



PLEA 2020 A CORUÑA



35th PLEA Conference on Passive and Low Energy Architecture

Planning Post Carbon Cities

Editors:

Jorge Rodríguez Álvarez

&

Joana Carla Soares Gonçalves



PLEA

Sustainable Architecture and Urban Design



UNIVERSIDADE DA CORUÑA



Sustainable Architecture and Urban Design



Escola Técnica Superior de Arquitectura
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Foreword

The organization of the 35th PLEA Conference has been an enormous challenge. The unprecedented circumstances that preceded it required flexible and, at the same time, determined decision making. Once finished, we hope that PLEA 2020 becomes a landmark in the longstanding and unique trajectory of PLEA. It has been its first virtual Conference; arguably, the one with the lowest carbon footprint (which is being calculated by some participants). The organizational expenses were lower than those for a physical conference, which allowed for a substantial reduction in the participation fees. According to the participants' comments and feedback, the event was quite satisfactory. The environment was, overall, dynamic and engaging, the debate was fluid and there were numerous opportunities for interaction, considering the limitations. The high quality of the technical presentations was one of the most important factors, as they kept ongoing attention during the three days. The keynote speakers brought fresh and diverse ideas to the discussion. The roundtables were often enriched with the comments and remarks from the participants, enhancing direct interaction with the speakers as well as among themselves.

On the other hand, it was a little disappointing that we couldn't share the experience of A Coruña's city life or the beautiful Galician landscapes with the PLEA community. As much as we and the environment can benefit from virtual events there are certain opportunities (immersion in other culture, casual encounters during coffee breaks...) that require physical presence. It seems likely that a balance between virtual and face to face meetings is to be found in future events. We hope we can host such an event in A Coruña after the pandemic is over.

The central theme of PLEA 2020 was the Post Carbon City. When the potential subjects to be addressed in the conference were first discussed, most of the topics were related to energy efficiency, ventilation, comfort, daylight, mobility, microclimate or materials...However, in our opening statement we also proposed a paradigm shift to start designing "the cities we want in the future, to construct utopian visions in which urban progress is based on ecology, equality and wellness". A few months later we find ourselves studying how buildings and cities influence wellness and disease. Some widely established assumptions about sustainable urban models need to be reevaluated according to a new set of criteria, which in some cases may contravene the rules of efficiency. However, the need for high quality indoor and outdoor environments will be strongly reinforced after this episode. People staying at home during lockdowns, quarantines or due to remote working create new scenarios and demand greater flexibility and performance in domestic environments. The provision of comfortable outdoor spaces where social interaction is safer during the epidemic has led to a number of cities taken unprecedented measures. This could be a unique opportunity to set up the urban agenda for the forthcoming climatic challenges. Quoting the PLEA 2020 Award acceptance speech by prof. José Fariña "We are already in a period of urgency and it is necessary to act".

A number of articles presented in the Conference have showcased novel methodologies, from data mining to machine learning, while other papers relied on well-established methods, such as field observations and measurements, physical prototypes or computer simulations carried out



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by a wide array of software tools. Overall, reviewers seemed to praise those proposals with a clear potential to be implemented, regardless of their methodology. By contrast, very specific case studies that offered little insights beyond the case at hand or established knowledge tended to be penalized. Half of the awarded and commended papers and posters addressed urban aspects (the microclimatic effect of vegetation, temporary urban interventions, the value of urban nature, urban canyons...). The climatic adaptation of buildings for future conditions was also a central topic both in the conference and in five awarded papers; the social approach to sustainability was not a minor subject as it was thoroughly addressed in at least three awarded articles and in a good number of papers presented at the Conference.

The selection of the papers to be presented followed a rigorous process. We received around 850 abstracts, from 1,500 authors affiliated to some 300 organizations from 60 countries. All the abstracts were reviewed by at least two reviewers in a double blind process. The first round required some 1,700 reviews to select 450 abstracts, which were to be converted into full technical papers. A second round of reviews was conducted to finally select 306 articles: 37 as posters and 269 as oral presentations.

All the material generated from this Conference is now freely accessible through the official repository of the University of A Coruña (ruc.udc.es), the PLEA 2020 website (plea2020.org) and PLEA (plea-arch.org). In addition, all the videos have been uploaded to PLEA 2020 YouTube Channel, including the keynote sessions and roundtables.

([PLEA 2020 youtube channel](#)).

