ICLEI
Local Governments for Sustainability
EUROPE

Design recommendations to reduce exposure to air pollution

Thrive Zone Amager

Final Report - December 2021

Gehl

Thank you to the following contributers:

Project Group

MILJØPUNKT AMAGER

UrbanDigital

TEKNOLOGISK INSTITUT

BACKSCATTER

STUDIO PROFONDO

And to our project supporters:

GRUNDEJERFORENINGEN HAVNESTAD

Grundejerforeningen Ørestad City

outsider

VIKING DOME

Netto

PLANTORAMA

FRAK

Hougaard El & Teknik Autoriseret el-installatør ApS

BETASTUDIO

AFA JCDecaux

Gehl — Copenhagen

Project Team
Jeff Risom, Partner
Louise Kielgast, Associate
Martin Nielsen, Technical Designer
Kym Lansell, Project Manager
Alexandra Burgos Fuentes, Architectural Assistent

Contents

Introduction

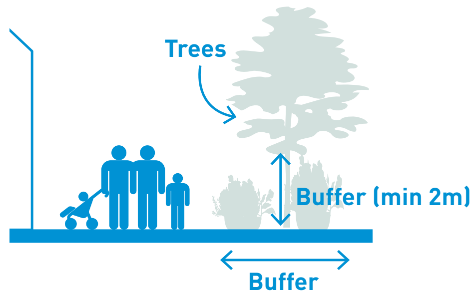
Aims and booklet use

The aim of the Thrive Zone Amager project has been to use temporary pilot installations as a realistic test of how to address air pollution in cities. The project has investigated how Ultra Fine Particles, Black Carbon and PM2.5-PM10 particles behave in city-specific contexts, whilst also exploring ways of reducing exposure and creating inviting public spaces for people.

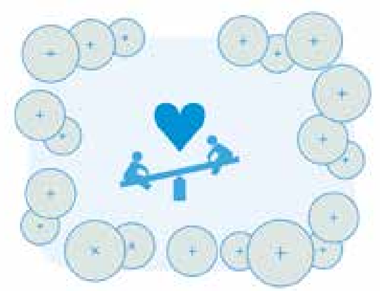
This booklet highlights the findings of the pilot process and provides refined urban design recommendations for cities aiming to reduce citizen exposure to air pollution. In doing so, the project uses Gehl's Measure-Test-Refine methodology to enhance our understanding of urban design and its impact on people. The booklet also builds on existing 'Thrive Zone' urban air pollution concepts developed by Gehl and partners (Gehl et al. 2019).

Thrive Zone UFP Toolbox (2019)

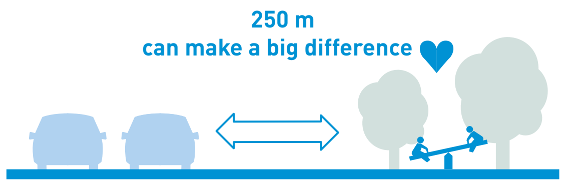
The Amager Thrive Zone pilots have provided a more nuanced understanding of the 'green pollution buffers' highlighted in Gehl's 2019 Thrive Zone work. In addition, the pilots have highlighted new knowledge (and gaps in knowledge) around wind, particle distribution, non-permeable barriers, and measurable differences between different types of vegetation barriers. The three Thrive Zone 2019 concepts that are more specifically addressed in the booklet are illustrated below:



1. Cleaner air street vegetation
green pollution buffers



2. Clean air buffer
green buffer around "stay and play places"

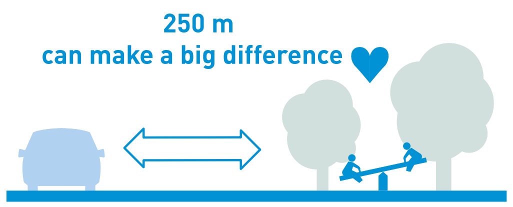


3. Location of playgrounds & institutions away from pollution sources

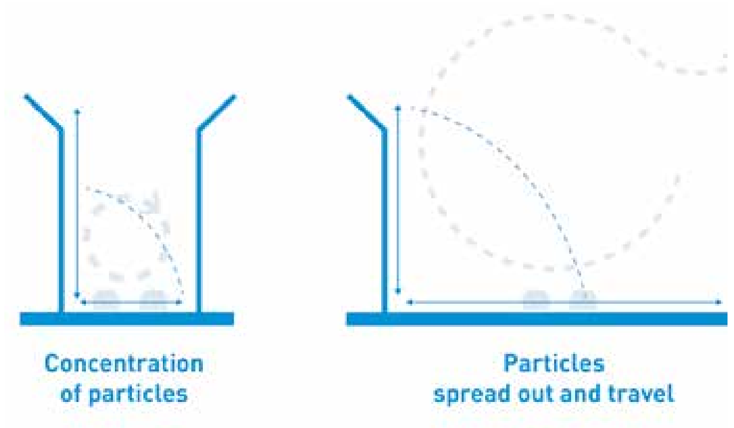
Urban Form and Wind

Existing knowledge

Current research suggests particles behave differently in Street Canyons and Open Road type urban forms, due to local wind distribution of particles and street tree placement. It has also been suggested that a distance of 250m from roads can make a big difference to UFP exposure...



Behaviour of particles in diverse Street Canyons vs Open Roads:



Effects of vegetation barriers on particle distribution:

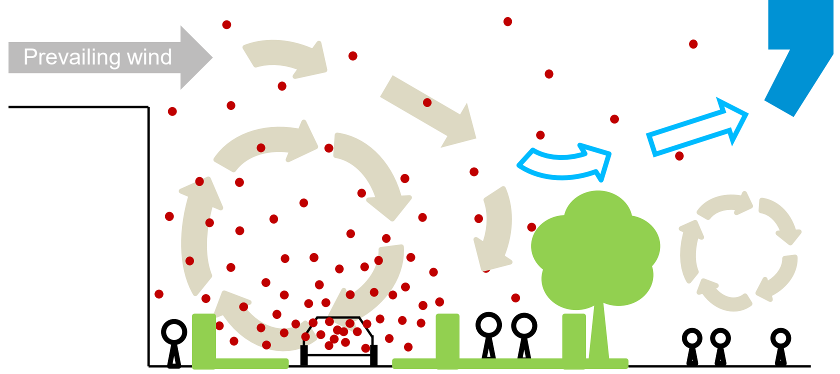


Image Source: Greater London Authority 2019

...in an open road environment...a vegetation barrier can as much as halve the levels of pollutants just behind it...Within parks, trees are very beneficial to the dispersion of pollution: they disturb the flow of air around them and increase the mixing of the more polluted air at street level with cleaner air above.

