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Impacts of Potted Tree Configurations on PM_{2.5} Concentration in the Field Lab Haarlemmermeer near Schiphol Airport

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SUMMARY

This study examines the impact of potted tree configurations on PM_{2.5} concentrations from air traffic emissions near Schiphol Airport. Air quality sensors collected data between 2022 and 2024 at a field lab 5 km from the Kaagbaan runway. ENVI-met simulations were first validated and calibrated using ground-truth measurements under stable meteorological conditions, followed by simulations of PM_{2.5} concentrations across six tree configurations in the field lab. The 'V7_End_Dense' configuration achieved the greatest PM_{2.5} reduction, while 'V2_Dispersed' and 'V3_Double_Row' showed moderate effects. In contrast, 'V4_Exposed,' 'V5_Exposed_Dense,' and 'V6_Gate_Dense' unexpectedly hindered reduction, highlighting the complex interactions between wind corridors, tree layouts, and built environments. The findings emphasise the need for long-term ENVI-met validation against real measurements, as seasonal variations were not captured in short-term analyses. Despite limitations, the study provides practical guidance for urban designers, highlighting the nuanced role of green infrastructure in mitigating aircraft-induced air pollution and emphasising the complexity of wind and pollution dynamics in urban environments.

Keywords: PM_{2.5}, aircraft emission, urban morphology, urban green infrastructure, tree configuration

1. INTRODUCTION

Particulate matter (PM_{2.5}) is widely recognised as a major contributor to illnesses such as heart disease, respiratory infections, and chronic lung disease, causing approximately 4 million deaths worldwide (Thangavel et al., 2022). Schiphol Airport, one of the busiest airports in the country, exposes nearby residents to elevated pollutant concentrations from air traffic, increasing health risks (RIVM, 2019). Research shows that linear green infrastructure positively impacts PM_{2.5} concentrations (Jeong et al., 2023a); However, studies on the effects of different tree configurations on air pollution, especially PM_{2.5}, remain insufficient compared to research in other domains such as urban heat, noise, and glare pollution (Lugten et al, 2024, Wuite et al, 2023). From a planning perspective, it is crucial to explore how trees mitigate air traffic-related pollution and identify the most effective tree configurations for filtering PM_{2.5}, benefiting residents exposed to air traffic pollution. To address this, the Urban Comfort Lab (UCLab) at AMS Institute established a field lab in Hoofddorp, located less than 1 km from Schiphol Airport's Kaagbaan runway. Between 2022 and 2024, the lab collected empirical data on sound pressure levels, air quality, meteorological conditions, and flight activity. These data form the foundation for ongoing and future research in a semi-controlled lab environment, aimed at evaluating the pollution mitigation effects of urban greenery. The lab findings are intended to address real-world challenges related to climate and built environments.

According to Dellaert and Hulskotte (2017), air pollutant emissions from civil aviation including PM have increased significantly in recent years in the Netherlands. Green infrastructure, such as trees, can help reduce urban PM_{2.5} concentrations (Isaifan & Baldauf, 2019b). Jeong et al. (2023b) examined the impact of urban street trees on PM_{2.5} concentrations and found that reductions depend on tree presence and planting structure. Notably, areas with multi-layered planting structures (e.g., shrubs, arbours) experienced greater reductions. Similarly, Wu et al. (2021) assessed three road green belt configurations and found that combinations of arbour and shrub species performed best in reducing PM concentrations from road traffic.

Although studies on tree impacts on air pollution and PM_{2.5} are limited, existing research suggests trees can mitigate pollutant concentrations by capturing particles or reducing secondary pollutant formation (Isaifan & Baldauf, 2019a). Chen et al. (2017) investigated different abilities of tree species to capture PM_{2.5} after rainfall and identified species with high PM-capturing potential in urban areas. Liu et al. (2022) used ENVI-met (a numerical modelling tool) to analyse how tree height influences PM_{2.5} concentrations near roads and found that the optimal height depends on street canyon openness. Traffic-related PM emissions can also be affected by trees, evidenced by Popek et al. (2022) who studied PM accumulation in urban forests and identified key influencing factors, including crown width, leaf area density, and seasonality.

While existing studies explore tree characteristics (e.g., height, crown width) and their effects on PM emissions from road traffic, very rare research has examined PM emissions from air traffic or their correlation with tree configurations (e.g., tree layout). This gap is likely due to the lack of long-term aircraft pollution measurements beneath tree canopies at street level, as well as the confounding effects of urban heat islands (UHI) from diverse anthropogenic activities. This paper examines aircraft emissions and three key factors influencing simulation accuracy: area geometry (e.g., courtyards, tree configurations), pollutant sources (e.g., air traffic volume, emission position), and meteorological conditions affecting dispersion.

