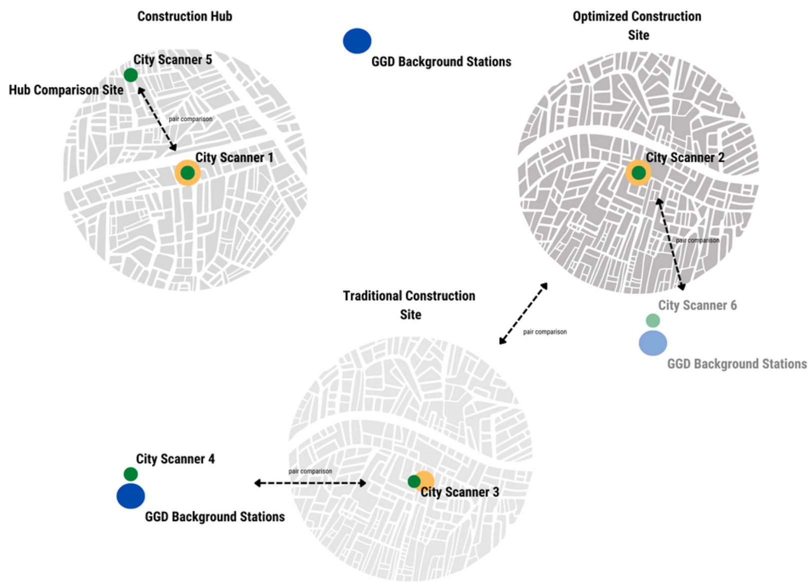


Figure 3: proposed research setup, which was later adapted.

This strategy would lead to both onsite as well as offsite emission measurements. Here the mobile sensors would be employed to evaluate the spread and diffusion of air pollutants around construction sites. A graphical representation of the envisioned data collection was developed and is presented in Figure 4. During the project, we repeatedly engaged with construction hubs in Amsterdam, Rotterdam, and even Eindhoven. Due to the early stage development of each hub, none were suitable for further research. A fully developed proposal for a case study about quantifying emissions from trucks at one of these hubs ended up unexecuted as the construction hub only received one delivery per day - which would not nearly be representative of an active hub with multiple deliveries, pick-ups, and on-site activities.

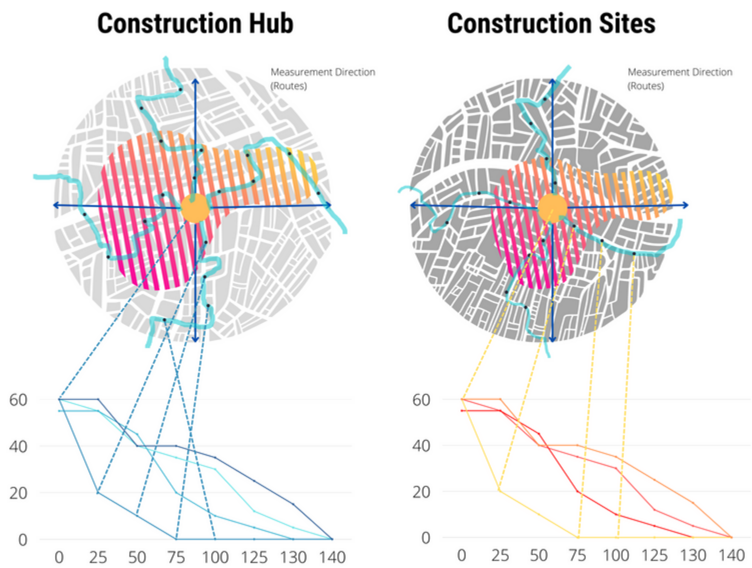


Figure 4: schematic of the envisioned data collection process.

Multiple real-life constraints, such as those detailed above, were discovered during the project, and the plan was adapted accordingly. Through more extensive on-site measurements, where manual qualitative data was collected about the activities on each construction site, the research was able to produce several key deliverables. WP3.4 is therefore able to deliver 4 separate but related research activities - with the learnings described further in the next sections.

Air Quality Monitoring Around Construction Sites

Background

Air pollutants are increasingly studied due to their health effects and prevalence in densely inhabited cities. While there is a substantial body of literature on traffic-related air pollutants - construction activities have received less attention. In this study, we report on findings from 4 case studies trying to use low-cost sensing, combined with more expensive Black Carbon and UFP measurements to investigate these air pollutants from construction.

Air pollutants can consist of a wide variety of particles and gasses. Here we will briefly introduce the ones included in th study.

PM25 - CS

Particulate Matter 2.5 (PM2.5) refers to fine inhalable particles with a diameter of 2.5 micrometers or smaller suspended in the air. These microscopic particles originate from various sources, including vehicle emissions, industrial processes, and natural sources such as wildfires and dust storms. Due to their small size, PM2.5 particles can penetrate deep into the respiratory system, posing health risks. Prolonged exposure to elevated levels of PM2.5 is associated with adverse health effects, including respiratory and cardiovascular diseases, making it a key focus of air quality monitoring and regulatory efforts worldwide.

NO2 - CS

Nitrogen Dioxide (NO2) is a gaseous air pollutant that forms primarily from the combustion of fossil fuels in vehicles, power plants, and industrial processes. NO2 is a major component of nitrogen oxides (NOx), and its presence in the atmosphere contributes to air pollution. The gas can irritate the respiratory system and, over time, may lead to respiratory problems such as bronchitis and asthma. Traffic-related emissions are a significant source of NO2 in urban areas. Monitoring and controlling NO2 levels are essential for safeguarding public health and maintaining air quality standards.

BC

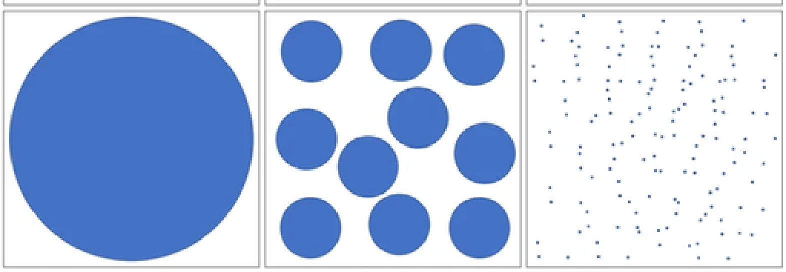
Black Carbon (BC) is a type of fine particulate matter composed of elemental carbon, typically in the range of nanometers to micrometers in size. It is generated through the incomplete combustion of fossil fuels, biomass, and biofuels. The small size of BC particles, which can range from nanoparticles to microparticles, allows them to remain suspended in the air for extended periods. This characteristic, coupled with their ability to absorb sunlight, contributes to their impact on climate patterns and global warming. When inhaled, these fine BC particles can penetrate deep into the respiratory system, posing health risks and being linked to respiratory and cardiovascular diseases. Major sources of Black Carbon include diesel engines, industrial processes, and residential heating. Monitoring and reducing BC emissions are crucial for both mitigating air quality issues and addressing climate impacts.