(Greater London Authority 2019, p10-13)

- UFP levels at the centre of Byparken were **twice** as high as roadside levels on Ørestad Boulevard

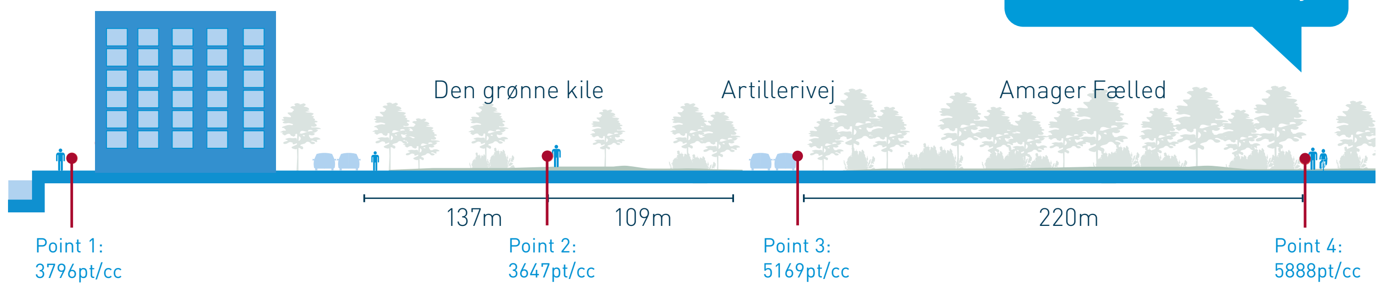
New knowledge

Thrive Zone Amager's **P-tracker UFP measurements*** of public spaces in Islands Brygge and Ørestad showed *higher* UFP levels in large local parks (at a 250m distance from roads) than on nearby roadside levels:

Islands Brygge

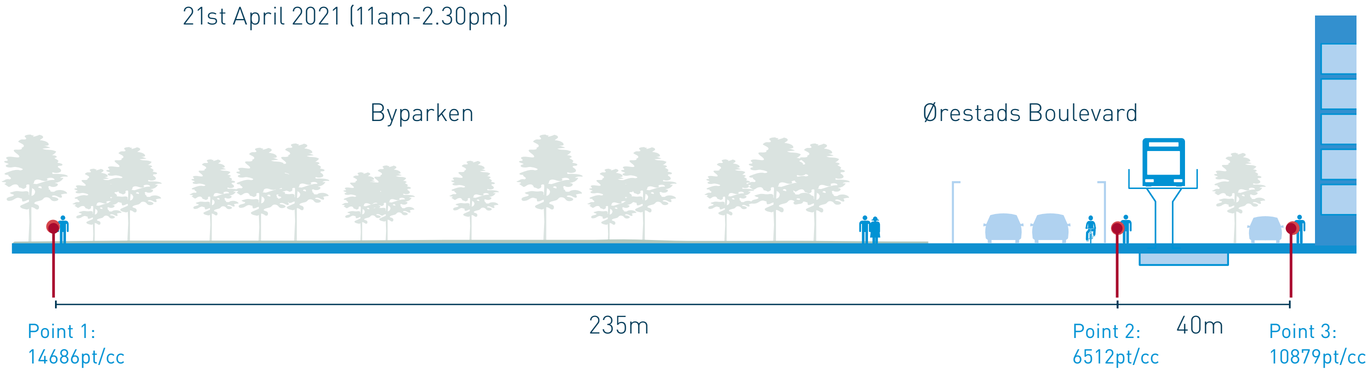
Prevailing NW Winds during measurement period:
26th April 2021(10.47am-2.30pm)

UFP values in Fælledparken were **higher** than on the street at Artillerivej



Ørestad

Prevailing WNW winds during measurement period:
21st April 2021 (11am-2.30pm)



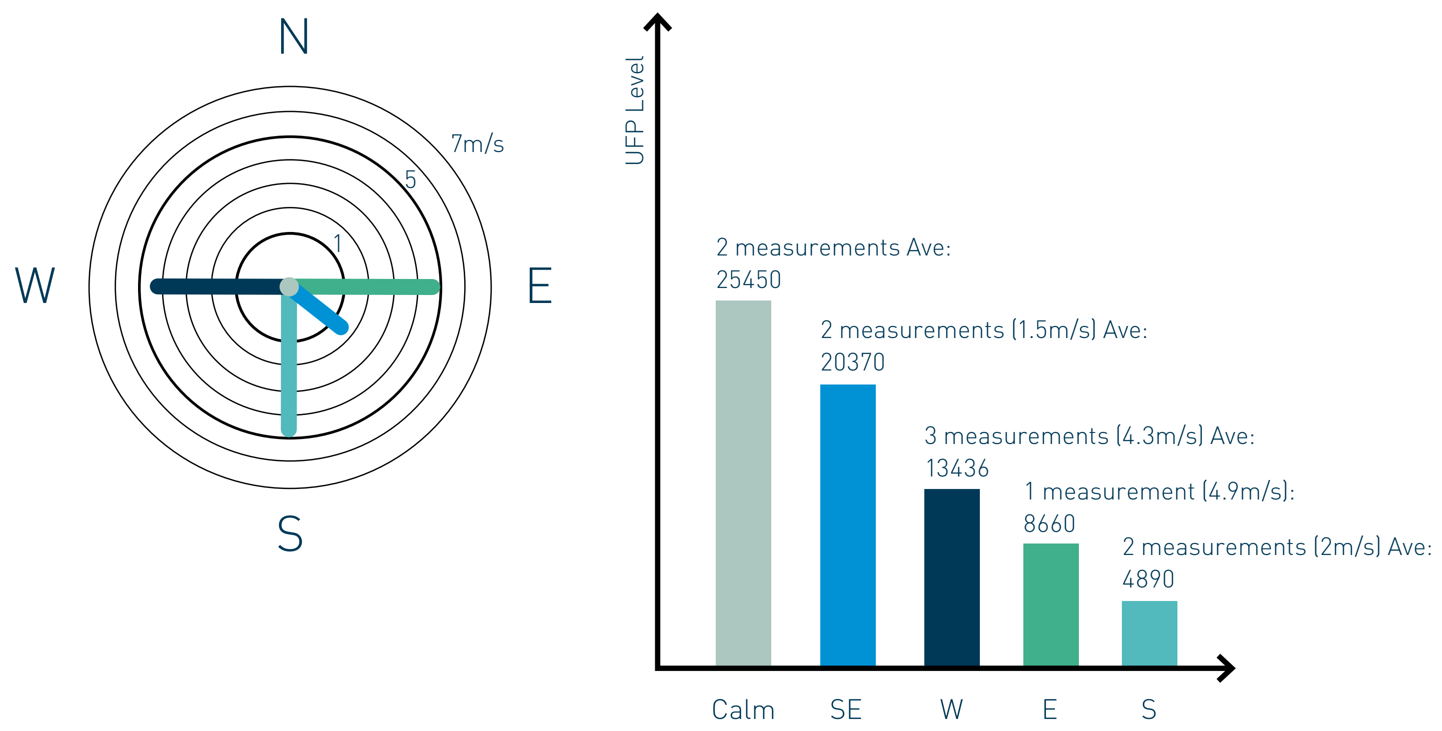
*Pre-pilot UFP measurements were undertaken for 30minutes on one day with a handheld P-tracker sensor, so further investigations of UFP levels in public parks are needed to confirm these findings.