Finally, I would like to express my gratitude to the global PLEA organization, for keeping up an invaluable network and stewarding high quality standards in all its Conferences. I would also like to thank the University of A Coruña, and, particularly, the School of Architecture for their constant support during these months, the regional government of Galicia: Xunta de Galicia, the local council of A Coruña, and all our sponsors and supporters. The presence of the President of the Galician Government, Alberto Nuñez Feijóo, the Mayor of A Coruña Inés Rey, the Chancellor of the University of A Coruña Julio Abalde and the Dean of the School of Architecture Plácido Lizancos, in the inaugural Ceremony was very special moment and their speeches reflected a commitment with values and ideas shared by the PLEA Community. The organization of PLEA 2020 wouldn't have been possible without the whole local organizing committee (Amparo, Cristina, David, Emma and Santiago) and the assistance of the PLEA 2020 team (Alba, Alvaro, Ana, Daniel and Erika). I wish you can find the PLEA 2020 Conference Proceedings at least as useful and enlightening as a compilation of timely and relevant research in Sustainable Architecture and Urban Design as the previous 34 PLEA editions.

Jorge Rodríguez Álvarez
PLEA 2020 Conference Chair



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PLEA 2020 – Planning Post Carbon Cities, the first on-line PLEA conference

The 35th International Conference on Sustainable Architecture and Urban Design, entitled PLEA 2020 – Planning Post Carbon Cities, was the first on-line PLEA conference. Due to the pandemic that hit the world in the beginning of 2020, the organizers from the University of A Coruña were forced to convert what was meant to be a live event with people's physical presence in the Spanish city of A Coruña, in Galicia, into an on-line one.

Despite the natural constraints of the on-line modus operandi upon human dynamics, the commitment of the organizers in providing an easy and reliable digital platform, coupled with the engagement of the participants populating live chats of technical and keynote presentations made the conference a vibrant forum of environmental technical knowledge sharing. The PLEA 2020 event had 306 papers presented and brought together more than 700 participants from over 60 countries who are interested and active in the field of environmental design, teaching and research, located in different parts of the world, spanning from the Americas to the Far-East Asia. The quality of the papers is particularly high. Members of the PLEA Board unanimously agreed to hand out 4 best paper awards and 3 best poster award, together with a number of commendations. Thanks must be due to the hard work of the members of the scientific committee and the conference organizers. Furthermore, during the opening ceremony of the conference, the PLEA Lifetime Achievement Award 2020 was presented to Professor Edna Shaviv and the PLEA Award 2020 was given to Professor José Fariña Tojo. May we send our congratulations again to both of them.

On a rather positive note, the virtual status of the conference in 2020, in which challenges and opportunities for the post carbon cities and, therefore, post carbon societies were broadly discussed, opened a new avenue for the PLEA community itself, focused on the reduction of its environmental impact, associated with air travel across the world to attend periodic scientific meetings. Following on the steps of organizers of the 35th International Conference on Passive and Low Energy Architecture, we expect that the next PLEA conferences will explore on-line possibilities, specially to facilitate the participation of those in regions of the world away from the conference location, whilst creating adequate conditions for safe physical presence, when possible, in order to bring back the unmeasurable richness of human interaction and the consequent advantages to knowledge sharing.

Joana Carla Soares Gonçalves
On behalf of the PLEA Board



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About the Keynote Lectures

The six keynote speakers addressed the theme of Planning Post Carbon Cities from a strategic design perspective and vision, qualified by research activities in real context as well as in the analytical realm. The role of people's behaviour and behavioural change, alongside the design focus of fulfilling people's needs and expectation in both buildings and urban design defined a common thread seen across all the six talks spread along the three-days conference.

Susan Carruth, from GXN, in Copenhagen, and **Klaus Bode** from Urban Systems Design (USD), in London, open the keynote talks. Susan gave the talk on Cities of the Future: Behaviourally driven, Materially Bound, in which she explored two themes: circular design and how to scale-up from materials to the design of cities, alongside the so-called behavioural design and their applicability in the planning of future cities. Following up, Klaus' presentation about Planning Post Carbon Cities: Our Challenges and Opportunities could not stress more the key role of occupants in reducing energy demand in buildings, calling for a design approach that he entitles human centric design, whilst revealing the potential for innovative and effective solutions at both building and masterplan scales, when based on passive environmental strategies and low-energy engineering.

In the second day of the event, **Cynthia Echave**, Urban Ecology expert based in Barcelona, talked about Liveability and Resilience from an Ecological Approach. In her talk, Cynthia explored innovative ecosystemic solutions liaising green economy, social inclusiveness and governance, focused on the Euro-Mediterranean Region and African cities. In the sequence, **Helle Søholt**, CEO and cofounder of Gehl, gave the talk The Need for People and Public Spaces. The long legacy of the design practice exercised by Gehl Architects in designing quality-urban spaces geared for pedestrians and social activities is well known. In this talk, Helle brought some of the latest examples of projects developed by the firm that contribute to make cities around the world more liveable and sustainable.

