The Engineering Exchange

Sources of pollution in Somers Town (traffic, trains, buildings)

This fact sheet focuses on sources of Particulate Matter ($PM_{2.5}$, PM_{10}) and Nitrogen Oxides (NO_X), as these two pollutants are recognised as the most harmful to people (NICE guidelines).

Table 1 shows the different sources of pollution for the Somers Town area from The London Air Emissions Inventory (LAEI). For $PM_{2.5}$ the main sources are Traffic (62%), followed by Non-Road Mechanical Machinery (NRMM) (16%), for PM_{10} the main sources are traffic (53%), followed by resuspension of particles from roads and surfaces (27%), while for NOx traffic is the overwhelming source (82%), then Domestic and Commercial Gas (i.e. heating and cooking in buildings) (12%). These figures are based on yearly averages and therefore do not indicate the sources of short term peaks which can have immediate harmful effects on some vulnerable groups.

Emissions sources	**$PM_{2.5}$**	**PM_{10}**	**NOx**
Construction and Demolition Dust	0.3%	2%	0%
Resuspension	2.0%	27%	0%
Other	5.2%	3%	0%
Domestic and Commercial other Fuels	2.6%	2%	1%
Rail	3.6%	2%	2%
NRMM	16.2%	8%	4%
Domestic and Commercial Gas	8.0%	4%	12%
Road Transport	62.2%	53%	82%

Table 1: Sources of Emissions in 2013, from LAEI data

LAEI uses a 1km grid system which does not match the ward boundaries. Figure 1 shows in yellow the area that has been used in the charts below. It is composed of two sections. In the north section, the impact of Euston road reduces and the impact of energy use in buildings rises.

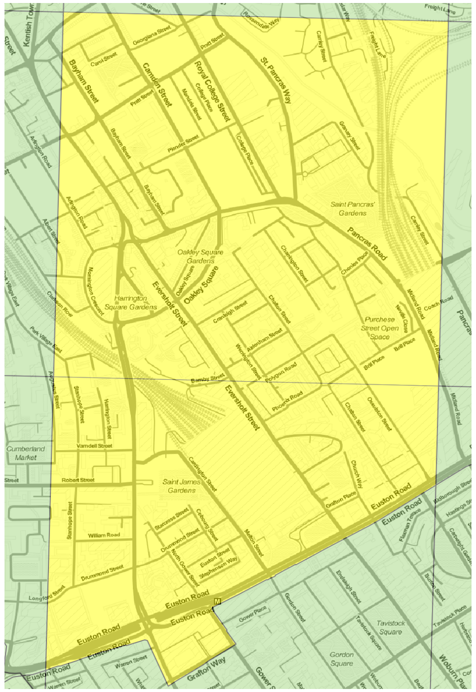

Figure 1: LEAI 1 km x 1 km background pollution grid covering Somers Town

Policies that can be implemented in Somers Town (Suggested in workshop 1)

A review by Kings College identified four main areas for intervention: (i) reducing private car use, **(ii) reducing emissions from all vehicles (making transport cleaner),** (iii) **reducing energy use by buildings** and (iv) reducing emissions from energy use by buildings (making electricity and heat generation cleaner). [1].

STNF identified ii and iii as areas they feel they can have the biggest impact on through the planning framework. The group were also interested in understanding the impact of the railways on local air quality. These three sources; transport, trains and buildings, are detailed in the next three sections, including the interventions and policies suggested in workshop 1.

Mechanisms that STNF can use

- Spending priorities for CIL
- Planning framework
- Direct action (Eg fliering drivers who are idling as suggested in workshop 1)
- Citizen science

Investigating further

Options for monitoring, modelling or additional research

- Citizen led monitoring, data sharing and data access
    - Examples from epidemiology of community based & participatory research (CBPR)
    - NOx and PM monitoring equipment is very expensive. Hand held monitoring devices can be inaccurate

- Industry / state sector monitoring with data sharing & analysis requirements.
    - Use planning framework to require industry or public sector base-lining and monitoring
    - Provide protocols enabling community access and analysis of data recorded.

- Suggestions for research provided by UCL team
    - Consider participatory budgeting exercise, and funds for a local RA to carry-out monitoring or evidence collecting.
    - Neighbourhood scale modelling of impacts and policies (but explain limitations)
    - Monitoring project for masters students to enable comparison of existing datasets /modelled results with measured effect. (eg train emissions, CHP emissions)
    - Scenarios discussion based on online visualisations eg LAEI projections about high levels of EV could be used to debate the future in Somers Town.
    - 3d map of energy performance of the buildings based on EPCs (residential) and DECs (non-res) to identify poorly performing buildings and target change.

Decision making criteria

- Baselining and generating evidence vs interventions to limit or mitigate sources of pollution
- Relative costs of different options
- Identify the groups most impacted by different sources & interventions

Initiatives and funding that exist

- Imperial applying for longitudinal health impacts funding
- GLA air quality initiatives
- UCL green wall suggestion for Somers Town (with HS2 and Camden / Birmingham)

1. Traffic

1.1. **Main sources of pollutants:** Diesel engine emissions (NO_2 & PM) and PM from brakes, tyres and road abrasion.

