CITY AIR QUALITY AT HEIGHT –

Lessons for Developers & Planners

WSP | PARSONS BRINCKERHOFF

CONTENTS

SUMMARY

Poor air quality is a key issue for most large cities. Oxides of nitrogen and other pollutants from diesel cars have been linked to an estimated 40,000 deaths in the UK each year, with 10,000 in London alone. The effects of poor air quality have an approximate cost of £20 billion to the economy. In 2016, the High Court ruled that the UK Government has failed to tackle illegal levels of air pollution across the UK. Solving air pollution was considered to be the most important environmental priority for the new Mayor to address in our 2016 survey of Londoners.

Air dispersion models predict a rapid improvement in air quality with height. This is because the majority of city air pollution is emitted from vehicles at ground level. However, there has been little monitoring undertaken to verify this assumption. In this study, we measured how nitrogen dioxide (NO_2) concentrations change with height by monitoring air quality at twenty six different locations across London and Cardiff.

The results show that air quality does indeed improve with height (mainly at roadside locations) up to the fourth floor of typical buildings. Beyond this a further reduction is minimal. In other cases, air pollution concentrations were relatively constant with height (typically in background locations).

While the results present a complex picture, our research shows that simple building design measures could make a big difference to the quality of the air that is drawn into buildings. Designers can make a big difference to the health of their occupants by adopting five key principles:

1. **Monitor and model air pollution dispersion from road traffic as part of the design process to identify the best place to locate building air intakes.**
2. **Locate air intakes away from main roads and higher than the fourth floor if possible.**
3. **Locate air intakes away from existing and new boiler flues. These emissions can be as significant as the impacts from road traffic.**
4. **Design buildings that themselves are part of the solution. Renewable energy systems, centralised energy facilities designed to appropriate Planning Guidance, and electric vehicle charging points are all best practice.**
5. **Avoid reliance on nitrogen oxide filters unless absolutely necessary for new buildings as these rely on regular maintenance and incur high costs for purchase, installation and management.**

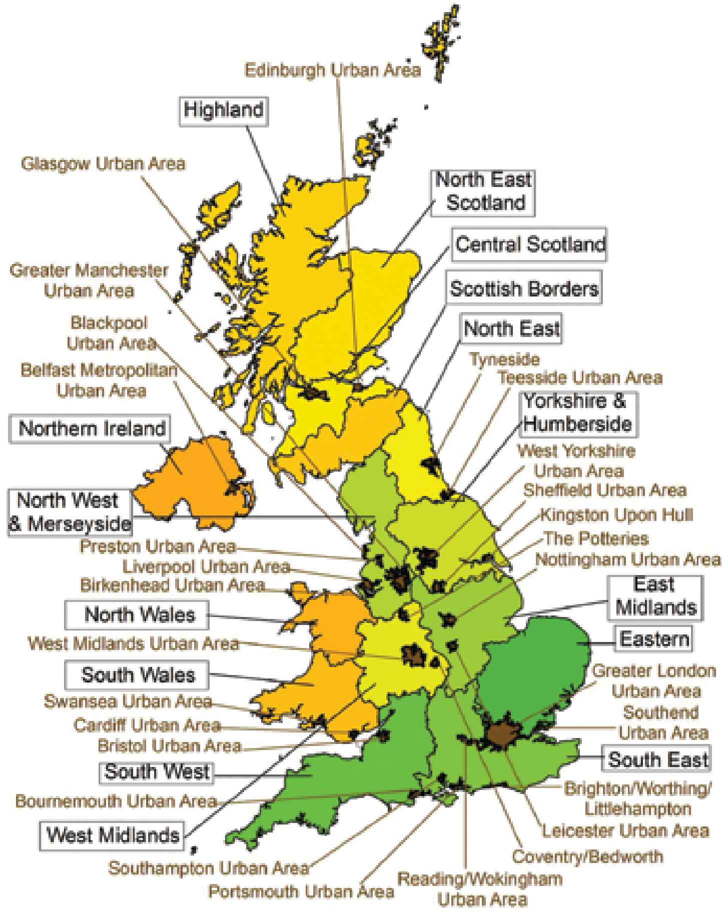

Figure 1: Indicates the 43 UK Zones and agglomerations for ambient air quality reporting to the EU.