In the closing day, **Michael Smith**, from Entre Nos Atelier, in San José, Costa Rica, and **Belinda Tato**, from Ecosistema Urbano, in Madrid focused on social aspects. Michael's talk on Regenerative Design and Spatial Justice brought a number of successful real-life projects in Latin America which exemplify his commitment with a social design agenda including community empowerment, environmental awareness and hands-on experiences based on inclusive design processes, mostly developed upon low-income environments. Belinda spoke about Ecosistema Urbano, showing projects based on knowledge from urbanism, architecture, engineering and sociology, resulting in what she calls urban social design, in which the design of environments, spaces and social dynamics come together in order to improve the self-organization of citizens, social interaction within communities and their relationship with the local physical and natural environment. Regarding the design process, both talks drew on the opportunities laying in participatory processes to create spaces for people.

Concluding, in addition to the emphasis put on the role of people in the design and planning of the Post Carbon City, by addressing issues of existing built environments, the keynote speakers collectively showcased a wide range of successful real and experimental projects, that highlight the advantages of a multidisciplinary approach, in reverting the current environmental and social conditions in cities around the world, in a creative and environmentally sound manner.

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SUSTAINABLE COMMUNITIES

Improving Hyperlocal Air Quality in Cities Impact of vegetation on pollutants concentration at pedestrian level

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ABSTRACT: Recent estimates published by WHO report that in 2016 outdoor air pollution caused 4.2 million premature deaths worldwide and urged urban planners, policymakers, and environmentalist to make health and wellbeing their number one priority when designing cities. In view of this, the current paper explores the effectiveness of trees and vegetation in dispersing air pollutants at pedestrian level by administering detailed fieldwork and spot measurement of both pollutants and microclimatic parameters close to one of the most polluted roads in London (Euston Road); followed by modelling a variety of real-life scenarios by using computational simulation application for validation and prediction. Whilst many studies agree in general on the mitigation of urban air pollutants by vegetation, the result of the current study contradicts this common understanding and demonstrates drastic increases in the concentration of particulate matters in the vicinity of trees. The results highlight that trees reduce wind velocity and air movement, causing pollutants to trap inside urban canyons. Therefore, planting more trees does not necessarily mean less pollution, at least locally. Instead, to alleviate air quality problems, more attention should be given to vegetation configuration, type, scale and most importantly, their locations and distributions within active urban pockets.

KEYWORDS: *Air pollution, Vegetation, Urban form, ENVI-met, Particulate matters*

1. INTRODUCTION

The recent Lancet report (2018) highlighted air pollution as the major cause of cardiovascular and respiratory illnesses and premature death in the world today. For instance, in 2015 pollutants such as Nitrogen Dioxide (NO₂) and Particulate Matter (PM₁₀, PM_{2.5}) have caused 64,000 premature deaths in the UK, out of which, 9000 belongs to a developed city like London. The health impacts of outdoor and indoor air pollution are well researched and established by a substantial body of research worldwide. In contrast, relatively little research has investigated the role that the built environment can potentially have on the concentration and dispersion of air pollutants [1].

Whilst the best way to tackle air pollution is to reduce and stop the pollutants at their sources, which must always be the primary focus of air quality policies, a secondary method, and one which has been increasingly perceived as effectively removing pollutants and improving urban life, is urban greenery [2]. There is a large body of studies referring to trees and their air purifying power and the fact that planting more trees is a cost-effective way to tackle urban air pollution [3]. In view of this assumption, the current paper explores the effectiveness of trees and vegetation in dispersing air pollutants at pedestrian level by administering detailed fieldwork and spot measurement of both pollutants and

microclimatic parameters; followed by modelling a variety of real-life scenarios by using computational simulation software for validation and prediction.

2. METHODOLOGY

As an empirical basis for this investigation, this paper intentionally conducted its research far from the roadside and within an open courtyard (plaza) which was identified as a high-quality active pocket [4] which encourages the users to stay for longer periods of time, therefore increasing the risk of being exposed to pollutants. Accordingly, the Regent's Place pedestrian plaza which is located adjacent to one of the most polluted roads in London (Euston Road), was chosen as the fieldwork site for this paper. The fieldwork was conducted during a time when the Square was expected to be much busier than other times. In that respect, the on-site spot measurements were only carried out on the locations with the highest activities and a greater number of people density.

The Regent's Place characterised by street canyon configuration with an aspect ratio (height over width) of 1.81 and Sky View Factor of 0.35 and the built-up areas are 15 times greater than the green spaces (including trees, hedges, green roofs). Based on previous studies done by other researchers, the high aspect ratio and low SVF have a direct impact on the microclimate of a

particular urban location (at a hyperlocal scale) [5]; specifically, on wind speed and its direction and accordingly influence the rate of dilution and dispersion of pollutants. Based on a scheme (Local Climate Zone) developed by Stewart and Oke in 2012, the study site classified as ‘compact high-rise’ where tall buildings are tightly packed beside each other with little green spaces and a few trees between them.