- Cycling NGO 'Sustrans' argues that the shift to electric vehicles will not reduce PM2.5 levels, which is the pollutant affecting the most people. They say 45% of particulate matter is caused by tyre and brake wear which will not be removed by the switch to electric vehicles (sustrans consultation).
- NICE guidelines state "Non-exhaust sources account for around 21% of PM2.5 from vehicles"

1.2. Identified concerns & evidence

Concerns from Workshop 1	Current evidence	Area used	Source
Idling vehicles	Idling outside schools, hospitals are critical. There is some evidence that training and information campaigns afffect time spent idling (for bus drivers and car drivers)	Global	NICE evidence review 2017
station traffic / taxis school run traffic	Sources of NOx pollution on Euston Road: Buses = 36%, HGVs = 26%, Taxi = 4%, cars = 20% Taxis are part of London's low emission zone regulations	Somers Town	GLA data 2011 - modelled
deliveries (business & residential)	Current GLA trial on EV vs diesel LGV. Baseline shows that EV more fuel efficient, but also drivers use less hard braking Delivery fleets part of London's low emission zone regulations	London	GLA Data 2017 - measured
Construction traffic	Major construction sites increase long term PM10 concentrations and the number of days when PM10 concentrations exceed 50µg/m3. "A large portion of the emissions results from site plant and road vehicles moving over temporary roads and open ground. If mud is allowed to get onto local roads, dust emissions can occur at some distance from the originating site." (construction site data is not usually used in AQ models because it's considered short term).	UK	IAQM Guidance 2011
NRMM	Accounted for 16.2% of PM2.5, 8% of PM10 and 4% of NOx in Somers Town area in 2011	Somers Town	LAEI data 2011 - modelled
Impacts of pollutants on different parts of the community	3 most vulnerable groups: 14yrs & under; 65yrs& older; people with chronic health conditions.	UK	NICE evidence review 2017

1.3. Impacts on different groups

Road pollution modelling is location specific. It can be used to identify particular groups at risk of traffic pollution. For example Figure 2 shows schools in Somers Town, all are within 150m of roads that exceed the EU limit value on NO2 (the metric that ClientEarth used in the Poisoned Playgrounds campaign). Different goups can be mapped; GP surgeries, old people's homes. However proximity doesn't always lead to exposure, as exposure depends on time spent outside and street design which affects how roadside pollutants are dispersed in the immediate environment.

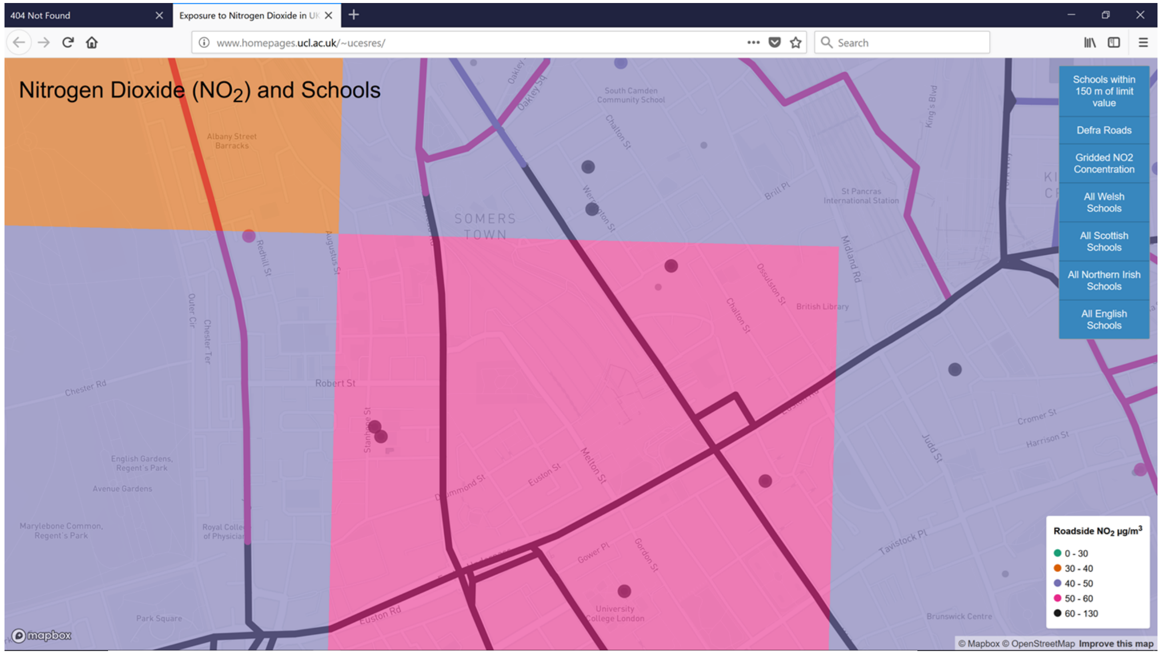

Figure 2: location of schools by roads with high NOx levels (source: SiCeds)