2. MATERIALS & METHODS

2.1 Data

ENVI-met is a 3D modeling software for microclimates and pollutant dispersion, but its accuracy in simulating particulate matter (PM) remains uncertain. Despite significant model limitations, some studies suggest it performs well in modeling PM₁₀ dispersion in urban street canyons (Hofman & Samson, 2014; Paas & Schneider, 2016). Therefore, we assess the validity of ENVI-met in simulating PM_{2.5} concentrations before evaluating intervention strategies.



Figure 2. ENVI-met model (left); Courtyard 2 double-row tree (middle); Courtyard 1 without vegetation (right)

The raw weather files were retrieved from the KNMI weather services and morphed with UHI effects to force the boundary conditions of the ENVI-met model. The simulation period was set to September 2023 to ensure a comprehensive comparison with measured PM_{2.5} concentrations, as this month had the highest recorded levels and the most complete dataset for the double-row tree configuration. Double row in courtyard 2 was chosen to be the tree configuration for validation and courtyard 1 was kept bare comprising a geometry with a slanted roof during simulation period. The layout of courtyards and double row tree configuration are shown in Figure 2.

Historical meteorological data for September 2023 was retrieved from the KNMI database and linked to a weather mast at Schiphol Airport. The dataset includes cloud cover, wind direction, wind speed, air temperature, relative humidity, and precipitation. Meteorological conditions from 6am on 14 Sep 2023 to the same hour on 17 Sep 2023 were extracted to adjust boundary conditions for validation, calibration, and simulation in ENVI-met. Using measured hourly flight data, hourly PM_{2.5} emissions from air traffic at Kaagbaan were calculated and implemented as a line source emission in ENVI-met, following the equation (1) by Smulders (2022).

$$\text{Line source } \left[\frac{\mu\text{g}}{\text{m}\cdot\text{s}} \right] = \frac{N \cdot E \cdot 1000 \left[\frac{\mu\text{g}}{\text{mg}} \right]}{d} \quad (1)$$

Where

N: number of hourly flights

E: PM emissions (mg/s) per flight

d: average distance between flights (m), 4167m

2.2 Simulation constraints

Over the past three years (2021–2024), the UCLab collected air pollution and meteorological data at a high temporal resolution (10-minute intervals). To ensure representative longitudinal analysis, specific criteria were applied: periods with relatively high PM_{2.5} concentrations were selected for simulation validation. Precipitation-free conditions were prioritized to avoid biases from wetting losses and splashing effects, as the Nanenos partector 2 (<30% error), BC Carbon (<25% error), and NodeMCU sensors V3 (<10% voltage-dependent error) have limited correction capabilities (Bezantakos et al, 2024; Naneos Particle Solutions GmbH, 2022). Wind direction was restricted to northeast–southwest, aligning with in-situ measurements identifying Kaagbaan runway as the primary pollution source, with emissions dispersing southwest (Thielen et al., 2024a). Wind speeds at roof level (10m) were kept below 3 m/s, as higher speeds negatively correlate with PM_{2.5} concentrations (Wang & Ogawa, 2015; Thielen et al., 2024b). Relative humidity was capped at 85% to maintain sensor accuracy and avoid misreading water particles as PM (Casari & Po, 2023). Finally, ENVI-met simulations were extended to 72 hours to ensure model convergence.

2.3 Validation and calibration protocols

ENVI-met validations and calibrations were iteratively conducted to assess atmospheric stability, verifying pollutant source presence, wind conditions, and courtyard materials. Validation was performed at a single point in the courtyard due to limited apparatus availability, selected based on PM sensor locations (Figure 3). Two citizen sensors were positioned at (29, 36) in Courtyard 1 and (29, 44) in Courtyard 2, both 1.5m above ground. Measured and simulated PM_{2.5} concentrations were compared across multiple calibration rounds, with results presented as time series data and discrepancies quantified using Root Mean Square Error (RMSE). Due to instability,

a constant wind direction (averaged over 72 hours) was maintained to approximate real-world conditions. Sensitivity tests included pollution source height (1-18m), configuration (line vs. surface source), and emission intensity normalization (divided by number of different heights, in this paper they are 18 for the wide surface or 36 for the narrow one) when transitioning from line to tilted surface sources. Once the calibrated scenario best aligned with measurements, it was applied as the boundary condition in ENVI-met for the follow-up simulations with different trees interventions.