UFP

Ultra Fine Particles (UFP) are a subset of particulate matter characterized by their extremely small size, typically ranging from a few nanometers to 100 nanometers. These particles are generated through various processes, including combustion, industrial activities, and natural sources. Due to their minuscule size, UFP can penetrate deeply into the respiratory system upon inhalation, reaching the alveoli and potentially entering the bloodstream. The small size and large surface area of UFP contribute to their unique properties and potential health impacts. Exposure to Ultra Fine Particles has been associated with adverse respiratory and cardiovascular effects, and ongoing research aims to understand their implications on human health. Mitigating UFP emissions is essential for improving air quality and safeguarding public health.

Combined these particles can shed light on how damaging the air quality can be. However, as described, the effects of the individual particles may differ. For an extensive review of these particles, we refer to an article on UFPs, as referenced here: Kwon, H. S., Ryu, M. H., & Carlsten, C. (2020). Ultrafine particles: unique physicochemical properties relevant to health and disease. Experimental & molecular medicine, 52(3), 318-328.

	10 μm (Coarse)	2.5 μm (Fine)	0.1 μm (Ultrafine)



	10 μm (Coarse)	2.5 μm (Fine)	0.1 μm (Ultrafine)
Total mass	1	1	1
Particle number	1	64	1,000,000
Surface area per particle	1	0.0625	0.0001
Total surface area per mass	1	4	100
	• Filtered in proximal airway • May irritate skin, mucosa	• Reaches peripheral airway • Cannot enter systemic circulation	• Higher adsorbed toxic material on surface • May enter systemic circulation

Image from Kwon, H. S., Ryu, M. H., & Carlsten, C. (2020). Comparison of the surface area of particles with different diameters.

Air Quality Monitoring Around Construction Sites

Executed research

WP3.4 developed 4 separate but related research activities. Each activity is briefly described, with the main conclusions.

Research 1: MAQC: Measuring Air Quality from Construction

Under the supervision of MIT/WUR 5 Master students from the TU Delft and Wageningen University conducted research at the construction site Cordeel. They deployed 4 City Scanner for several weeks around the construction site. Cordeel was largely excavating during this research period. Additionally, several knowledge exchange sessions were organized at the AMS Institute where partners of this project were invited to think along the research. These sessions provided extra dimensions to our activities. For example, safety managers for construction sites have a vested interest in protecting employees on site, also from air pollutants. Hence, this part of the industry could be an important ally in developing further air quality monitoring of construction sites.

This activity delivered key insights into the operational complexities involved in air quality monitoring around active construction operations - from simple power supply for sensors to having access to the right places on the construction sites at the right time. More than once monitoring needed to be suspended due to complications with the sensors, power supply, weather conditions, and last-minute changes to the schedule of the construction activities. In the end, all learnings have been summarized in the booklet found in annex 1. Additionally, the developed open-source code can be used by researchers and construction companies using low-cost technologies themselves

Research 2, 3 and 4: Sensors

While the previous research relied solely on the City Scanner device, research 2, 3, and 4 rely on a combination of **three devices:**

Firstly, the Partector 2 Aerosol Dosimeter, as depicted in Figure 5. This device, crafted by NANEOS, was utilized for measuring Ultra Fine Particles (UFP). Its functionalities encompass the capture of nanoparticles, particle counting, and determination of particle diameter (naneos particle solutions gmbh, 2022).

Figure 5: NANEOS Aerosol Dosimeter

The second tool utilized was for Black Carbon (BC) measurements and was the ObservAir DST, illustrated in Figure 6. This instrument featured an aerosol absorption photometer specifically configured to assess BC concentration. BC is a constituent of particulate matter pollution resulting from the incomplete combustion of fossil fuels or biomass (Distributed Sensing Technologies, 2023).

Figure 6: ObservAir DST

The third instrument in use was the CityScanner, showcased in Image 3. This instrument, characterized by its low-cost and modular design with Internet of Things capabilities, was developed by the Senseable City Lab at MIT. It was employed for quantifying concentrations of PM2.5 and PM10, and equipped with an Alphasense NO2 gas sensor. The CityScanner relies on laser technology to enumerate particles within various diameter-size bins, thereby making precise measurements of these particulate matter components. As a low-cost device, the City Scanner was calibrated using co-location with a reference grade monitor (as per: Wang, A. (n.d.). City Scanner In-Situ Calibration and Deployment: A Manual)

Figure 7: City Scanner - Whiteburn

Research 2: Case Study SWITI: Research

SWITI is located in Amsterdam South-east, an area with many ongoing developments. The precise location is indicated below, in Figure 8.