Source: https://www.gov.uk/government/publications/air-quality-in-the-uk-plan-to-reduce-nitrogen-dioxide-emissions

CHAPTER 1 - CITY AIR QUALITY IS POOR

Ambient air quality standards to protect human health have been set by the Government, including targets/objectives and mandatory European Union (EU) limit values.

AIR QUALITY FROM DIFFERENT PERSPECTIVES

As a nation, the UK is split into 43 zones for reporting compliance with air quality limit values set by the EU. In 2015, 38 of the 43 zones were identified as non-compliant for breaches of the annual mean NO_2 limit value. At a finer scale there are over 600 designated Air Quality Management Areas (AQMAs) within local authority areas. These AQMAs were identified due to breaches of NO_2 and PM_{10} limit values (see Table 1). A large proportion of the designated AQMAs are located in urban areas with high population densities. Such circumstances present a significant challenge when developing new areas with healthy environments.

NITROGEN DIOXIDE

The main components of air are nitrogen (approximately 78%) and oxygen (approximately 21%). When something is burnt in air (for example, petrol or diesel in car engines, or natural gas in domestic central heating systems), oxides of nitrogen (NO_x) are formed. Of particular concern with regard to human health is NO_2. Exposure to high concentrations of NO_2 can adversely affect human health. People with asthma and pre-existing respiratory illnesses are particularly sensitive.

PARTICULATES

The terms ‘PM_{10}’and ‘$PM_{2.5}$’ refer to very small particles which are a commonly associated with combustion processes (running vehicle engines, solid fuel/oil heating plant etc), demolition and construction activities, and industrial processes – among others. The particles are small enough to penetrate deep into the lungs. The finest particles can enter the bloodstream. The particles alone are harmful to health but can also comprise and/or carry toxic substances into the body. Cardiovascular and respiratory diseases are associated with exposure to such particles.