1.4. Interventions suggested in workshop 1

- Extend Central Activities Zone to north to cover NRMM pollution
- Car free days/ zones (e.g. around schools)
- Electric vehicles / Adding electric chargers
- Designated delivery drop off points
- Finance incentive paid to replace polluting taxi with electric Car (HS2 Developer tax, CIL)
- Resident-led campaign to stop idling
- Car free new residential developments (with access for people with disabilities, emergency services and municipal services e.g bin collections)

1.5. Evidence gaps and questions

- Urban modelling (e.g. Figure 2) uses yearly averages (annual means) whereas short term peaks in pollutants can be harmful for vulnerable groups. Case-studies and monitoring can be used to identify more specific exposure and harm to specific groups.
- NRMM emissions from upcoming construction projects will lead to increased yearly averages as well as short term peaks. How can these being adequately monitored and the information acted upon?

2. Trains

2.1. Main pollutants: NO2 CO and PM from Exhaust, and PM from non exhaust emissions

From the LAEI data, emissions from trains are much lower than those from cars, NRMM, or energy used in buildings. Nonetheless, the data about the impact of train stations on the surrounding environment is limited. Trains are not subject to the same level of emissions regulations as road vehicles and tend not to have exhaust treatment technologies. Train stations are not subject to the same air quality levels as outdoor air. Furthermore, “Increasing rail transport and ongoing development of high axle load trains and of high-speed trains can increase nonexhaust particle emissions.” [2]. In order to mitigate impacts, research suggests the first action should be to reduce emissions through treating the exhaust, changing engine and fuel composition. The second action should be ventilation to disperse concentrations in order to limit exposure for people inside the station. There is little evidence of dispersion of train and station emissions in the local environment.

2.2. Identified concerns and evidence

Identified concerns in workshop 1	**Current evidence for Paddington**[3] **& Birmingham New Street (BNSS)**[4] **(No studies of Euston or Kings cross)**
Engine emissions & non exhaust emissions	BNSS: Very high NO_2 levels inside station: a daily maxium hourly concentration of 1048 μg /m3 in comparison to an average of 75 μg /m3 for the Birmingham Ring Road, over the same period. Study suggests this is due to high number of diesel engine and limited ventilation within the underground station). More research needed to identify non-exhaust emissions
Emissions from station in local environment	BNSS: NO_2 emissions highest at station entrance by taxi rank and bus stops (see fig. 4 below) Paddington: $PM_{2.5}$ concentrations highest at Praed ramp entrance to the station (due to idling trains & other sources (eg gas cookers for food). Roadside had lower $PM_{2.5}$ levels impliying levels of $PM_{2.5}$ drop as you leave the station (see fig. 3 below) KCL report on on emissions monitored levels of PM10 and NO2 in Islington near East Coast Mainline (diesel engines) tracks found levels to be lower than predicted in models, and under the EU limits [5]
Cross Rail ventilation shaft	No relevant evidence found

2.3. Relevant studies

1) Paddington

70% of trains have diesel engines (more than most London stations) Trains can idle for up to 10hrs & idling accounts for 37.8 train hrs daily, acceleration accounts for 1.6 train-hr daily.

Recommendations. “If Paddington Station trains adopt diesel particulate filters with catalytic regeneration to meet emissions regulations (which is common with heavy duty on-road diesel vehicles), PM emissions would decrease by >90%.” But this would increase NO_2 concentrations. [3]

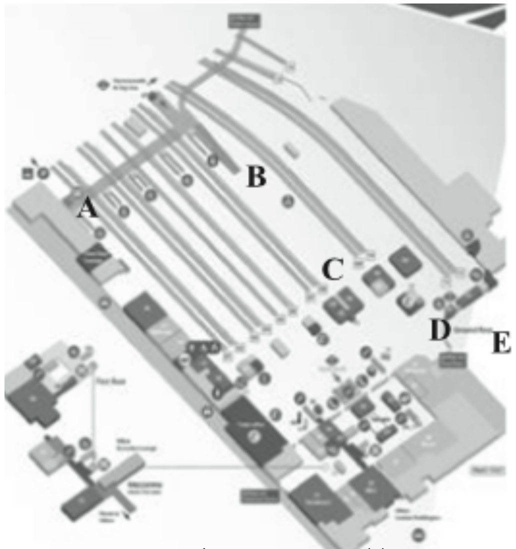

Figure 3 monitoring locations at Paddington Station

2) Birmingham new street station (BNSS)

Network Rail supported this study of air quality in and around Birmingham New Street Station [4]. NO_2 levels were very high with a daily maxium hourly concentration of 1048 μg /m3 [of NO_2] at the central site in comparison to an average of 75 μg /m3 for the Birmingham Ring Road, over the same period. However BNSS has a larger than average proportion of diesel trains, and the platforms are underground. Stations (e.g. like Euston) where the platforms are street level and open are not expected to have such a high concentration of NO2 by the authors.