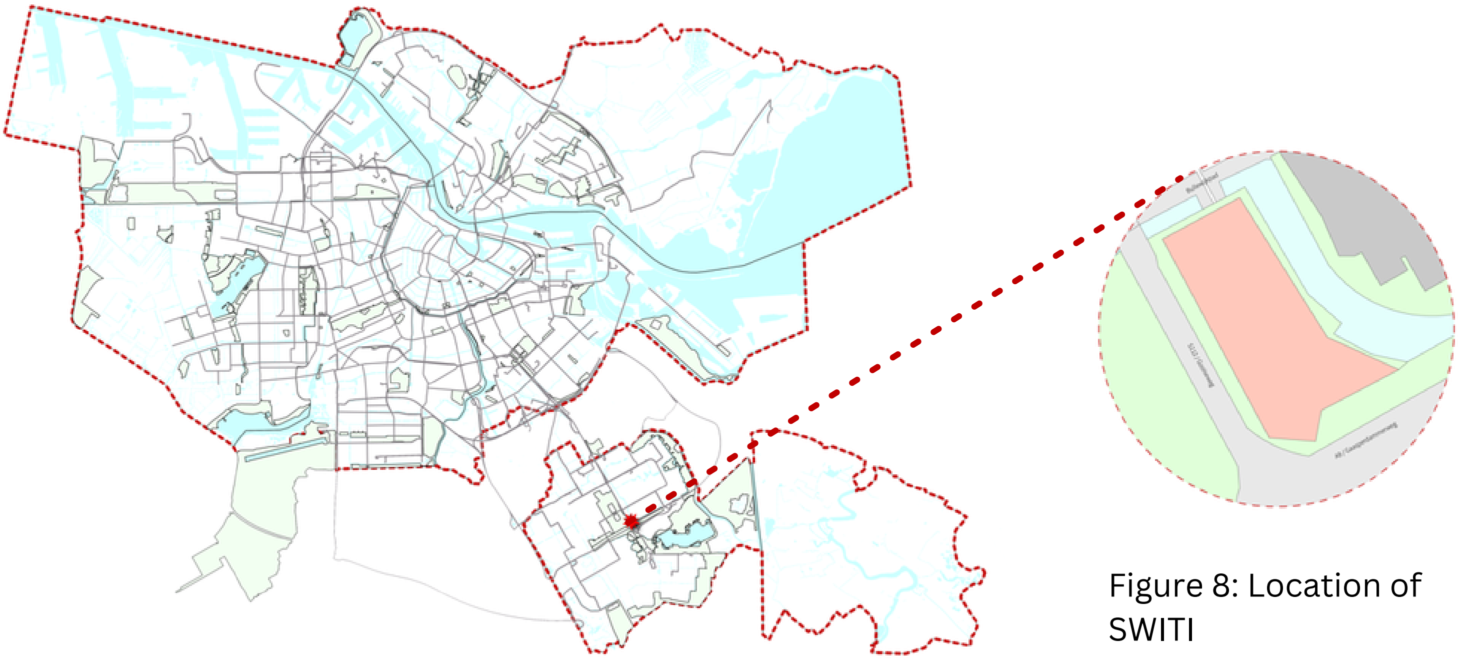


Figure 8: Location of SWITI

Switi consists of a mid-rise apartment building (8 stories), and various single-family homes. Built entirely with pre-fab CLT, as shown in figure 9. The construction dates ran from June 2023 to November 2023.

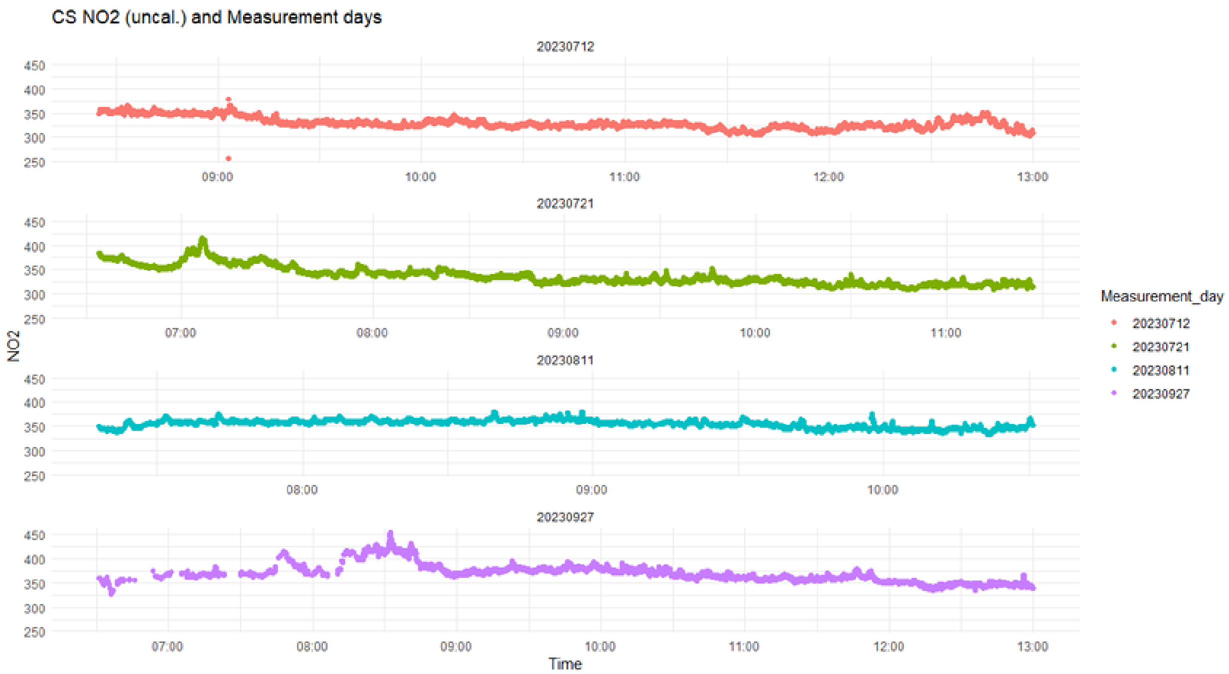
Figure 9: SWITI Site

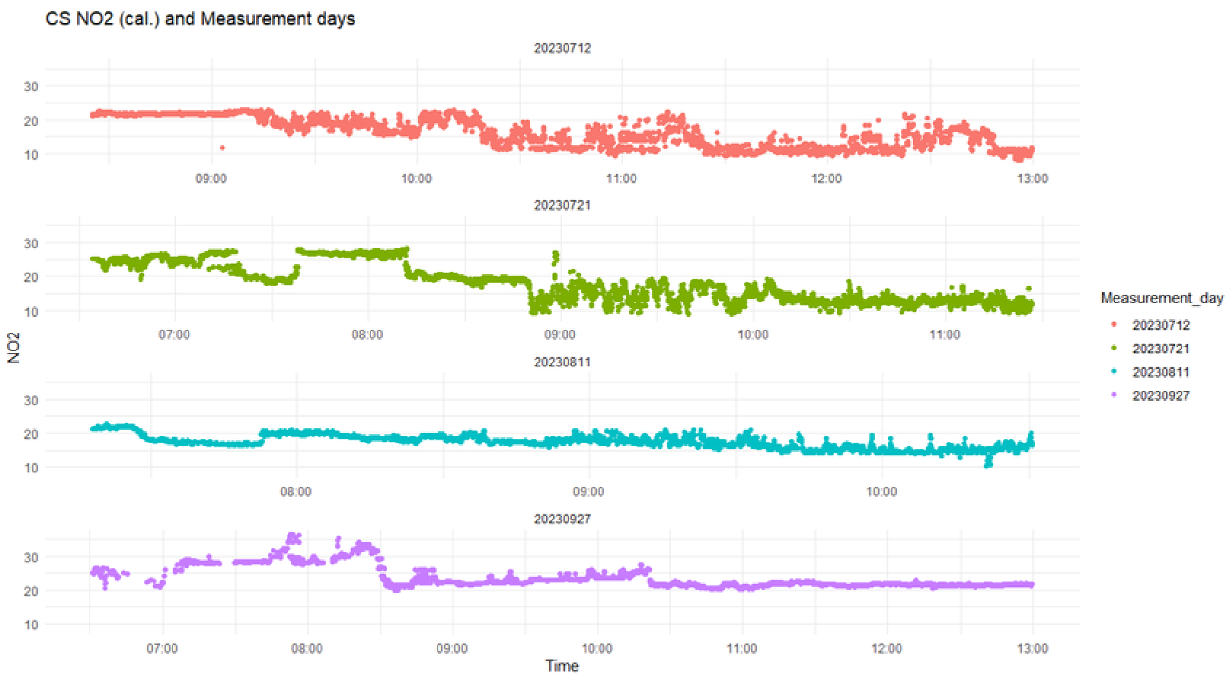
There were 5 measurement campaigns at SWITI, summarized below in the table. On day 2, the City Scanner was not operational, hence some data is lacking from the table. The activity level is derived from manually kept logs about the activities on site. The temperature, relative humidity (RH), and wind direction and speed are collected from weeronline.nl.