Urban Form and Wind

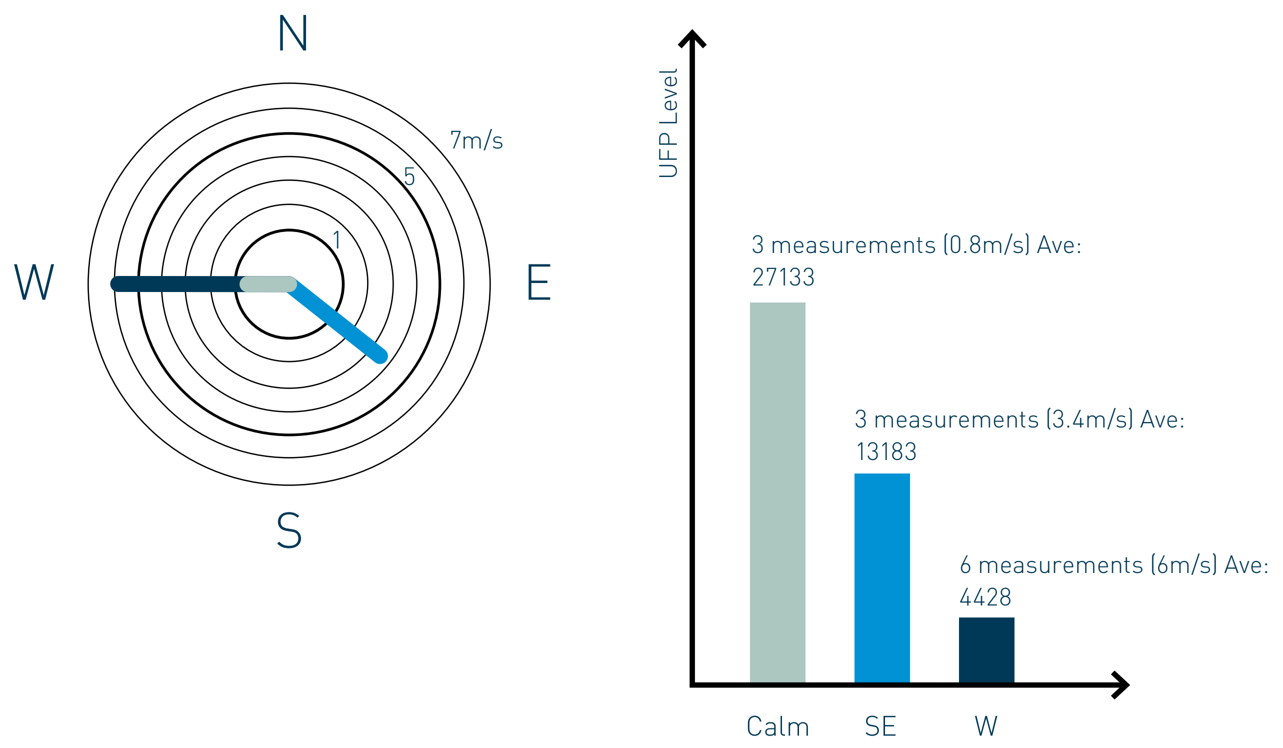
New knowledge

When **google's roadside measurements*** of UFP levels were compared with wind direction and speed during measurement days, a clear correlation was found between calm wind conditions and high UFP levels for all pilot sites. The measurements also show that South-West winds on Amager, produce the worst roadside UFP levels of all wind directions.

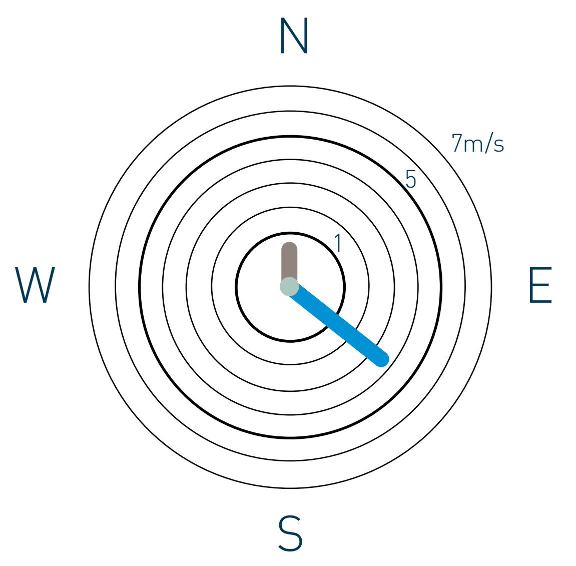
Fields Buslet, Ørestad



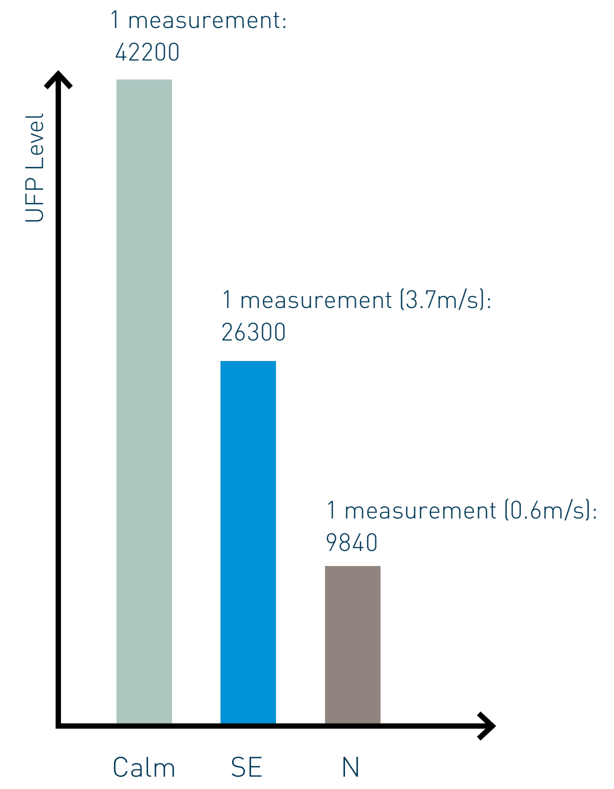
Artillerivej (by Den grønne kile), Islands Brygge



Sivegadne (Prismehaven), Ørestad



*UFP measurements for each wind direction are based on the Google car's 'driveby' readings across a maximum of 9 days, so further studies of wind effects on UFP levels over longer periods is needed to confirm these findings.