Figure 4: Location of Diffusion tubes around Birmingham New Street Station (source: Hickman et al. 2018)

Figure 4 shows the location of diffusion tubes used to monitor air quality outside the station. Site A had the highest concentration of NO_2 (79μg/m3), and site K the lowest (46 μg/m3). The authors suggest the location of the taxi stand and bus stops at site A may have contributed to the higher level, whereas Site K is in a pedestrian zone.

The authors recommend

1) Turn off diesel engines
2) Long term strategy to shift away from diesel to electric trains, but point out that this is not current govt. policy. Dept. for Transport is looking at hybrid engines for near future.

They note the following gaps & research needs:

- "An investigation into tail pipe measurements to gain an understanding of the nature of diesel engine emissions from a variety of different train types.
- The measurements of concentrations of metallic particles from brake, rail and overhead line wear.
- The development of an understanding of pollutant dispersion in railway environments, in particular the dispersion by slow moving trains" [4]

2.4. Interventions suggested at workshop 1

- Collective ideas with HS2, Crossrail NPF, Camden Local Plan
- Code of construction practice – ensure standards are enforced

2.5. Evidence gaps & uncertainties

More research is needed to understand

- Volume of emissions from diesel trains at Euston and Kings Cross
- Non-exhaust emissions from all trains at Euston and Kings Cross
- Mitigation strategies already deployed in the station and others that are possible
- Dispersal of pollutants in the local environment
- Localised impact of ventilation shafts on local environment

3 Buildings (heating systems)

- **Main pollutants:** NOx and PM from the energy systems providing heating and hot water to housing.

3.1 Identified concerns

Concerns from Workshop 1	Current evidence
Local CHP plants	Somers Town is a potential site for district heating development. London heat map (Figure 5) shows ; 10 communal heating systesm for LB Camden's housing estates (blue squares); 2 Combined Heat and Power plants, one at Origin Housing's St Richard's House/Hillwood House (0.097 MWth & 0.054 Mwe yellow square) & one at Brill Place energy centre (red diamond) (3 x 1.3MWth boiler & 1 x CHP 0.901MWe & 0.957MWth) DH can reduce local emissions if replacing communal boilers with energy source outside the neighbourhood. Communal boilers and CHP have chimneys helping to disperse pollutants in contrast to individual gas boilers.
Additional emissions from new builds	UCL team could model impact of increased housing on local emissions with data on building type, no. of units and heating source.
Construction related emissions	Existing impact assessments?

3.2 Evidence gaps and questions

- Brill Place assessment[6] modelled NOx emissions and found very limited impact, but used modelled background levels, rejecting the higher monitored levels.
- What are actual emissions now operational?
- Main process for dispersion is stack height – have chimneys complied with proposed heights for CHP? Will new building development limit dispersal?
- Impact of removing existing estate boilers?
- What new housing will be connected?
- What energy reduction measures does the planned upgrade of existing housing have?

3.3 Interventions suggested in workshop 1

- Code of construction practice – ensure standards are enforced
- Regs on operational emissions for new builds (BREAM standards)
- Traffic Management Plan
- Involve SNPF in an impact assessment of construction Traffic

Figure 5 map of communal heating infrastructure in Somers Town

4. Trees & Greening

4.1 Key concerns raised at workshop 1

Identified issues	**Current evidence (nb urban cases are modelled or from labs – no monitoring studies found, no studies of Somers Town found)**
Tree type & maturity	Vegetation type needs to be considered against the desired outcome. **PM deposition** is helped by having trees with sticky excretions and rough bark and leaves (e.g. conifers), but other research [7] recommends varying vegetation to capture various types of PM. Trees have been found best at **NO2, SO2 & Ozone removal.** To avoid worsening **urban canyons**, landscape using shrubs, bushes, flowers, and grasses instead of taller species of plants, as a number of computer models and wind tunnel studies have found that tall trees limit ventilation and pollutant dispersal. No evidence on tree maturity has been found, however engineering firm Arup are experimenting with temporary greening, such as green hoardings covering construction sites, to explore benefits.
Tree location	Vegetation collects more **PM** if located in a place with a good airflow from the source of the pollution and for this airflow to be turbulent. However in very windy places PM deposited on vegetation is likely to be re-suspended in the atmosphere. To avoid worsening **urban canyons** vegetation should be well spaced and tree height should be below roof-top level. **Tree shading** requires planning to deliver benefits and not restrict natural ventilation and cooling. Green roofs and walls provide insulation and shading. They are expensive to build and maintain, but in some areas they are more viable than cheaper options like tree planting or open spaces, and the insulation and shading benefits may be more easily quantified and therefore costed in comparison to air quality benefits.
Impacts on health & well-being	Some studies find **a reduction in stress** from simply seeing the natural environment. These include reducing blood pressure [8], reducing stress hormone cortisol and pulse rate [9] and assisting patient recovery [10,11]. Many studies use self-reported **improvement in mental health** when discussing the benefits of green space [12–14] including reduction in stress and anxiety when moving to greener areas [15,16], improvements in mood, and lower frustration when walking through green areas [17,18] and a reduction in prescription of antidepressants with increased tree coverage [19]. There is limited evidence that exposure to environmental microorganisms modifies the human microbiome and **regulates immune function** [20]. **Negative impacts**: Trees and plants may exacerbate allergies and have been associated with a higher prevalence of asthma and childhood allergic sensitization to tree pollens [21].
Support socio-economic development & community-building	Tree coverage appears to be a strong factor influencing **social cohesion**, and appears to facilitate reduction in crime, particularly in poor, inner-city neighbourhoods [22,23]. Greening can improve 'liveability' which may **increase the value** of an area, or, more negatively, lead to '**green gentrification'**[24]. There are some case-studies looking at **skills and employment opportunities** offered by green infrastructure, e.g. a Lambeth group offers horticulture and bee-keeping training courses, and in Walthamstow Marshes you can learn about medicinal properties of plants from local herbalists leading walking tours (http://www.hedgeherbs.org.uk/).
Support bio-diversity	It is not clear the extent that trees and greening support biodiversity in any significant way [25] and increasing biodiversity in urban areas carries some risk for local wildlife and human health, by for example helping invasive species to spread [26].