SWITI	Day	PM25	NO2	UFP	BC	Activity Level	Temp	RH	Wind
Day1	12-7-2023	15.87	16.09	5827.99	0.549	Medium	22	71	4 W/S-W
Day2	14-7-2023	na	na	11398.12	1.8	High	22	68	2 S/S-W
Day3	21-7-2023	11.26	18.08	12674.72	2.067	Medium	20	77	1-2 S-E
Day4	11-8-2023	15.28	17.49	9351.04	0.712	No activity	27	77	2 S-E
Day5	27-9-2023	18.55	23.06	5827.99	0.549	Medium/High	24	68	2 S-E

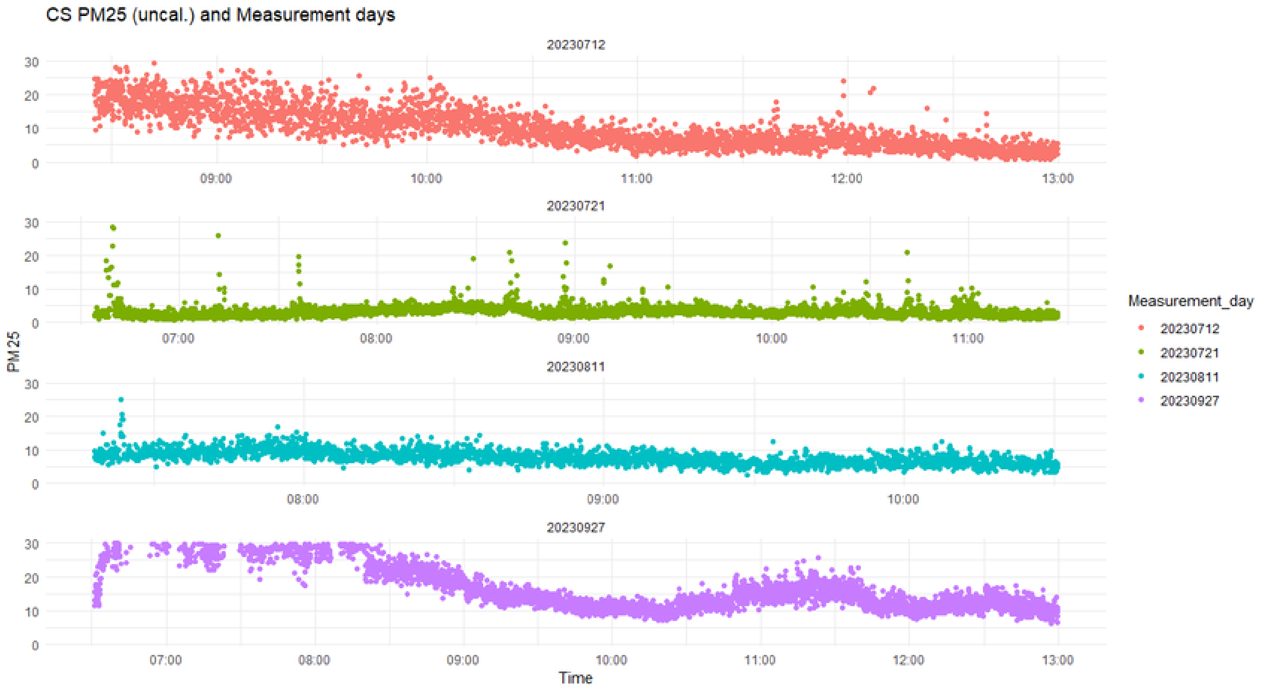
First, City Scanner data is presented. Second, the UFP data is analyzed. Third, the BC data is shown. Fourth, an analysis is presented of UFP and BC combined.

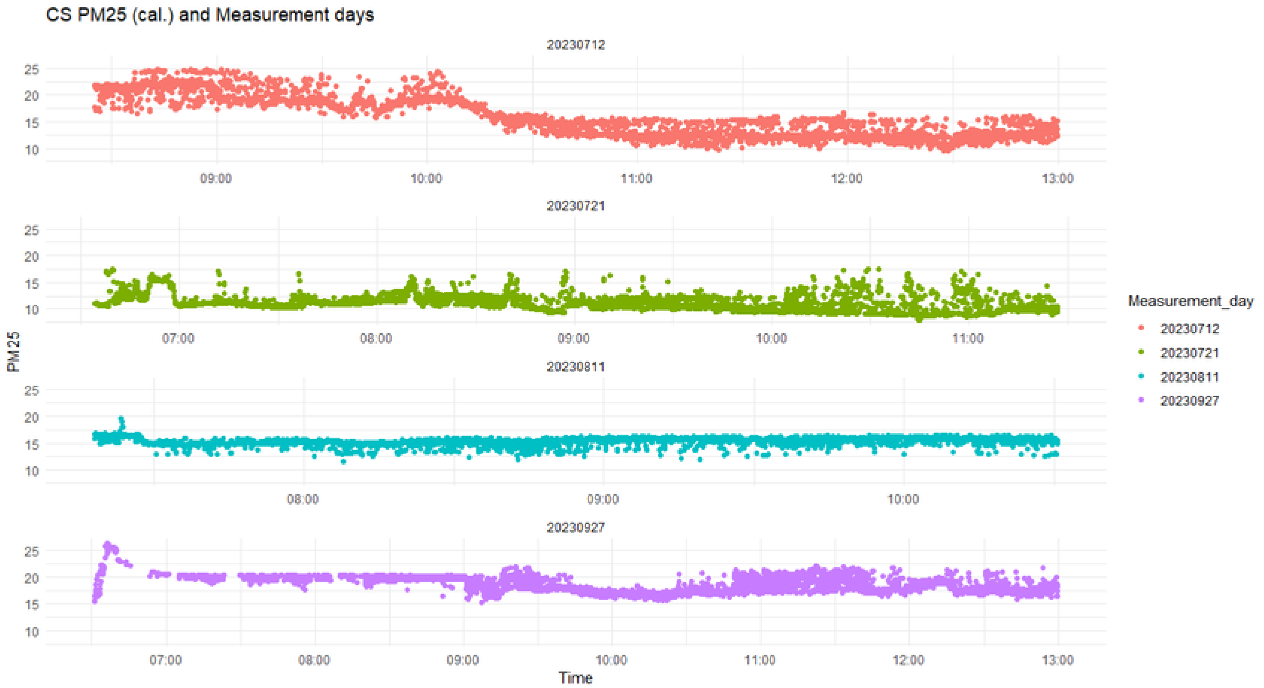
The collected NO2 data is shown below, both calibrated and uncalibrated according to the procedure in Wang (n.d.).