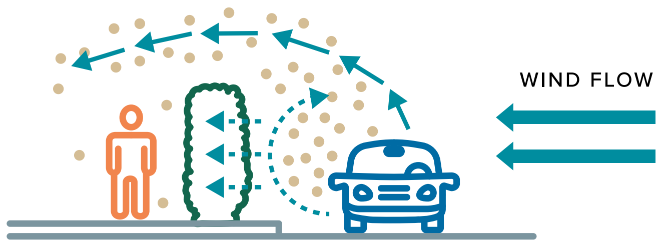
Vegetation Barriers

Existing knowledge (UFP behaviour)

Current research highlights these differences in structure of vegetative barriers (in open road situations):

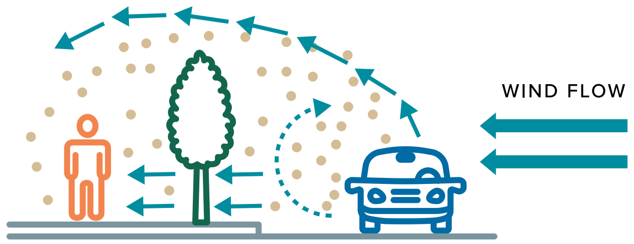
Type 1

Open road with a hedge acting as a barrier between traffic emissions and pedestrians.



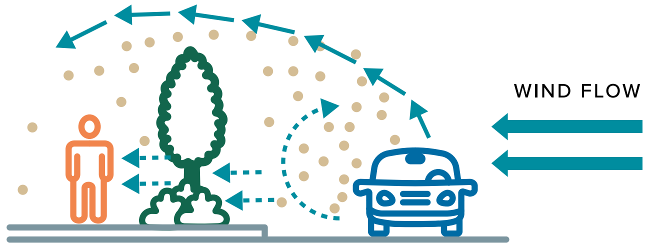
Type 2

Open road with trees acting as a filter between traffic emissions and pedestrians.*



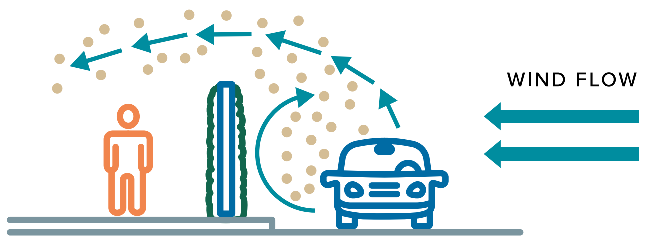
Type 3

Open road with combined vegetation barriers between traffic emissions and pedestrians.



Type 4

Open road with a green wall acting as a barrier between traffic emissions and pedestrians.



*Under some conditions, due to a windbreak effect, pollutants can stagnate behind a sparse row of trees, leading to deteriorated downwind air quality (Abhijith and Kumar, 2019).

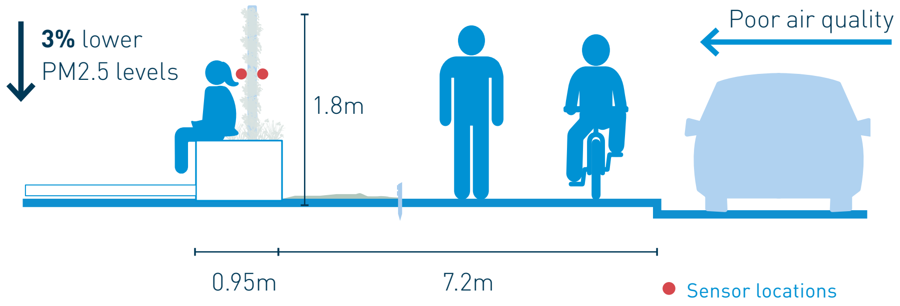
Source: Kumar et al. 2019

New knowledge (PM2.5 behaviour)

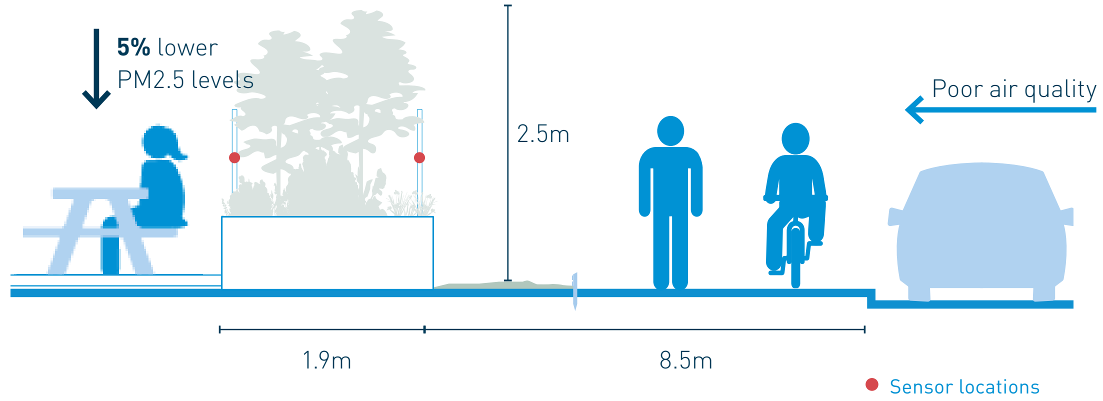
Our research highlights the effects of a new type of vegetative structure (on open roads):

Type 5

Open road with an evergreen, thin green wall (without a non-permeable barrier)



The pilot process also found a measurable difference between the effects of a 1.9m wide Type 3 Barrier and the Type 5 Barrier:



Social Benefits

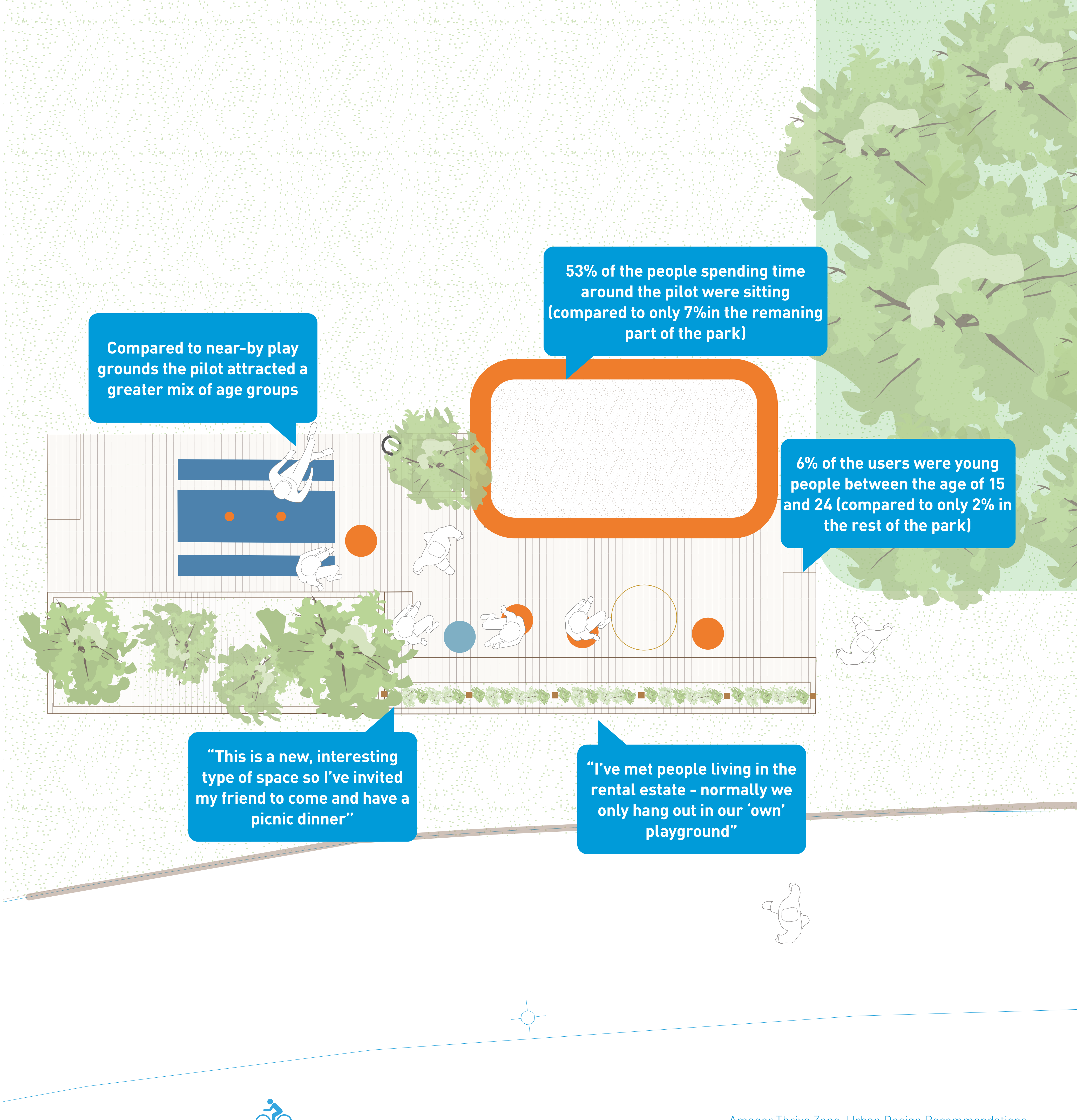
A win-win for public life and air quality

In addition to aiming for reduced exposure to air pollution, the installations were also assessed for their positive social impacts, and thus their broader health impact. The pilots successfully achieved this by i) providing different types of social meeting spaces, ii) inviting people to spend time outside, and iii) encouraging use of green areas for a range of activities.

The installation included a vegetation barrier with integrated seating, picnic benches, sandpit, colourful plantings and lighting. The installation taught us the following:

- colourful furniture attracts all ages from small children to older children, and teenagers
- the sandpit and integrated seating allowed parents to comfortably sit and socially interact, while watching their children play
- the vegetation barrier along the street created a increased sense of security from traffic, and improved acoustic conditions for holding conversations near the road

Pilot in Den Grønne Kile, Havnestad, Copenhagen



Non-Permeable Barriers

Materials and Design

Due to high levels of air pollution and poor microclimatic conditions (relentless, strong winds and large open spaces) experienced in public places around Ørestad, the Thrive Zone team decided to create a series of more human scale protected semi-outdoor meeting places for locals in the form of polycarbonate domes. The domes created protected places for bus passengers who can wait up to 20mins per bus on polluted roadsides. The 3mm polycarbonate structures also created a semi-controlled laboratory environment for testing the deposition behaviour of PM2.5 and UFP on plants located inside the domes, with the addded impact of realistic daily use by locals.