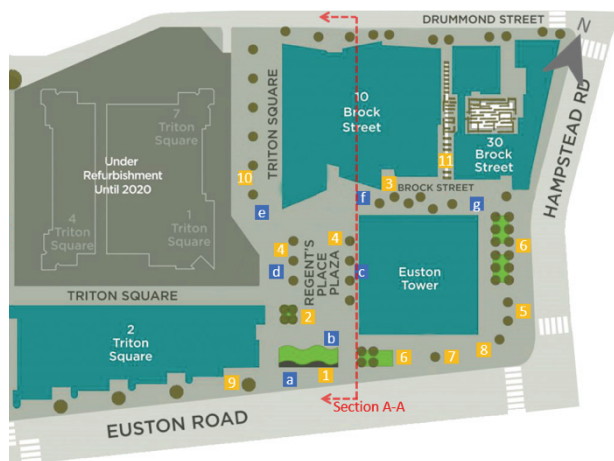


Figure 1: The Regent's Place Plaza.
 ■ Locations where the measurements were taken
 ■ Location of trees; description provided in table 02
 Section A-A illustrated in figure 05

In terms of population density and activities, close to 12,000 visitors, workers, and residents passing through the plaza each day. Despite its mixed-use, the square is mainly being used by office workers throughout the weekdays and getting populated during lunchtime (11:30 am – 3:00 pm). With its high quality and stylish sitting areas which have mainly sited under the trees, more people are attracted to stay, sit, eat, meet, enjoy, and interact with each other. The square also enjoys access to a number of restaurants, and during the summer/warmer season the restaurants offer more tables and chairs for people to have their meals in the outside open air. There is also an annual events programme, involving summer events during lunchtimes, charity events, farmers markets and other social events. For that reason, this study conducted during the lunchtime (11:00 am – 3:00 pm) and over the summer period (August 2018) where the square was expected to be much busier than other times. In that respect, the site divided into two characteristics and the on-site spot measurements were carried out on, first, locations with the highest activities and a greater number of people density, i.e. location b, c, and d, fig. 1. Second, locations which were seen to offer a better understanding of how air pollutants enter the site or disperse from the site, i.e. location a, e, f and g.

The concentration of particulate matter has increasingly become more significant inside the urban canyons where the urban form and urban features (i.e. solid and porous barriers) are intensifying the concentration of pollutants and increasing health problems [6]. For that reason, apart from Nitrogen Dioxide (NO₂) which is a major concern for Euston road; this study has considered to measure and evaluate two further key urban pollutants; these are particulate matter with a diameter of 10 microns (PM₁₀) and particulate matter with a diameter of 2.5 microns (PM_{2.5}).

2.1 Micro-meteorological observation and monitoring of street-level air pollutant concentration

In this study, two portable real-time monitoring devices have been used: Aeroqual Series 200, which is a Portable Air Quality Monitor and Vane Anemometer and Thermo hygrometer, Testo 410-2. Air pollutants and micro-meteorological parameters measured for the period of 30 minutes at each point with readings taken every 5 minutes and average values have been logged-in for further use in the computational analysis at modelling stage (Table 01).

Sunny Day		Meteorological conditions on 3 rd August 2018 - Fri						Street-level air pollutant concentration							
Location	Time (hrs:mins)	Air Temperature (°C)		Relative Humidity (%)		Wind Velocity (m/s)		Wind Direction (m/s)		NO ₂ (µg/m ³)		PM ₁₀ (µg/m ³)		PM _{2.5} (µg/m ³)	
		P*	S**	P	S	P	S	P	S	P	S	P	S	P	S
a	11:00 – 11:30	29	27	56	54	2.2	2	SSW	SSW	119	94.6	34	23	14	14
b	11:35 – 12:05	28	27	60	54	1.4	2	SSW	SSW	76	94.6	22	23	6	14
c	12:10 – 12:40	25	28	63	51	0.4	2	-	SSW	51	137.3	47	21.3	29	18.1
d	12:45 – 13:15	24	28	60	51	1.2	2	W	SSW	43	137.3	19	21.3	18	18.1
e	13:20 – 13:50	24	29	67	43	1.0	2	S	SSW	52	94.9	31	24.6	20	19.3
f	13:55 – 14:25	26	29	58	43	2.8	3	WSW	SW	57	94.9	26	24.6	9	19.3
g	14:30 – 15:00	27	30	57	38	1.5	3	-	SW	101	72.5	30	30.4	16	16.3

Table 01. Meteorological and air pollution data for 3rd August 2018. *P = Primary data, **S = Secondary data related to meteorological conditions extracted from www.metoffice.gov.uk and air pollution data obtained from londonair.org.uk ‘Westminster - Marylebone Road – kerbside’ monitoring station operated by King’s College London.