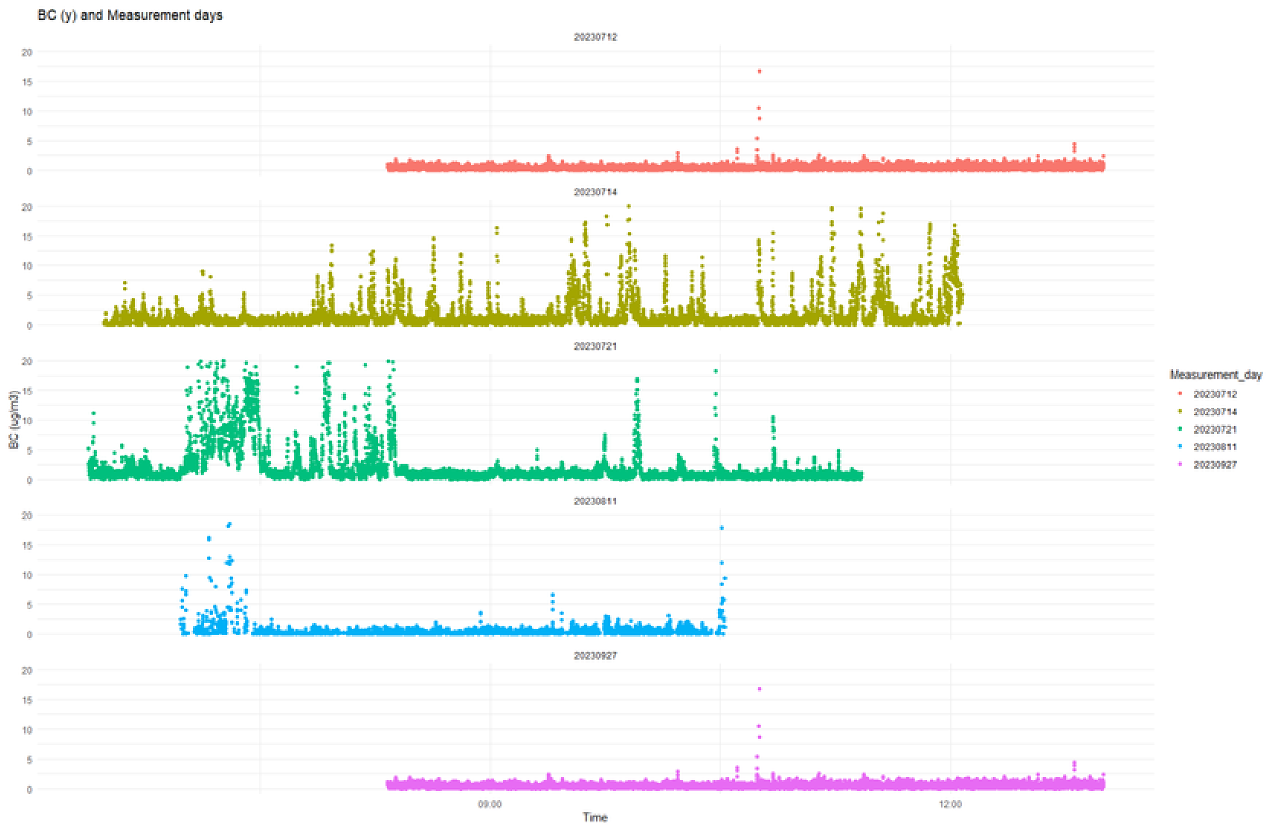
The collected PM2.5 data is shown below, both calibrated and uncalibrated according to the procedure in Wang (n.d.).





The collected UFP data is shown below - noticeable is the variability on days 2 and 3 of data collection at SWITI.

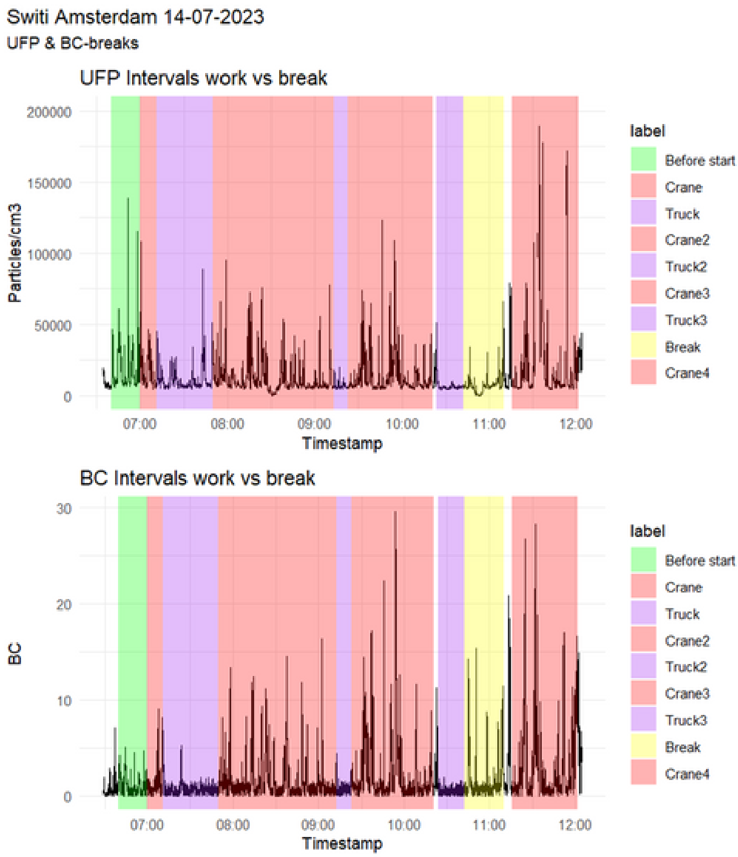
The collected BC data is shown below - noticeable is the variability on days 2 and 3 of data collection at SWITI.