Prismehaven Dome Effects, Ørestad

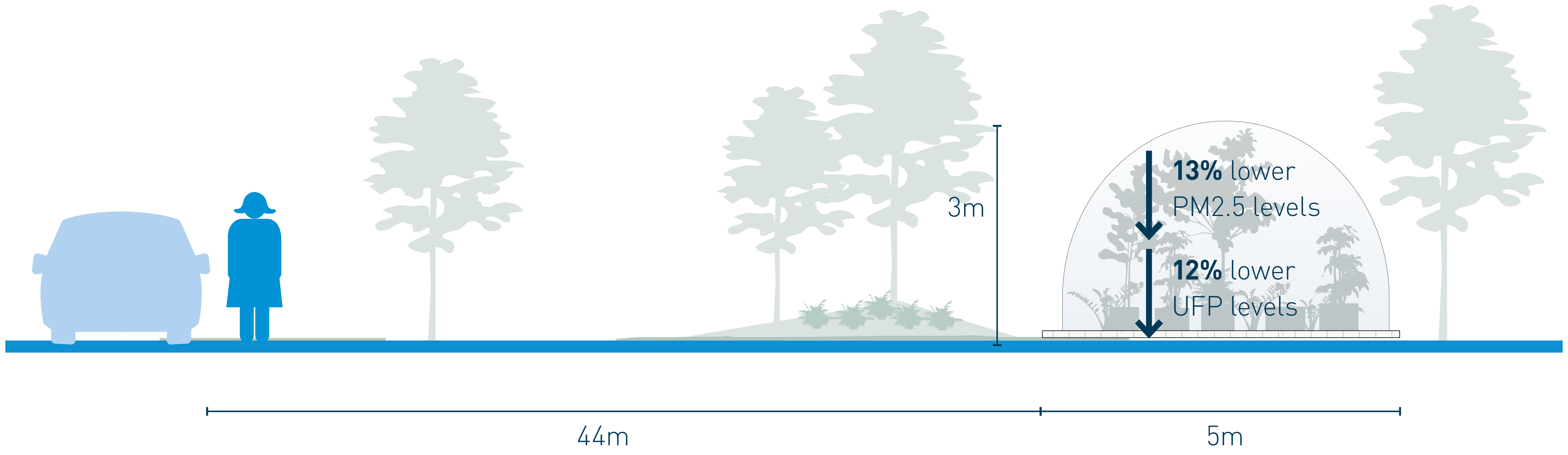



Image © Joakim Züger

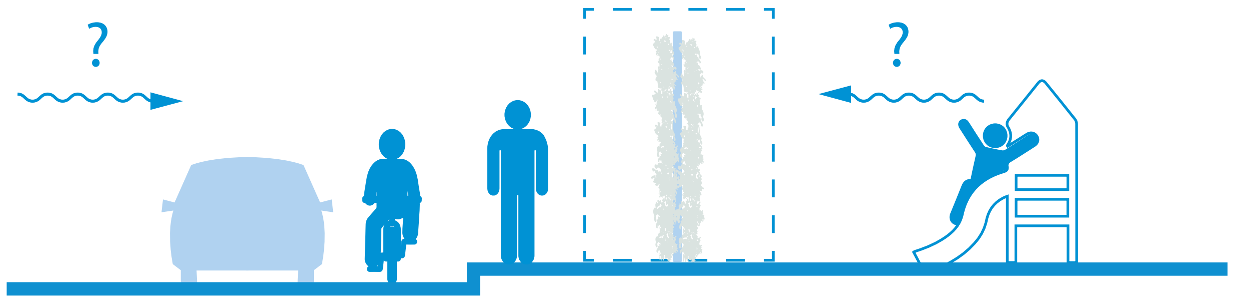

Image © Joakim Züger


Image © Joakim Züger

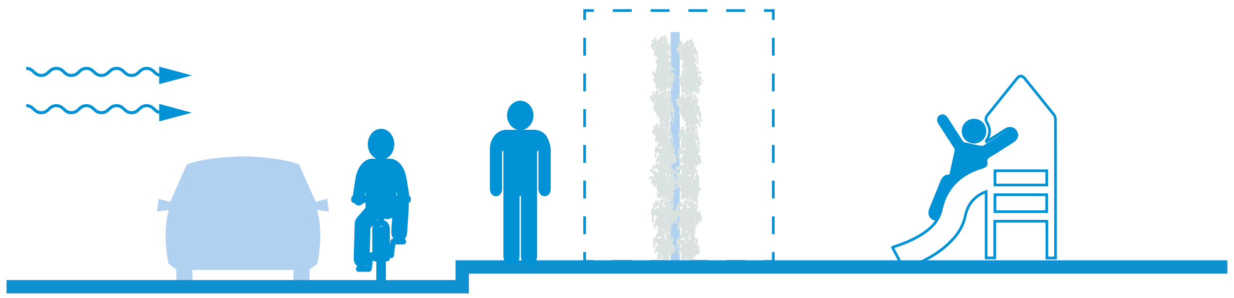
Design Recommendations

Effective Vegetation Barriers

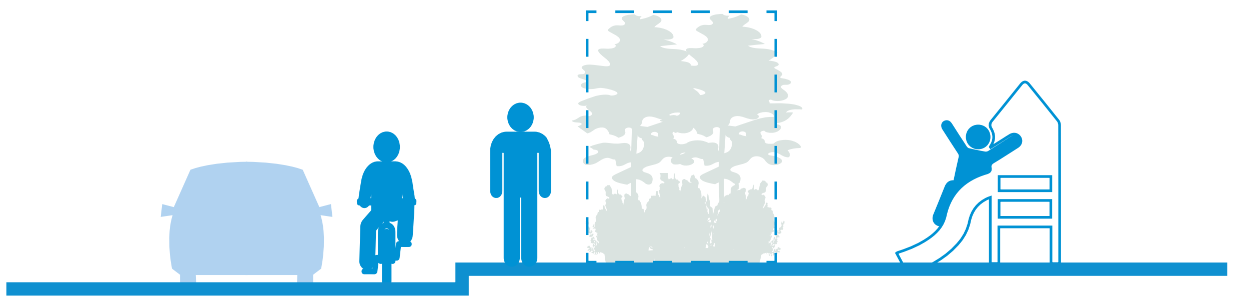
1. Conduct wind analyses prior to design to evaluate the most problematic wind directions for local air quality.



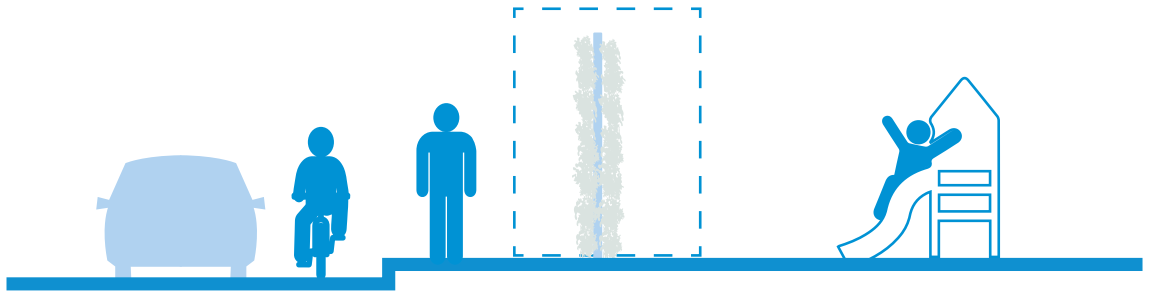
2. Ensure proposed vegetation barriers protect against the most problematic wind directions at the specific site



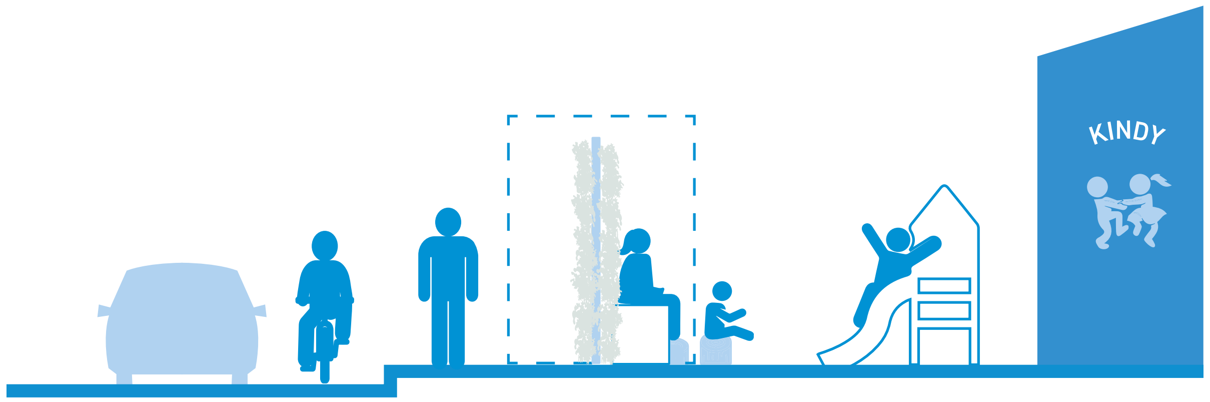
3. Design with thicker Type 3 Vegetation barriers where space permits (and incorporate non-permeable barriers if feasible)