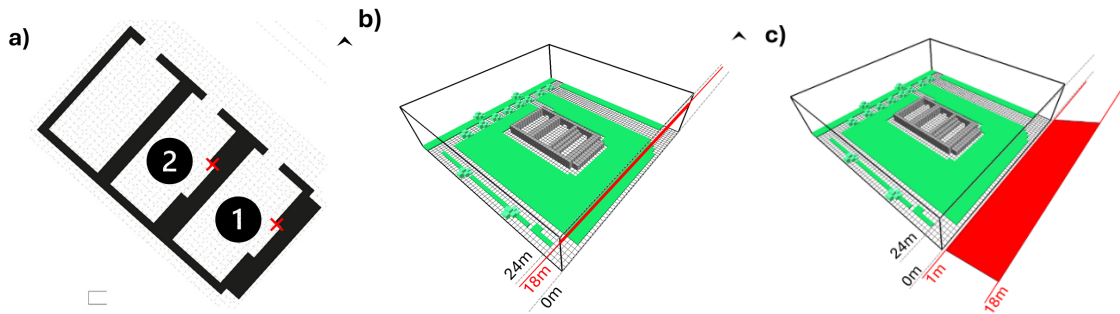


Figure 3. a) Positions of citizen sensors (red crosses) in Courtyard 1 and 2, b) Pollutant source as a line at 18m, and c) Pollutant source as a tilted plane, consisting of 18-line sources ranging from the height of 1m to 18m

2.4 Tree configuration

All seven configurations, including the baseline ‘Bare’ scenario (no vegetation) were selected from the tree configuration log (Figure 4) and tested in ENVI-met to assess their impact on air pollution.

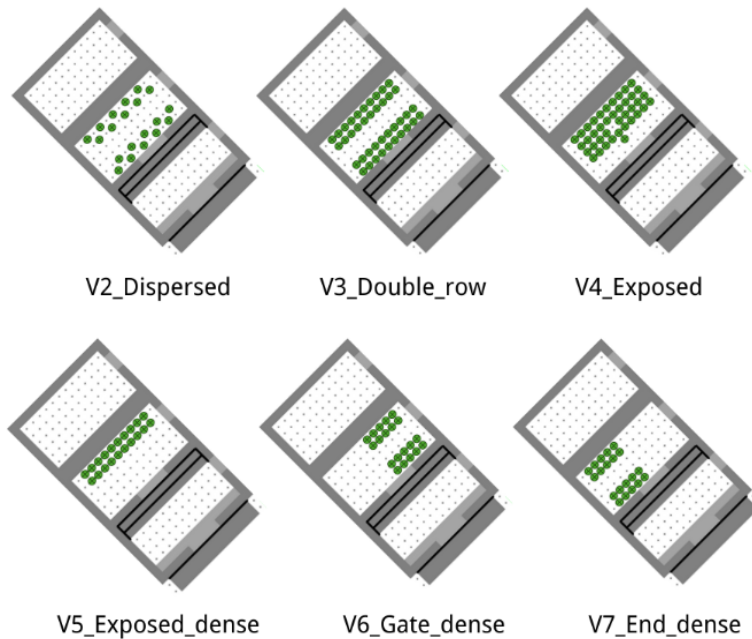


Figure 4. Tree configuration log in Courtyard 2, UCLab, from 2023 to 2024. V3 was used for validation.

3. RESULTS

3.1. Validation and calibrations

The RMSE results indicate that the modified pollution source aligns most closely with the measured data (Figure 5). Figure 6 illustrates PM diffusion in the Y-Z section under the modified pollution source, featuring a line-to-surface source with 18 steps at uniformly spaced heights.