As both BC and UFP measurements demonstrate a high variability of days 2 and 3, we analyzed their overlap, to ensure correct measurement results, shown below.

Further analysis of BC and UFP was conducted, specifically looking at activities from the manually kept logs. On the right, we visually show one of these analyses.

There is a clear signature of activities in UFP and BC concentrations. Especially the diesel crane causes major spikes in UFP and BC concentrations. UFP values were measured of over 150.000 particles per cm3. While some breaks in the activities can be clearly seen in the measurements, other breaks are not so clear. Hence, there might be additional sources of UFP and BC not captured in the logs.



Research 3: Case Study Post: Research

The Post Rotterdam project located in the city centre of Rotterdam, as shown below.

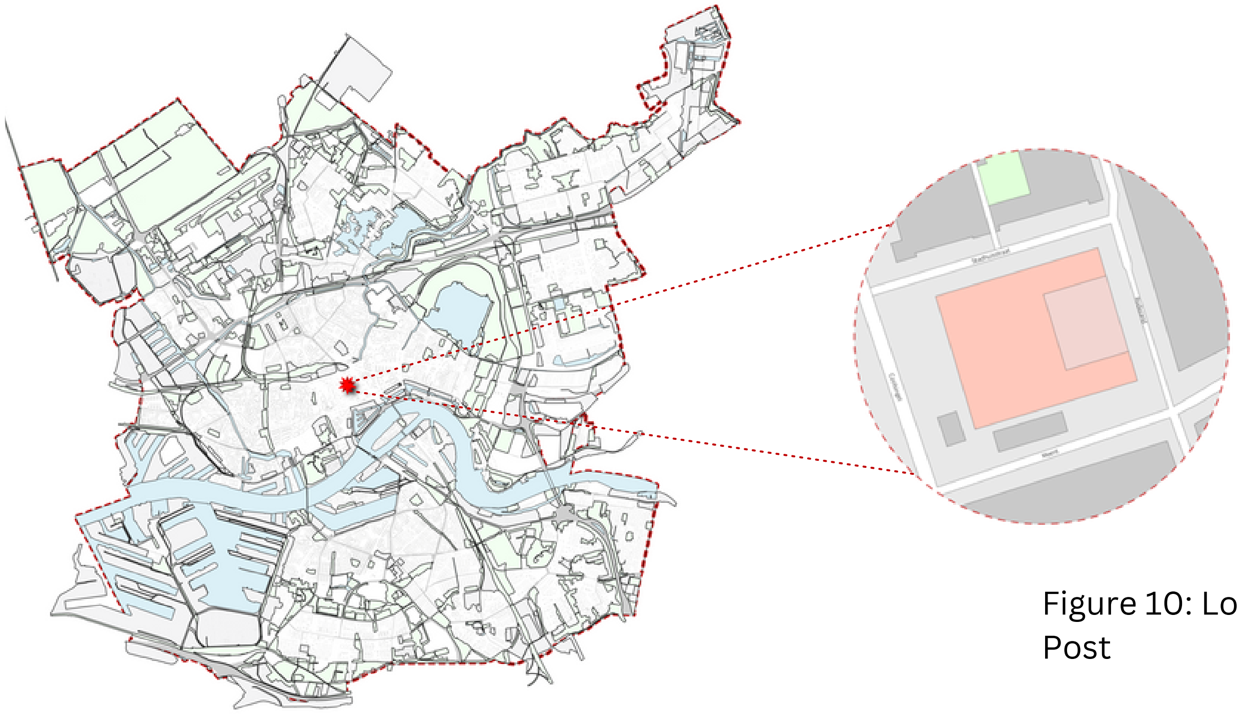


Figure 10: Location of Post

Post is a mixed high-rise building built with a conventional steel and concrete structure. The construction dates run from 2022 to January 2025.

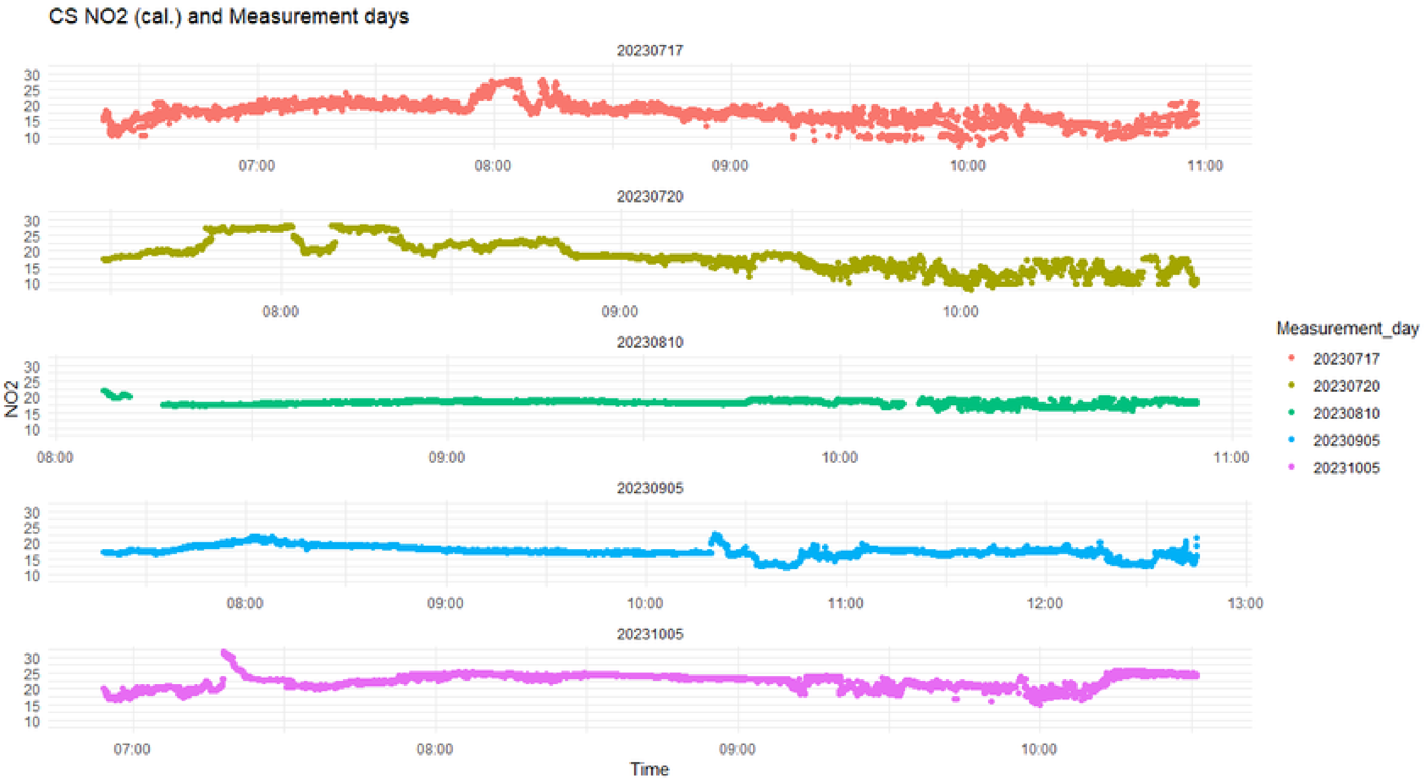
Figure 11: Post Site

There were 6 measurement campaigns at Post, summarized below in the table. On day 4, the City Scanner was not operational, hence some data is lacking from the table. The activity level is derived from manually kept logs about the activities on site. The temperature, relative humidity (RH), and wind direction and speed are collected from weeronline.nl.