4. Where space is tight, incorporate non-permeable barriers (ie. 3mm polycarbonate) with thinner Type 5 Vegetation Barriers to improve their effectiveness

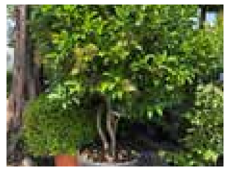


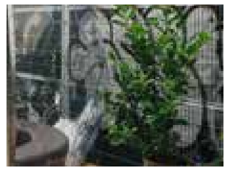
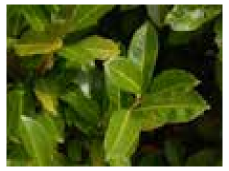
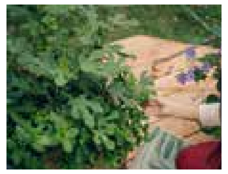
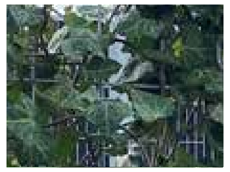
5. Consider surrounding communitiess/facilities and incorporate in-built seating (or other social furniture) within air pollution barriers to improve social environments

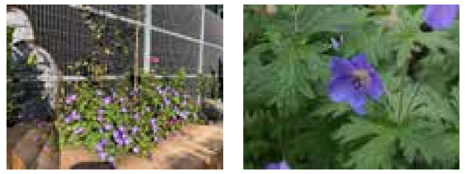
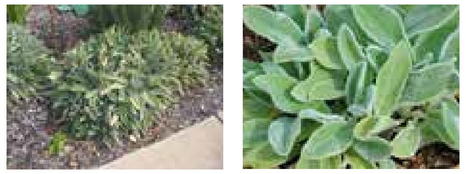
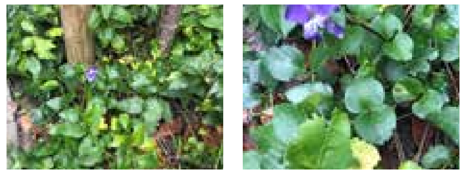
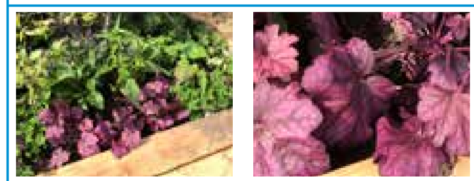
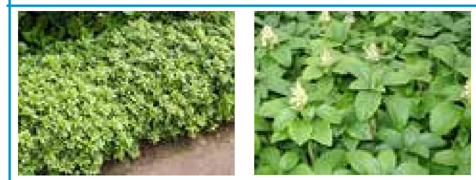
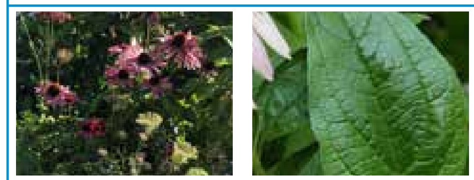
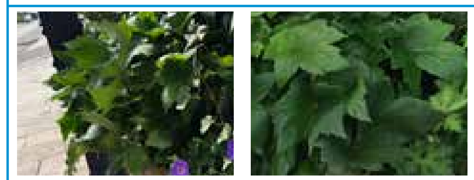


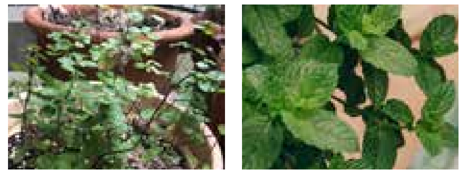
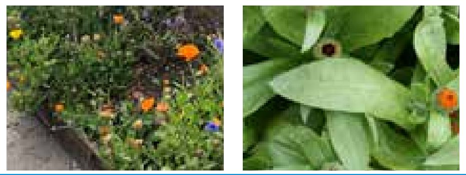
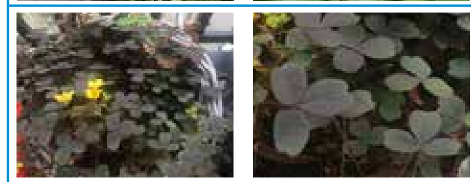
Thrive Zone Plant Matrix
Danish and Northern European Climates

The Amager Pilots, we used many of the specific species that are recommended for deposition of air pollution particles (in Kumar et al. 2019, Kumar & Barwise 2020), as well as new species which added a more biodiverse mix to the existing palette, and seasonal interest for people using the pilots in the summer months. The plant matrix also highlights the greenhouse tolerant plants that successfully survived the warm 2021 summer inside the polycarbonate Domes.

Trees			Evergreen	Greenhouse Tolerant	Broad Leaf	Hairy Leaf	Waxy Leaf	Seasonal Interest
		*Viburnum tinus 'Lucidum'* Viburnum	●	●				
		*Sorbus intermedia* Swedish Whitebeam			●	●		
		*Malus domestica* Apple						●
		*Citron citroen* Lemon		●	●		●	●

Shrubs and Hedges			Evergreen	Greenhouse Tolerant	Broad Leaf	Hairy Leaf	Waxy Leaf	Seasonal Interest
		*Strelitzia augusta* White Bird of Paradise	●		●			
		*Buxus sempervirens* Boxwood	●					
		*Prunus laurocerasus* Cherry laurel	●		●		●	●
		*Pinus mugo 'Columnaris'* Mugo Pine	●				●	
		*Amelanchier laevis* Allegheny serviceberry						●
		*Ficus carica* Fig		●	●	●		
Climbers								
		*Vitis* Grape		●	●			●
		*Hedera hibernica 'Woerner'* Common Ivy						