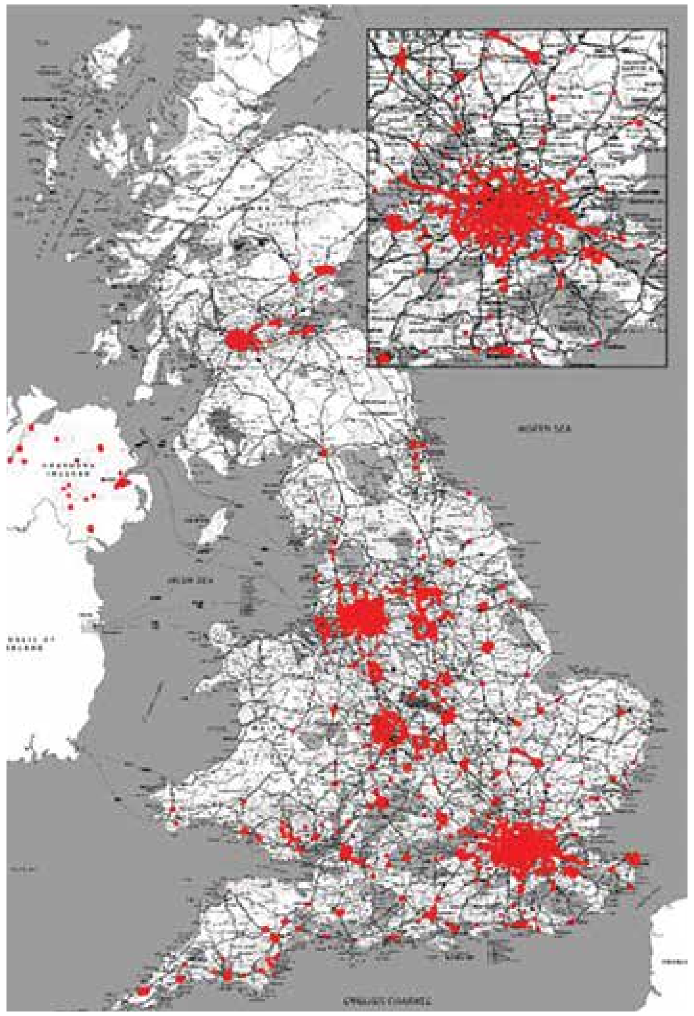

Figure 2: Declared AQMAs for the UK. The AQMAs tend to be most concentrated and extensive in urban areas with large numbers of pollution sources and dense populations. The London (inset), Birmingham, Manchester and Glasgow conurbations are prime examples.

Source: https://uk-air.defra.gov.uk/aqma

Pollutant	Objective Declared	England	Wales	Scotland	N. Ireland	London
Nitrogen dioxide NO2	1-Hour and Annual Mean	23	2			8
Nitrogen dioxide NO2	1-Hour Mean	1				
Nitrogen dioxide NO2	Annual Mean	479	35	23	19	25
Particulate Matter PM10	24-Hour Mean	27	1		1	22
Particulate Matter PM10	Annual and 24-Hour Mean	4		1	6	7
Particulate Matter PM10	Annual Mean	2				
Particulate Matter PM10	Scotland Annual and 24-Hour Mean			4		
Particulate Matter PM10	Scotland Annual Mean			16		

Table 1: Current AQMAs by Pollutant and Objective Declared

Air pollution adversely affects human health, playing a role in many chronic conditions such as cancer, asthma, heart disease, and neurological changes linked to dementia.

A study by the Royal College of Physicians (RCP) in 2016 examined the impact of exposure to air pollution and indicated that around 40,000 deaths in the UK each year can be attributed to exposure to outdoor air pollutants. The financial cost is considerable – approximately £20 billion every year (around 16% of the total NHS budget).

It has been widely reported that major cities such as London, Birmingham, Leeds, Liverpool, Cardiff and Edinburgh will still in be in breach of the EU limit value for annual mean NO_2 concentrations for at least another five years. The expected breaches of the EU limit value in major cities are in part due to the continued growth in vehicle use, increases in the average distance travelled and the general popularity of travelling by road. Couple these reasons with the recent diesel emissions scandal where some car manufacturers applied cheat devices to ensure emissions compliance with the EU emission standards during testing, it is considered reasonable that the EU limit value would still be exceeded for the foreseeable future. While the limit values continue to be exceeded there is the potential that substantial fines may be imposed by the EU on to the UK Government. Under the Localism Act the financial burdens could be devolved to local government, which could have consequences for development in areas of existing poor air quality, where these costs could be passed onto developers through Section 106 agreements or significant development restrictions imposed.

Furthermore, the costs of mitigating poor air quality are additional to these health and legal costs. The total cost burden of poor air quality to the UK economy and tax payers therefore stands to be significant.

Poor air quality at regional and local level is already making the development of land challenging. As publicity and public awareness inevitably increase, air quality is moving up the political agenda with increasing pressure on local authorities to act. For the foreseeable future, selecting potential development sites and considering the impacts appropriately will become ever more crucial in achieving successful planning applications.

NO_2 levels across London far exceed the air quality objective with no sign of any real improvement in the near future. This issue is top of the agenda with the new Mayor of London who stated: "With nearly 10,000 people dying early every year in London due to exposure to air pollution, cleaning up London's toxic air is now an issue of life and death" .