Both air quality and microclimatic parameters have been compared and ratified against live official data from www.metoffice.gov.uk and the nearest fixed meteorological and air quality monitoring station to the study site. In this case, ‘Westminster - Marylebone Road – kerbside’ monitoring station operated by King’s College London has been chosen, which sits within a kilometre distance from the study site. The equipment sets are placed with a reference height of 1.5 meter above ground level. The study also captured data in several days and weather conditions, i.e. sunny, rainy, and relatively windy day. However, in this paper, only data and results pertaining to the 3rd August are used for

illustration. On this particular day, the wind direction was the same as London prevailing wind direction, making this day a good representation of typical London wind behaviour for most of the year.

2.2 Computer simulations for validation and prediction

Parallel to the spot measurements and data collection, the complex microclimate phenomena and a range of issues, including air pollution dispersal/concentration, air movement in and around buildings, pedestrian level wind environment and the impacts of non-morphological features on air movement, i.e. vegetation, bus stops and cantilevered shading structures, which project at least one meter beyond the side of a building have been modelled and simulated on ENVI-met version 4.4.3. In order to correlate the relationship between vegetation and pollutants concentration, in addition to modelling the current scenario, a no-green scenario has also modelled and simulated for the plaza.

ENVI-met, which is a 3D CFD (Computational Fluid Dynamics) application, has been selected as air pollution dispersion simulation tool due to its proven reliable outcomes that were examined by previous researchers [7,8,9]. This Eulerian, time- dependant dispersion model uses RANS equation as its turbulence modelling and is capable of computing a large number of air plume particles as they emit from their original source [10]. Moreover, it uses the Finite Difference Method (FDM) to solve the multitude of partial differential equations in the model, which allows ENVI-met to use relatively large time steps but still remaining numerically stable. Moreover, with its fine resolution between half a meter to 10 meters and a typical time frame of 24-48 hours and a time step of 1-5 seconds, the model is able to simulate complicated scenarios and display the interactions between solid and porous barriers at various levels and resolutions in a very graphical format. The graphical representation of various scenarios created and produced by the LEONARDO tool included in ENVI-met package. As it was mentioned, the field spot measurement only conducted for 4 hours (11:00 am – 3:00 pm), therefore, in order to cover the total simulation time the data inserted in ENVI-met collected from ‘Westminster - Marylebone Road – kerbside’ monitoring station. The result of the ENVI-met simulation were thereafter compared with the field spot measurement values and further analysis and validation is provided in Result & Discussion section of this paper.

Data related to roads, buildings, vegetation, and surfaces material recorded and gathered through conventional field measurement, satellite-based

measurement and official GIS documents/maps (Ordnance Survey which is the UK governmental mapping agency). Collected data from official GIS checked and verified against conventional field measurement data, and in some cases, aerial perspective published by Bing Maps and Google Maps used to minimise possible errors. Information related to vegetation characteristics such as species name, height, crown shape/size, clear stem height, and Leaf Area Density (LAD), leaf persistence and surface cover have been described in Table 02.

Vegetation Location	Vegetation Scientific name	Vegetation Common name	Vegetation Height (meter)	LAD (High/Low – Dense/Sparse)	Hairiness 0 (Smooth) – 10 (silky)	Stickiness 0 (Leathery) – 10 (Highly viscid)	Leaf Surface	Evergreen/Deciduous	Trunk Size	Crown shape/Size	Clear Stem height (meter)
1	Buxus	Box Hedging	1	High	0	1	Evergreen	N/A	Hedge	0	
2	Hedera helix	English Ivy	0.3	High	0	1	Evergreen	N/A	N/A	0	
3	Platanus x acerifolia	London Plane	10	Low	5	3	Deciduous	Medium	Broadly Oval (Heart-Shaped)	2.5	
4	Platanus x acerifolia	London Plane	10	Low	5	3	Deciduous	Medium	Broadly Oval (Heart-Shaped)	2.5	
5	Prunus	Cherry Tree	4	Low	3	2	Deciduous	Small	Irregular (Heart-Shaped)	2	
6	Tilia	Lime Tree	8	High	4	6	Deciduous	Medium	Broadly Round (Spherical)	2.5	
7	Tilia	Lime Tree	8	High	4	6	Deciduous	Medium	Broadly Round (Spherical)	2.5	
8	Platanus x acerifolia	London Plane	4	Low	5	3	Deciduous	Small	Irregular (Heart-Shaped)	2	
9	Platanus x acerifolia	London Plane	10	Low	5	3	Deciduous	Medium	Broadly Oval (Heart-Shaped)	2	
10	Quercus cerris	Turkey Oak	15	Low	2	2	Deciduous	Medium	Broadly Oval (Heart-Shaped)	4	
11	Buxus	Box Hedging	2	High	2	1	Evergreen	N/A	Hedge	0	