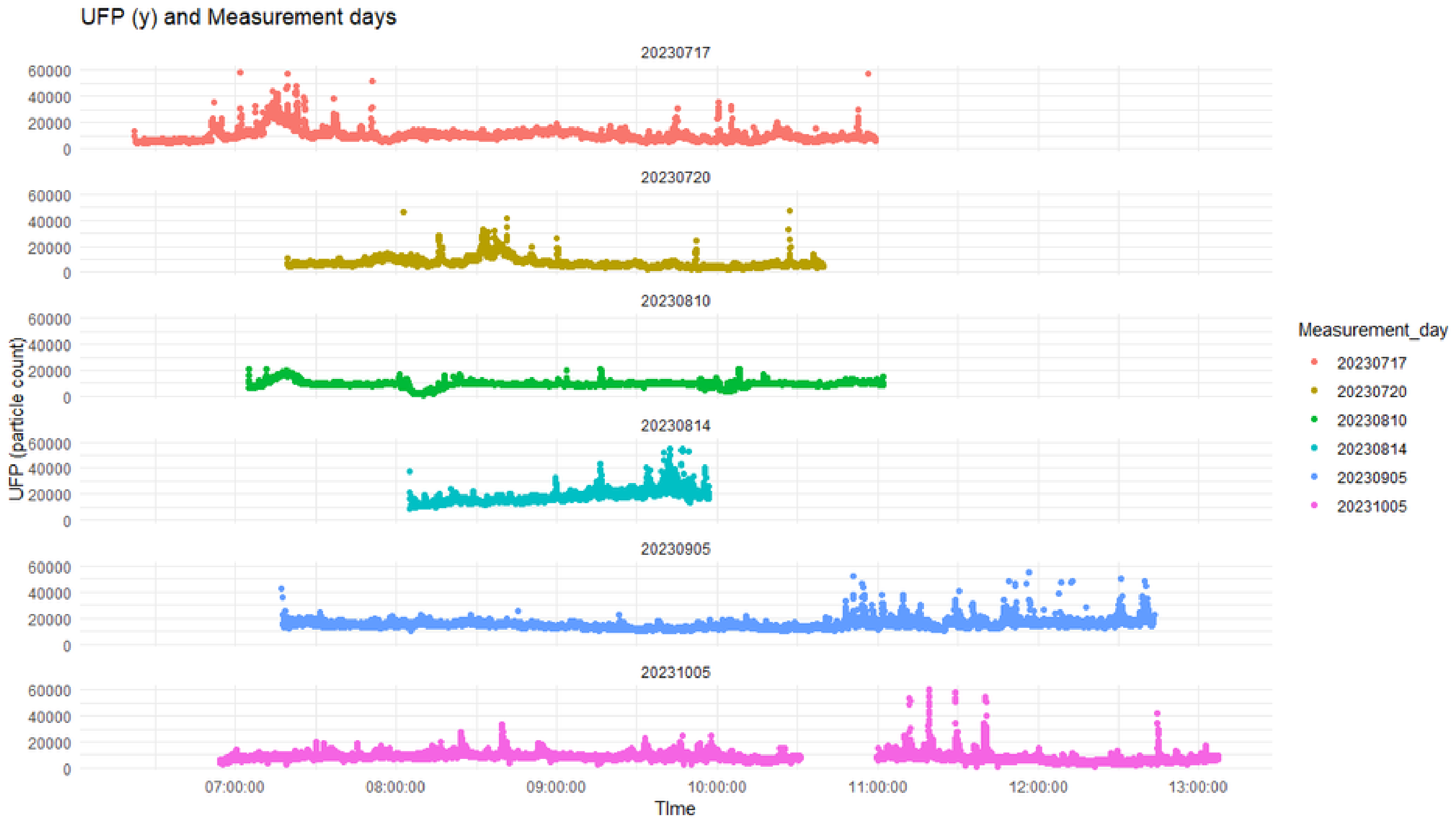
POST	Day	PM25	NO2	UFP	BC	Activity Level	Temp	RH	Wind
Day1	17-7-2023	17.61169	17.34581	10378.99	0.747679	Medium	22	73	3-4 S-W
Day2	20-7-2023	11.13361	18.43881	7518.248	0.565831	Medium	22	n	1 N-W
Day3	10-8-2023	12.19217	18.14624	9421.483	0.294807	No activity	25	75	1 S
Day4	14-8-2023	na	na	18722.31	0.63401	Very low	27	77	2 S-E
Day5	5-9-2023	12.2028	17.27703	15261.26	0.601357	Medium/High	29	71	2 E
Day6	5-10-2023	15.00444	22.28513	8366.659	0.478925	Medium/High	22	71	2 S-E

First, City Scanner data is presented. Second, the UFP data is analyzed. Third, the BC data is shown. Fourth, an analysis is presented of UFP and BC combined.