4.2 Evidence gaps & uncertainties

Citizen scientists have revealed much higher concentrations of pollution than those recorded by the official monitoring networks and has also demonstrated lower pollution levels near green spaces. However there are issues with handheld monitoring devices consistently showing higher measurements than fixed. Much of the scientific evidence on air pollution and green infrastructure is from studies in rural or forested landscapes, wind tunnels and laboratory studies. The results may not be directly applicable to urban applications of green infrastructure in contexts which are much more complex and subject to variability in weather, climate and other environmental conditions.

Nonetheless, the evidence has been used to model the impacts of trees on urban air quality. For example, using the i-Tree Eco Tool, the RE:LEAF partnership assess 'London's urban forest' and estimate that the pollution removal by direct air pollution filtration by trees in Inner London is 11 tonnes of carbon monoxide, 288 tonnes of nitrogen dioxide, 86 tonnes of ozone, 28 tonnes of sulphur dioxide, 43 tonnes of $PM_{2.5}$ particulates and 105 tonnes of PM_{10} ([27]. Such assessments are not able to examine the specific location, vegetation type, the built environment, the weather and other contributing factors which will be important for determining neighbourhood-scale benefits and impacts of trees and greening.

The problem is further complicated by the fact that while trees do absorb some harmful pollutants, they do not absorb others. They emit VOCs and trees may act as ventilation blocks in urban street canyons[28]. Therefore, it is important to take a full inventory of what benefits trees and other vegetation can and cannot provide in terms of better air quality.

4.3 Interventions suggested at workshop 1

- Identify areas in existing residential estates that could be greened
- Relocate mature trees if possible
- Support community gardening initiatives and children getting involved in gardening
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4.4 Options for monitoring, modelling or additional research

- Citizen led monitoring, data sharing and data access
  - Map estates to identify green space and potential for green space

- Industry / state sector monitoring with data sharing & analysis requirements
  - Investigate use of temporary greening during construction works to limit PM (eg any air quality benefits to green hoardings for example)

- UCL Academic Ben Croxford is working with Camden and HS2 on a plan to get a green wall to limit impact of Euston Road pollution on Somers Town, although has not yet managed to get a lot of support.

4.5 Existing evidence

Green infrastructure can improve air quality by diluting and dispersing pollution, directly removing pollutants from the air by deposition and absorption on plant surfaces, and counteracting the urban heat island effect. However, trees and greening can also have negative effects on air quality by increasing urban canyons and emitting volatile organic compounds which can contribute to the formation of street-level ozone and carbon monoxide.

Trees and greening also have other positive effects on air quality like increased well-being, shading and increased economic value of the area. But, the evidence about the positive and negative impacts of trees and greening on local urban environments is limited and uncertain. It is hard to isolate the effects of trees and greening from other elements in the built environment.

- **Removing PM10 & PM 2:** Particulate matter (PM) concentrations have been found to be lower in areas with a higher tree cover [29] and the GLA's urban tree canopy has been estimated to remove between 852 and 2121 tonnes of PM10 per annum [30]
- **Removing NO_2, SO_2 & Ozone:** Plants can absorb polluting gases through their leaf stomata. They also emit gaseous chemicals called isoprenoids that remove ozone from the atmosphere [31]. The biggest impacts appear to be for sulphur dioxide (SO2). The impacts on nitrogen dioxide (NO2) absorption are less because even though vegetation absorbs NO2, NOx[1] is emitted by vegetation and by soil. In warm periods, canopies emit NOx leading to chemical reactions that produce low level Ozone (O3)[32].Trees and greening can also be harmed by too much pollution, reducing their ability to remove polluting gases [32].
- **Shading:** Vegetation can reduce air temperatures through shading and evapotranspiration. This can reduce the amount of energy used in buildings by reducing solar radiation and surface temperature [24]. In one study the use of summer air-conditioning energy was reduced by 10-35%[33]. Surfaces with a green canopy layer are 5-20 degrees cooler than sunlit surfaces[34–36]. Lower air temperatures can also reduce the chemical reactions that produce secondary air pollutants in urban areas [37]. However, vegetation can reduce wind velocity and so reduce natural ventilation and cooling of building surfaces[38]. As such, strategic tree planting is vital to optimise the effect of shading on buildings whilst also promoting effective natural ventilation.
- **Worsening the urban canyon effect:** Vegetation can inhibit ventilation by blocking airflow, leading to a negative impact on air quality at specific locations [28,39,40]. Furthermore, little is known about the influence of vegetation in higher-density, built-up environments and the main factors that affect air quality [40].