Table 02. Description of the study site’s vegetation characteristic. Locations shown on fig. 01 in yellow numbered label

It is worth mentioning that the ENVI-met models are not working reliably at their model borders and the grids very close to them. For that reason, the nesting area of all simulation scenarios chosen sufficiently large to increase the accuracy and numerical stability of the simulation result [11]. Based on the guideline prescribed by previous researchers [12] five nesting grid cells were empirically set on each side of the model and accordingly the z-grid set to 3 times higher than the tallest building in the model site [13]. In order to accelerate the computational (rendering) time of the simulation, it was decided to lower the resolution to 4 for all axis (dx, dy and dz). Other setting and configuration considerations have been summarised in Table 03.

Modeling area file (.inx) settings		Simulation file (.sim) settings	
Model Location		Start and duration of model run	
Location	Central London	Start Date (DD.MM.YYYY)	03.07.2018
Latitude (deg.-N,-S)	51.49	Start time (HH:MM)	06:00
Longitude (deg.-W,+E)	-0.31	Total simulation time (h)	16
Model Geometry		Initial meteorological conditions	
Grid dimension (x, y, z)	75 x 75 x 60	Wind speed at 10m height (m/s)	2.5
Grid cells size (dx, dy, dz)	4m, 4m, 4m	Wind direction (deg)	225
Model rotation out of grid north	-19.00	Air Temperature (°C)	17 (min.) – 32 (max.)
Nesting Grids	5	Relative Humidity in 2m (%)	36 (min.) – 94 (max.)
Number of nesting grids		Pollution Dispersion	
		Operation mode	Multi Pollutant
		Chemistry (NO-O3-NO2)	Dispersion & Action Chemistry

Table 03. Study site input file in ENVI-met 4.4.3.

3. RESULTS & DISCUSSION

The first item revealed from the fieldwork spot measurement was that, 3rd August which was a sunny day recorded as the most polluted day in comparison to 9th (rainy day) and 24th August (windy day). This is more distinct when we look at the PM₁₀ and PM_{2.5} levels and less noticeable in the case of NO₂ levels. Interestingly, the result of 9th August which was the rainy day scenario recorded PM₁₀ and PM_{2.5} at even lower level than a windy day, but still, NO₂ was relatively high, and this has been identified as a reoccurring pattern for all other study days. In order to investigate this results further, the results of fieldwork spot measurements for the three study days of 3rd, 9th and 24th August 2018 were compared against the ENVI-met simulation of the same dates and times to firstly validate ENVI-met simulations and secondly to evaluate the effects of trees on the concentration of mentioned pollutants at the monitoring site (Regent's Place) (in this paper only data and results pertaining to the 3rd August are used for illustration). As Table 04 shows, there is a slight difference between the simulation values and measured data. The level and value of the various meteorological parameters and air pollutants simulated by ENVI-met are consistently lower than what has been measured on-site.

Sunny Day		Meteorological conditions on 3 rd August 2018 - Fri								Street-level air pollutant concentration							
Location	Time (hrs:mins)	Air Temperature (°C)		Relative Humidity (%)				Wind Velocity (m/s)		Wind Direction (m/s)		NO ₂ (µg/m ³)		PM ₁₀ (µg/m ³)		PM _{2.5} (µg/m ³)	
		FM*	EM**	FM	EM	FM	EM	FM	EM	FM	EM	FM	EM	FM	EM	FM	EM
		1	11:00 – 11:30	29	27	56	54	2.2	1	SSW	SSW	119	90	34	15	14	9
2	11:35 – 12:05	28	27	60	54	1.4	0.5	SSW	SSW	76	90	22	10	6	6		
3	12:10 – 12:40	25	25	63	57	0.4	0.5	-	-	NNW	51	30	47	10	29	6	
4	12:45 – 13:15	24	25	60	58	1.2	1	W	WSW	43	30	19	5	18	3		
5	13:20 – 13:50	24	25	67	59	1.0	1	S	SSW	52	30	31	5	20	3		
6	13:55 – 14:25	26	25	58	55	2.8	2.5	WSW	SW	57	30	26	5	9	3		
7	14:30 – 15:00	27	25	57	59	1.5	2	-	-	SSE	101	60	30	10	16	6	

Table 04. Comparison between data gathered during fieldwork measurement and data extracted from ENVI-met simulation result. *FM = Field measurements **EM= ENVI-met simulation.