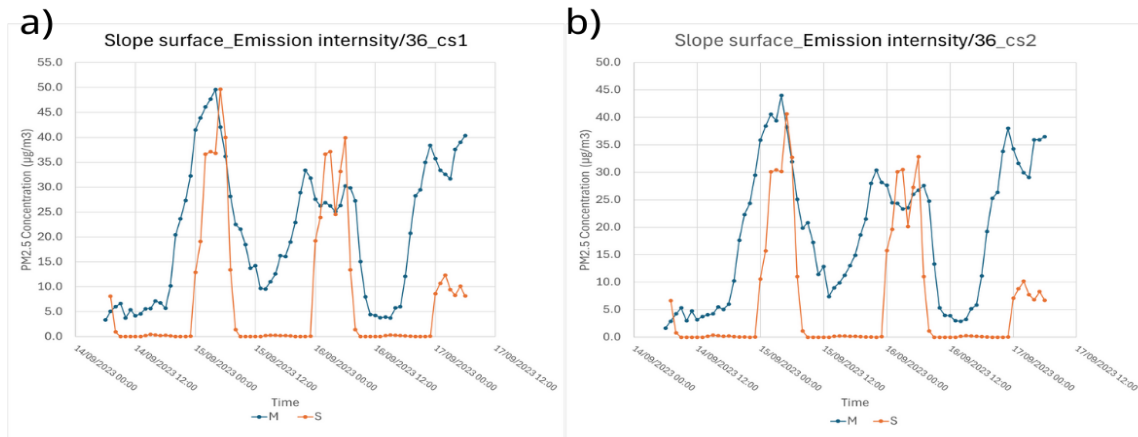


Figure 5. Temporal validations comparing simulated PM_{2.5} concentrations with measured data in a) Courtyard 1 and b) Courtyard 2 (blue line: measurements, orange line: simulation).

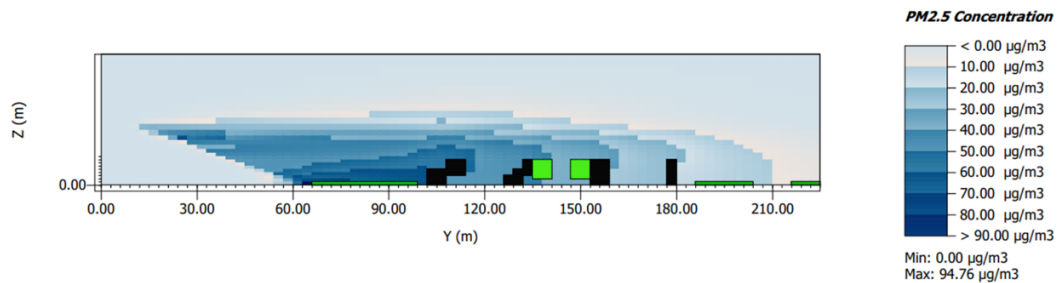


Figure 6. Y-Z section of PM concentration with Pollutant source as a tilted plane

3.2. PM_{2.5} patterns with different tree configurations

Courtyard 2 (trees courtyard) was meshed and divided into 78 grids, and the absolute PM concentration difference for each grid was calculated. Figure 7 illustrates the intra-courtyard PM_{2.5} concentration at 6am and the difference with other five tree variants. The *V7 End Dense* and *V3 Double Row* configurations demonstrated the most significant PM_{2.5} reductions compared to other layouts. The largest reductions occurred at the end side and upper left side of Courtyard 2, while PM_{2.5} concentrations increased near the gate side.

Figure 8 presents the descriptive statistics of absolute PM concentration differences for each tree configuration, supported by a Kruskal-Wallis test. The negative average absolute difference in PM

concentration between *V3 Double Row* and *B1 Bare Ground* indicates that the double-row configuration effectively reduces PM_{2.5} concentrations in Courtyard 2. In contrast, the positive average absolute difference for *V4 Exposed* suggests an increase in PM concentration compared to the baseline. Among configurations with 20 trees, *V2 Dispersed* and *V7 End Dense* contributed to PM reduction, with the greatest decrease under *V7 End Dense*. Conversely, *V5 Exposed Dense* and *V6 Gate Dense* led to increased PM concentrations in Courtyard 2.