Emitting VOCs Trees emit volatile organic compounds (VOCs) which can go on to form ozone, a harmful pollutant at ground level [28].

[1] From Wikipedia: 'In atmospheric chemistry, NOx is a generic term for the nitrogen oxides that are most relevant for air pollution, namely nitric oxide (NO) and nitrogen dioxide (NO2). These gases contribute to the formation of smog and acid rain, as well as tropospheric ozone.'

5 Street canyons and air quality

Street canyons are streets with buildings continuously lined up on both sides [41] and are especially common in central London. They can become pollution hotspots due to increased traffic levels and reduced natural ventilation (Vardoulakis et al., 2003), leading to trapped air within the street. Symmetrical street canyons contain buildings that have the same height on either side, whereas asymmetrical canyons have different building sizes on either side (Vardoulakis et al., 2003), which has important implications for influencing airflow. The climate within a street canyon is controlled largely by micro-meteorological effects rather than those meteorological effects that influence dispersion generally [42].

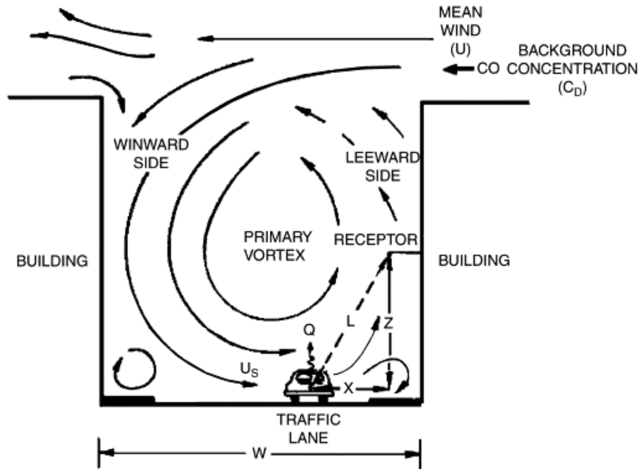
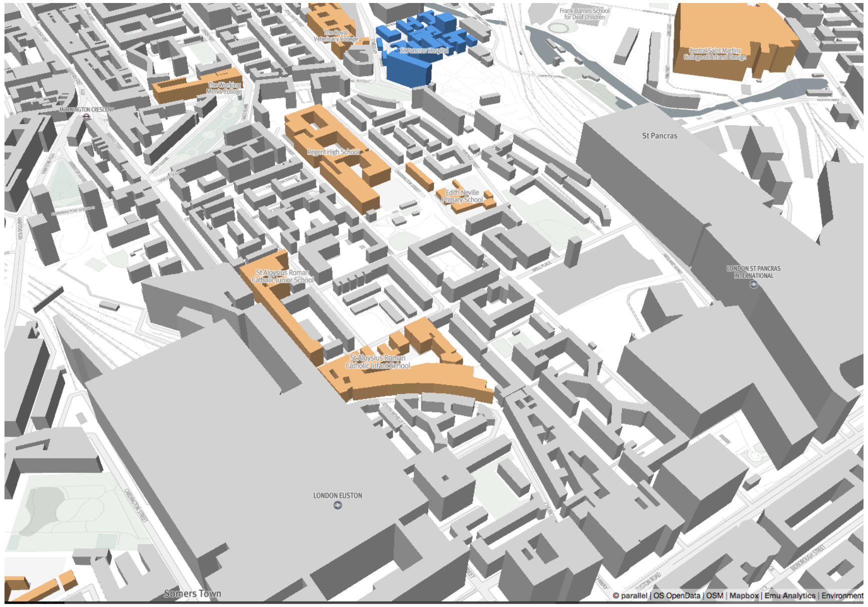


Figure 6: Pollution dispersion in a street canyon (source: Dabberdt et al., 1973).

5.1 Current evidence

Research on pollutant distribution in street canyons suggests the following:

- In most street canyons pollutant concentrations are higher on the leeward side of the street than the windward side when winds are blowing perpendicular to the street.
- Very narrow street canyons are less affected by perpendicular winds blowing over the top and so pollution concentrations on both sides of the street are more likely to be the same
- Pollutant concentrations are highest at street level and rapidly decrease vertically (depending on surface roughness and atmospheric stability).
- Ambient winds which are parallel to the street and/or low in speed cause pollutant concentrations to build, as does increased traffic volume.
- Pollutants can ventilate from the street in less than four minutes under typical ambient wind speeds.