This ratio changes depending on the given meteorological conditions on the given days; however, in general, the pollution values in ENVI-met are always lower in value than the fieldwork spot measurement data. For example, the NO₂ and PMs concentration are respectively 1.4 and 3.2 times higher in recorded fieldwork spot measurements. In the case of meteorological parameters in most cases, the values are closely similar. These differences were expected as the background concentration data (for pollutants) and meteorological data which have been added in ENVI-met were extracted from the meteorological station which was located about a kilometre away from the study site ('Westminster - Marylebone Road – kerbside'), moreover, there were various simplification and

assumption had to be made while modelling the site in ENVI-met. However, the most interesting aspect of this comparison which is also the main interest of this research is that the measured data and simulation data conclusively and broadly correspond to each other and more precisely confirmed and aligned over the pollution concentration zones.

In order to analyse the simulation results in more detail and understand the impact of trees on air pollution concentration, it was decided to compare the microclimate parameters both in the current urban configuration and in a scenario where there are no trees or vegetation. In this paper, the simulations with a greater significance have been presented in the next pages. For that reason, the data selected for illustration is also related to the busiest (activity and population wise) time of the plaza, which was 1 pm (lunchtime).

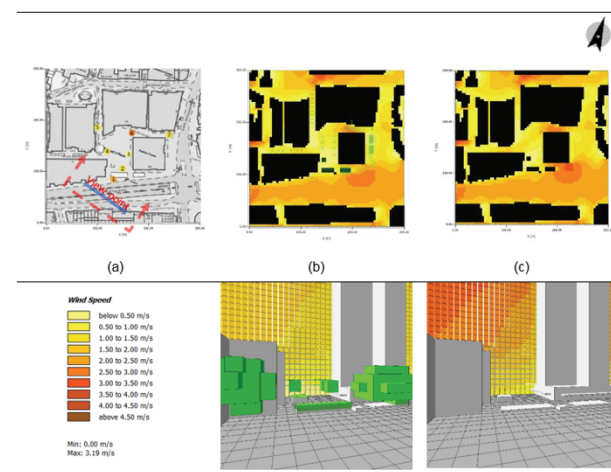


Figure 02. Snapshot of wind velocity and direction map at pedestrian level (1.5 m height from ground) for August 3rd, 2018, 13:00 h. (a) fieldwork spot measurements (b) ENVI-met simulation of current scenario (c) ENVI-met simulation of no-green scenario.

The simulation outcomes are quite revealing in several ways. First, the relative humidity is much lower in the no-green scenario, and this supports previous findings which have shown a decrease in relative humidity in no-green scenarios. Meanwhile, in the case of air temperature, the changes are not noticeable, and we do not see a great temperature difference between the two scenarios. This can be related to the low leaf area index of the trees and their clean stem height. This has been highlighted in Table 02. The wind aspect is the most interesting finding. Based on the result of the fieldwork and ENVI-met simulation, it is clear that trees in high and low density urban areas affect the wind velocity and its behaviour. As illustrated in Fig. 03 wind

velocity and vegetation have inverse correlation meaning that the wind velocity decreases with an increase in vegetation volume especially in the case of trees with high leaf area density (LAD). This drop of velocity has a direct impact on a higher concentration of pollutants, and in the case of Regent's Place, the high level of pollutants concentration can be found around the sets of trees which are located on the east and west side of the plaza (fig. 01 - location c and d). This scenario is exacerbated during the London prevailing wind direction of SSW and those trees planted in north and northeast of the square (fig. 01 – location e and f) slow down air velocity further and avoid pollutants to disperse from the plaza, therefore, led to a higher concentration of pollutants under the group of trees located in the east and west side of the plaza. Specifically, PM_{2.5} is 120% greater around the group of trees in location (c) and PM₁₀ values are even higher and stand at 175%. It has been noted that there is not much difference in NO₂ concentration values and the two scenarios (current and no-green) are almost the same but still around trees we can observe that the values are slightly higher than no-green scenario. It is worth mentioning that, the impact of trees on wind flow greatly depend on the vegetation shape and species, as well as the density of the urban context, i.e. planting high LAD heart-shape or spherical crown shape trees with low clear stem height and little space from each other, could slow down air velocity at pedestrian level (the urban canopy layer) and increase the concentration of pollutants. Previous research done by Edward NG [14] and several other studies [5,15,16] on designing for urban ventilation and urban thermal comfort, has established that a high-density urban area induces a weak wind flow and the current study shows that planting more trees will only exacerbate this already-slow wind speed reducing it even further.

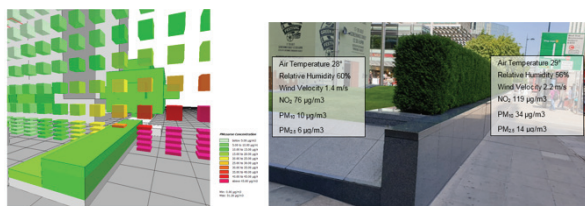


Figure 03. Snapshot of PM₁₀ concentration map around hedgerow at the south side of the Regent's Place (left). Fieldwork spot measurements (right). August 3, 2018, 11:00 h.