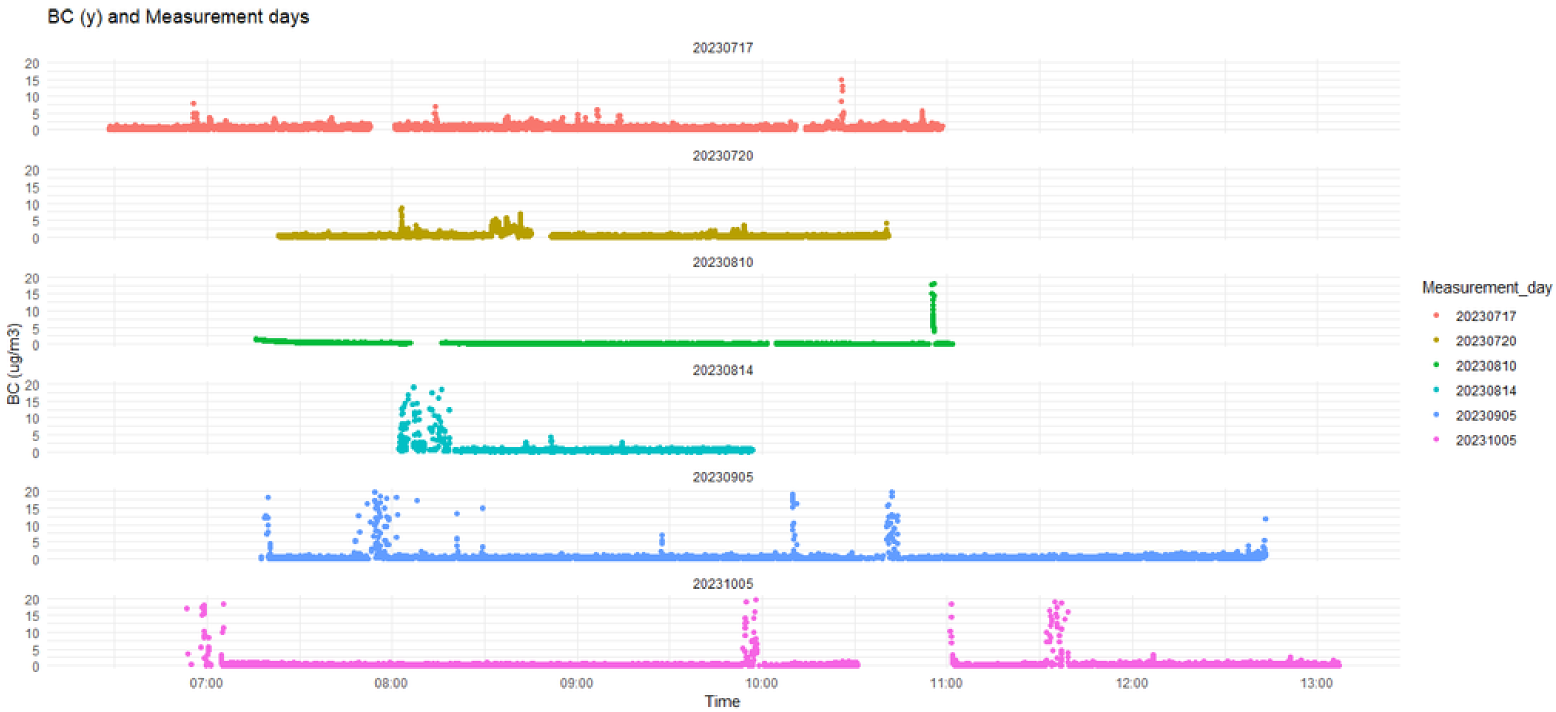
The collected NO2 data is shown below, calibrated according to the procedure in Wang (n.d.).



The collected UFP data is shown below.



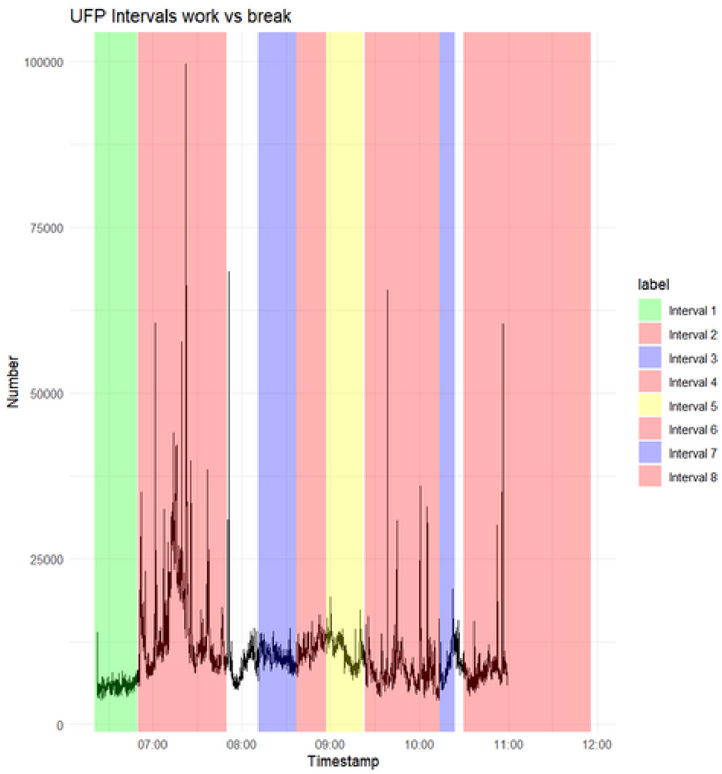
The collected BC data is shown below - noticeable is the variability on days 2 and 3 of data collection at SWITI.



We analyzed the overlap between UFP and BC, as with the SWITI case, to ensure correct measurement results, as shown below. Notice the deviations in BC and UFP measurements - indicating a potential issue with the UFP sensor during some of the measurements.

As with SWITI, we also analysed the UFP and Bin relation to the log of activities. A sample is shown on the right from the 17th of July 2023.

Here we also measure high UFP values, with several measurements above 50.000 particles per cm3. All these spikes happen during high activity on the site.



Research 4: Air Pollution from High-rise Construction in Rotterdam: Comparison of black carbon (BC), ultrafine (UFP)and particulate matter (PM2.5 and PM10) ambient concentrations from conventional and biobased (Cross-Laminated Timber CLT) construction methods

Under the supervision of Juliane Fry and Ruben Vrijhoef, a master's student completed a comparative analysis of air quality around 3 construction sites, Switi, SAWA, and Post. The results of this study can be found in Annex 2.

Conclusion and recommendations

Our results show that UFP and BC are good tracers for construction diesel activity, while NO2 and PM are not, because they have substantial additional regional sources. This is demonstrated by the greater contrast among activity levels for UFP/BC than for NO2 / PM.

As our field measurements demonstrate that UFP and BC are good tracers for construction diesel activity, more frequent measurements of these air pollutants at construction sites could enable the construction sector to better understand which activities and phases of construction produce the most air pollution.

UFP particle counts can exceed 100.000 particles per cm3 during high activity on the site. However, more research is needed to link UFP exposure to health outcomes.

Overall we find that Switi produces less air pollution than POST as shown with BC and UFP measurements. However, it is complex to derive actual emissions from construction in an urban context. A different, more laboratory focused, research setup could aid in establishing a more fundamental body of literature on this topic.

We also conclude that a lack of knowledge in the construction sector about the air pollution exposure risks - and how construction activities contribute to air pollution - could pose a major risk to the health of construction workers and citizens living close to these activities. More measurements could help the construction sector.