5.2 Concerns from Workshop 1

- Densification due to CIP
- New developments incl. KQ, HS2, Cross rail
- Dangoor walk identified as a major concern

To understand the impacts of particular street canyons the specific weather and built environment factors need to be monitored and modelled to get accurate picture of the pollutants and their dispersal.

In workshop 1, the group stressed the need to focus on mitigating the impacts, accepting that street canyons are inevitable. They also suggested some interventions that could reduce pollution at source and minimise impacts of construction which will introduce pollutants and worsen the effect of street canyons during the construction process.

5.3 Interventions suggested at workshop 1

Some idea that were suggested in workshop 1 are:

- Retrofit existing estates and buildings to improve wind flow and reduce urban heat island (eg cooling street canyons to reduce chemical reactions).
- Planning and building design to include voids, and building fabric / surfaces which increase the air flow (wind permeability)
- Planning and building design to reduce energy emissions from new developments once occupied
- Planning and building design to reduce use of cars in developments, particularly related to deliveries
- Target construction process to reduce emissions from construction traffic and NRMM, particularly by using electric vehicles and redlining some areas from access by this traffic (eg schools).

References

1. Hesketh R, Jones L, Hinrichs-krapels S, Kirk A, Johnson S: **Air quality improvement initiatives in other cities: A brief review of evidence to inform the Westminster City Council Air Quality Task Group**. 2017,
2. Abbasi S, Jansson A, Sellgren U, Olofsson U: **Particle emissions from rail traffic: A literature review**. *Crit Rev Environ Sci Technol* 2013, **43**:2511–2544.
3. Chong U, Swanson JJ, Boies AM: **Air quality evaluation of London Paddington train station**. *Environ Res Lett* 2015, **10**.
4. Hickman A, Baker C, Cai X, Delgado-Saborit J, Thornes J: **Evaluation of air quality at the Birmingham New Street Railway Station**. *Proc Inst Mech Eng Part F J Rail Rapid Transit* 2018, **0**:95440971775218.
5. Fuller G, Baker T, Tremper A, Green D, Priestman M, Carslaw D, Dajnak D, Beevers S: *Air pollution emissions from diesel trains in London*. 2014.
6. Vital Energi: *Addendum to support an update to the previously discharged condition No.4 of planning application 2013/0884/P 1.* 2017.
7. Janhäll S: **Review on urban vegetation and particle air pollution - Deposition and dispersion**. *Atmos Environ* 2015, **105**:130–137.
8. Hartig T, Evans GW, Jamner LD, Davis DS, Gärling T: **Tracking restoration in natural and urban field settings**. *J Environ Psychol* 2003, **23**:109–123.
9. Song C, Ikei H, Igarashi M, Miwa M, Takagaki M, Miyazaki Y: **Physiological and psychological responses of young males during spring-time walks in urban parks**. *J Physiol Anthropol* 2014, **33**.
10. Nakau M, Imanishi J, Imanishi J, Watanabe S, Imanishi A, Baba T, Hirai K, Ito T, Chiba W, Morimoto Y: **Spiritual Care of Cancer Patients by Integrated Medicine in Urban Green Space: A Pilot Study**. *Explor J Sci Heal* 2013, **9**:87–90.
11. Raanaas RK, Patil GG, Hartig T: **Health benefits of a view of nature through the window: a quasi-experimental study of patients in a residential rehabilitation center**. *Clin Rehabil* 2012, **26**:21–32.
12. Cohen-Cline H, Turkheimer E, Duncan GE: **Access to green space, physical activity and mental health: a twin study.** *J Epidemiol Community Health* 2015, **69**:523–9.
13. Sturm R, Cohen D: **Proximity to urban parks and mental health**. *J Ment Health Policy Econ* 2014, **17**:19–24.
14. Nutsford D, Pearson AL, Kingham S: **An ecological study investigating the association between access to urban green space and mental health**. *Public Health* 2013, **127**:1005–1011.
15. Alcock I, White MP, Wheeler BW, Fleming LE, Depledge MH: **Longitudinal effects on mental health of moving to greener and less green urban areas**. *Environ Sci Technol* 2014, doi:10.1021/es403688w.
16. White MP, Alcock I, Wheeler BW, Depledge MH: **Would you be happier living in a greener urban area?** *Psychol Sci* 2013, **24**:920–8.
17. Aspinall P, Mavros P, Coyne R, Roe J: **The urban brain: analysing outdoor physical activity with mobile EEG.** *Br J Sport Med* 2013,
18. Berman MG, Kross E, Krpan KM, Askren MK, Burson A, Deldin PJ, Kaplan S, Sherdell L, Gotlib IH, Jonides J: *Interacting with nature improves cognition and affect for individuals with depression*. 2012.
19. Taylor MS, Wheeler BW, White MP, Economou T, Osborne NJ: *Research note: Urban street tree density and antidepressant prescription rates—A cross-sectional study in London, UK*. 2015.
20. Flies EJ, Skelly C, Negi SS, Prabhakaran P, Liu Q, Liu K, Goldizen FC, Lease C, Weinstein P: **Biodiverse green spaces: a prescription for global urban health.** *Front Ecol Environ pp* 2017, **15**:510–516.
21. Lovasi GS, O'Neil-Dunne JPM, Lu JWT, Sheehan D, Perzanowski MS, MacFaden SW, King KL, Matte T, Miller RL, Hoepner LA, et al.: **Urban Tree Canopy and Asthma, Wheeze, Rhinitis, and Allergic Sensitization to Tree Pollen in a New York City Birth Cohort**. *Environ Health Perspect* 2013, **62**:647–649.
22. Troy A, Morgan Grove J, O'Neil-Dunne J: **The relationship between tree canopy and crime rates across an urban–rural gradient in the greater Baltimore region**. *Landsc Urban Plan* 2012, **106**:262–270.
23. Kuo FE, Sullivan WC: **Aggression and Violence in the Inner City: Effects of Environments via Mental Fatigue / Aggression and Violence in the Inner City: Does Vegetation Reduce Crime?** *Environ Behav* 2001, **33**.
24. Natural England: *Microeconomic Evidence for the Benefits of Investment in the Environment 2 (MEBIE2)*. 2014.
25. Hostetler M, Allen W, Meurk C: **Conserving urban biodiversity? Creating green infrastructure is only the first step.** *Landsc Urban Plan pp* 2011, **100**:369–371.
26. Faeth SH, Bang C, Saari S: **Urban biodiversity: patterns and mechanisms.** *Ann New York Acad Sci pp* 2011, **1223**:69–81.
27. Kenton Rogers, Sacre K, Goodenough J, Doick K: *Valuing London's Urban Forest*. 2015.
28. Buccolieri R, Salim S., Leo L., Di Sabatino S, Chan A, Ielpo P, de Gennaro G, Gromke C: **Analysis of local scale tree-atmosphere interaction on pollutant concentration in idealized street canyons and application to a real urban junctioN**. *Atmos Environ* [date unknown], **45**:1702–1713.