Further analysis of the result showed that the large hedgerow located at the south side of the site (fig. 01 – location a) is the most effective element in dispersing or blocking (depositing) pollutants. In accord with the result of fieldworks, the ENVI-met simulation with the exception of NO₂, have indicated the same and showed

a substantial improvement in air quality in location (b) (immediately after the hedgerow) (Fig 04). Previous studies conducted by a number of researchers [16,17] are in support of the above findings. In addition to that, in 2018 similar experiment conducted by King's College London has found levels of NO₂ reduced by 23% when an ivy screen wall was installed and placed between school playground and a busy road [18]. For that reason, it has been decided to take this strategy a step further and pilot scenarios where hedgerows which have proven to be even more effective than ivy screen [19] can be employed as a barrier and stop the PMs from congregation under the group of trees at Location (c).

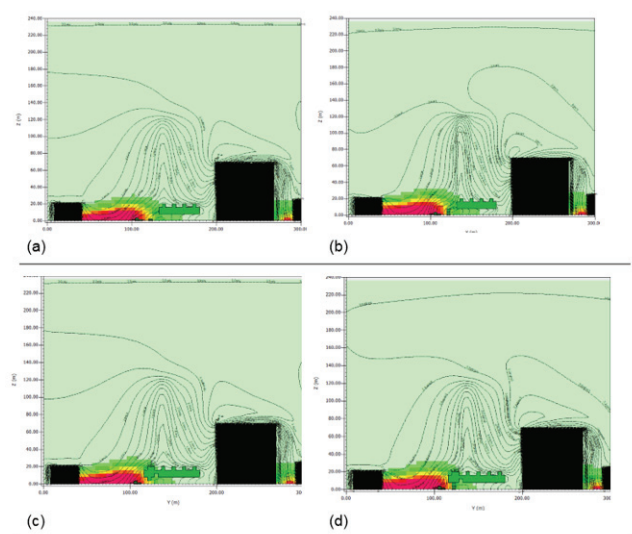


Figure 04. Section a-a illustrating PM₁₀ concentration map at pedestrian level with (a) adding a 2-meter height hedgerow; (b) adding a 4-meter height hedgerow; (c) adding an 8 meter Tilia tree (lime tree); (d) adding a 2-meter height hedgerow and an eight-meter lime tree, immediately after the existing hedgerow on the south side of the site.

The first scenario (a) was to add a parallel hedgerow immediately after the 'near wake' of the existing hedgerow (fig 04 - a). the result shows a pronounced reduction in pollution level (PM₁₀) and has limited the distance which air pollution can travel (downwind). Furthermore, it has been noticed that the inlet airflow partly blocked by the two rows of hedges and partly separated upward and generated skimming flow. In the second attempt and in order to avoid the formation of skimming flow, the 2-meter hedgerow increased to 4-meter height. However, the simulation outcome showed that 4 meter height porous barrier is not enough to influence the flow turbulence as minimal reduction in terms of pollution level has been observed. In the third attempt, a 4 meter hedgerow has been replaced with an eight meter Tilia tree (lime tree, similar species as to the group of trees at East side of the site) to offer protection

over a larger distance downwind. The result showed a further reduction in the distance which air pollution can travel but not much difference in terms of air pollution concentration at pedestrian level. For that reason and as a final mitigation strategy, both hedgerow and tall trees put back in their suggested places to provide the maximum protection in terms of distance, downwind and pollution concentration at the pedestrian level (Fig 04 d).

4. CONCLUSION

Whilst many studies agree in general on the mitigation of urban air pollutants by vegetation through their deposition and dispersion properties, the result of the current research contradicts this common understanding and demonstrates drastic increases in the concentration of particulate matters in the vicinity of trees. The results highlight that trees reduce wind velocity and air movement, causing pollutants to settle around and under trees' canopy. This is more distinct when we look at the PM₁₀ and PM_{2.5} levels and less noticeable in the case of NO₂ levels. Therefore, planting more trees does not necessarily mean less pollution, at least locally. Instead, to alleviate air quality problems, more attention should be given to vegetation configuration, type, scale and most importantly, their locations and distributions within the given active urban pocket. The findings from this research provide a fruitful area for further work to determine the exact effectiveness of vegetation in urban spaces throughout the year (summer and winter scenarios). Further investigation and modelling in different urban form with diverse vegetation type and spatial quality are required to be conducted to establish a better understanding of this matter. Needless to say that, we need more effective tree planting policy which takes the above challenges into account, and urban planners need to consider the impact of urban trees and green spaces on air quality at hyperlocal scale.

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