Groundcovers		Evergreen	Greenhouse Tolerant	Broad Leaf	Hairy Leaf	Waxy Leaf	Seasonal Interest
	*Geranium 'Rozanne'* Cranesbill		●				●
	*Stachys byzanthinia* Lamb's-ear		●	●	●		
	*Tropaeolum majus* Garden Nasturtium		●	●	●		●
	*Vinca minor* Myrtle	●				●	●
	*Lavandula angustifolia* English Lavender		●				
	*Fuchsia magellanica* Hummingbird Fuchsia		●				●
	*Heuchera sp.* Coral Bells		●				●
	*Pachysandra terminalis* Japanese Pachysandra		●				●
	*Echinacea purpurea* Purple Coneflower		●				●
	*Anemone japonica KONIGIN CHARLOTTE* Windflower			●			●

Groundcovers		Evergreen	Greenhouse Tolerant	Broad Leaf	Hairy Leaf	Waxy Leaf	Seasonal Interest
	*Cimicifuga ramosa 'Chocoholic'* Black Snakeroot			●			●
	*Timian* Thyme	●	●		●		
	*Mentha* Mint	●	●		●		●
	*Allium schoenoprasum* Chives	●	●				●
	*Citronmelisse* Lemon Balm		●		●		
	*Calendula offininalis* Marigold		●		●		●
	*Oxalis vulcanicola* Coral Bells		●				●

Pilot Process

Reflections and tips for future projects

Conducting and evaluating the results of the pilot's effect on local air pollution is complicated as there were many stakeholders and environmental variables to consider. The following points highlight some of the challenges to be aware of.

1. Real World Imperfection: Reductions in exposure to air quality are hard to prove in real world situations due to many variables at play - wind, temperature, rain, users interacting with components and general everyday usage affect the intervention and resulting data. However, real life pilots are important in order to know how reduction of exposure solutions can work in real life as they can highlight unexpected factors that impact air pollution (e.g. people smoking near installations).

2. Sensors: Good quality sensors that 1) measure UFP and ii) can be installed for long periods of time, are not easily accessible. This meant, in this project, that the pilots were unable to capture particle behaviour at UFP levels, and has thus reduced the applicability and scaleability of the data. Air quality measurements of similar particles from different sensors need calibrating by specialists - ensure specialists are engaged from Day 1 and that daily monitoring of data is undertaken. Ensure specialists have enough sensors available and enough resources to install and remove sensors. The number of sensors available determines pilot size, scale and number of installations.

3. Land owners: Where pilots are proposed on municipal land, aim for municipal partnership from the beginning of pilot project, to ensure a smoother permissions process in relation to temporary use of council land, as well as for more ownership of the outcomes. The same applies to other land owners, where pilots are proposed on private land.

4. Nearby Institutions: Since air pollution affects young children the most, ensure to engage with neighbouring institutions as early on as possible, if they are identified as target groups in your project.

5. Air quality technical details: Pilot projects related to air quality should be regarded as professional installations and require a much wider group of builders and installation consultants to work together, such as electricians and sensor technicians. Testing vegetation barriers also requires a large amount of plantings and thus a professional gardening company is advised for installation and long term maintenance of plants over the pilot period.

6. Access to water and electricity: The sensor installations demand that nearby access to power is essential when considering pilot location. Sensors also require background data measurements which is typically on the rooftop of a 6 story building. The large amount of plantings also means that close access to a water source is necessary.

7. Timeline: To attain maximum value for money, resources, labour effort, and air quality data collection, construction should commence in early spring (after frost period) and to run pilots until late autumn (or even an entire year to see the deciduous effects of winter on vegetation barriers). Pilot projects of this scale typically need min. 8 months planning before construction starts.

8. Baseline data: Ensure pre-pilot existing air quality conditions are conducted prior to installation, to ensure comparable data is available.

8. Post-pilot material life: Have a circular economy strategy in place for used materials, once pilots are removed. Where can different parts or the whole installation be re-used? Or how can it be adopted to suit other purposes?

Recommendations
Future Research

1. Public space measurements
Long term air quality measurements of public spaces as clear comparisons with roadside measurements. To date, most air quality measurements are done on roadside locations and not in public spaces or parks, where people spend the most time.

2. Effects of wind speed and direction
More longer term air quality measurements which show the impacts of wind speed and wind direction on local pollution levels are needed.

3. Protective distance of vegetation barriers
Further research into how big an area benefits from the protection of vegetation barriers is needed.

4. Non-permeable barrier materials
Further testing of other non-permeable barriers that are appropriate for use in public spaces would be useful.

4. Semi-controlled plant environments
Further testing of the semi-controlled dome environment (without plants) to distinguish what effect plants have on particle deposition behaviour. Additional measurements of the effects of humidity and temperature on particle deposition within the controlled dome environment would also be good to understand.

5. Improved air sensor technology
Instrument development of low cost sensors that can detect Ultra Fine particles should be prioritised.

Recommendations
Pilot Scaleability

VEGETATION BARRIERS

1. Well suited in locations with low pollution levels
Research suggests that even small reductions can have a great health impact, where existing pollution levels low. Hence vegetation barriers are recommended for locations where pollution levels are not very high.

2. Revitalisation of existing green spaces
Vegetation barriers are recommended as ways to revitalise 'left-over' or unused green spaces, by introducing more biodiversity and introducing social furniture.

3. Green fences around playgrounds and institutions
Vegetation barriers can increase protection from traffic and traffic noise, while reducing exposure to air pollution for children in spaces where they spend most of their time.

DOMES & TRANSPARENT BARRIERS

1. Healthier and more inviting bus stops
Redesign bus shelters to protect against air pollution, while creating a more comfortable, social waiting environment.

2. Transparent pollution barriers for daycare institutions
Transparent barriers to protect the most exposed day care institutions.

3. Community green houses
Use domes to build community-driven gardens that can activate spaces all year around.

4. Human-scale spaces for exposed environments
Micro-spaces that can protect from both noise, wind and air pollution, eg. under bridges, close to heavy trafficed streets, or in wind swept open spaces.

Reference List

Gehl, Utrecht University, Google, Copenhagen Solutions Lab, Bernard Van Leer Foundation 2019, *Adding air quality to city planning - Designing Thrive Zones for our youngest residents*

Greater London Authority 2019, *Using Green Infrastructure to protect people from air pollution,* Birmingham Institute of Forest Research (University of Birmingham), the Global Centre for Clean Air Research (University of Surrey) and Transport for London.

Kumar, P Abhijith, KV & Barwise, Y 2019, *Implementing Green Infrastructure for Air Pollution: General Recommendations for management and plant species selection,* University of Surrey, doi.org/10.6084/m9.figshare.8198261.v1

Kumar, P & Barwise, Y 2020, *Designing vegetation barriers for urban air pollution abatement: a practical review for appropriate plant species selection, CLimate and Atmospheric Science,* Vol 3, No 12