29. Freiman MT, Hirshel N, Broday DM: **Urban-scale variability of ambient particulate matter attributes.** *Atmos Environ pp* 2006, **40**:5670–5684.
30. Tallis M, Taylor G, Sinnett D, Freer-Smith P: **Estimating the removal of atmospheric particulate pollution by the urban tree canopy of London, under current and future environments**. *Landsc Urban Plan* 2011, **103**:129–138.
31. Velikova V, Edreva A, Loreto F: **Endogenous isoprene protects Phragmites australis leaves against singlet oxygen**. *Physiol Plant* 2004, **122**:219–225.
32. Fowler D, Flechard C, Skiba U, Coyle M, Cape JN: **The atmospheric budget of oxidized nitrogen and its role in ozone formation and deposition.** *New Phytol pp* 1998, **139**:11–23.
33. Rosenfeld AH, Akbari H, Bretz S, Fishman BL, Kurn DM, Sailor D, Taha H: **Mitigation of urban heat islands: materials, utility programs, updates. Energy and buildings, , pp..** 1995, **22**:255–265.
34. Shashua-Bar L, Hoffman ME: **Geometry and orientation aspects in passive cooling of canyon streets with trees.** *Energy Build pp* 2003, **35**:61–68.
35. Asawa T, Hoyano T, Yamamura S, Asano K, Matsunaga T, Shimizu K, Buccolieri R, Salim SM, Leo LS, Sabatino S, et al.: **Passive methods of creating good thermal environments in outdoor space-An investigation of microclimates in the outdoor space of residential areas.** *Proc PLEA* 2000,
36. Lay OB, Tiong LG, Yu C, Litschke T, Kuttler W: **A survey of the thermal effect of plants on the vertical sides of tall buildings in Singapore.** *Proc PLEA* 2000,
37. Taha H: **Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat.** *Energy Build pp* 1997, **25**:99–103.
38. Akbari H: **Shade trees reduce building energy use and CO 2 emissions from power plants.** *Environ Pollut* 2002, **116**:S119–S126.
39. Salim SM, Cheah SC, Chan A: **Numerical simulation of dispersion in urban street canyons with avenue-like tree plantings: comparison between RANS and LES.** *Build Environ pp* 2011, **46**:1735–1746.
40. Wania A, Bruse M, Blond N, Weber C: **2012. Analysing the influence of different street vegetation on traffic-induced particle dispersion using microscale simulations**. *J Environ Manage* 2012, **94**:91–101.
41. Nicholson SE: **A pollution model for street-level air**. *Atmos Environ* 1975, **9**:19–31.
42. Hunter LJ, Johnson GT, Watson ID: **An investigation of three-dimensional characteristics of flow regimes within the urban canyon.** *Atmos Environ Part B Urban Atmos* 1992, **26**:425–432.