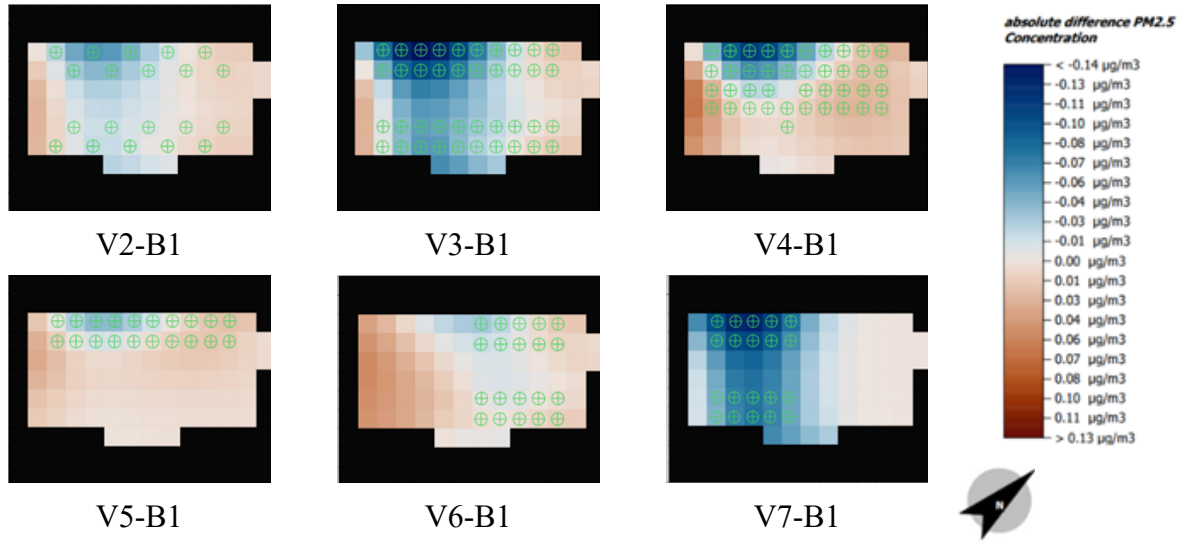
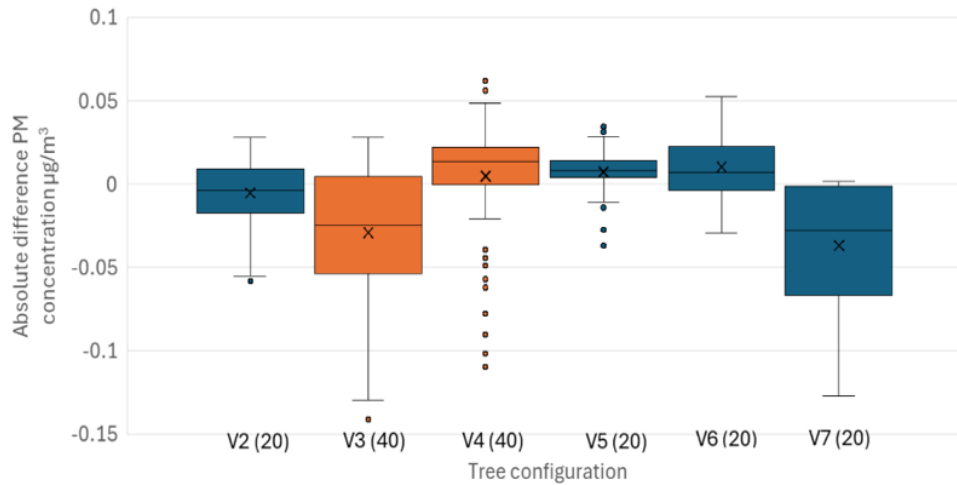


Figure 7. Absolute difference of PM concentration in grids of courtyard 2 (tree courtyard) at 6am.



	V2_B1	V3_B1	V4_B1	V5_B1	V6_B1	V7_B1
Mean	-0.00548	-0.02913	0.004863	0.007234	0.010225	-0.03678
STD	0.018442	0.038209	0.033129	0.012244	0.019581	0.03509

Figure 8. Descriptive statistics of the absolute PM concentration difference at 6:00 AM for each tree variant (V) compared to the baseline (B). Orange represents variants with 40 trees, and blue denotes those with 20 trees.

4. DISCUSSIONS & CONCLUSIONS

This study demonstrates that under controlled conditions—constant wind direction (averaged over the simulation period), a pollutant source modelled as a tilted plane (1 m to 18 m high), and emission intensity scaled to 1/36 of the initial value—ENVI-met performs well in simulating PM_{2.5} over a 72-hour period in September compared to real measurements. Among the six configurations tested, the *End-Dense* layout had the most significant impact in reducing PM_{2.5} concentrations in courtyard spaces affected by air traffic pollution. For urban planners, these findings highlight the importance of considering both pollutant dispersion patterns and site-specific wind conditions when designing tree layouts. Dense tree clusters in strategic locations, such as pollutant accumulation zones, can effectively reduce PM_{2.5} concentrations, while uniform tree distribution may help prevent wind corridors that allow unfiltered pollutant flow. We recommend that tree configurations should balance air pollution mitigation with acoustic and thermal effects, adopting a multidimensional approach to enhance overall urban comfort. Future research should incorporate additional pollutant sources, particle size interactions, and long-term simulations to improve the accuracy and applicability of PM_{2.5} reduction strategies in diverse urban environments.

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