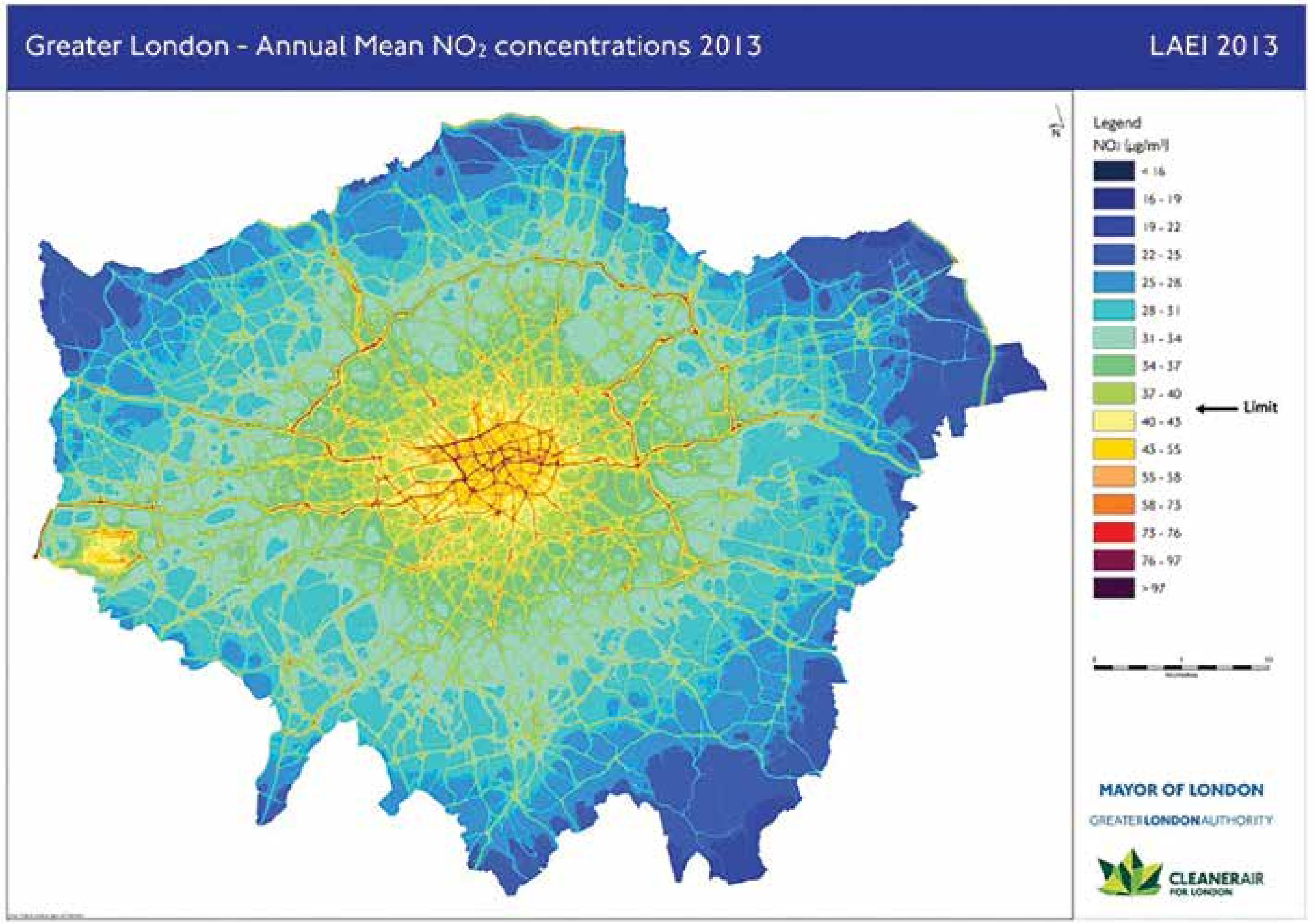

Figure 3: The 2013 modelled data provided by the Greater London Authority (GLA) represents the baseline concentrations of NO_2 in London. The modelled data indicates that the EU limit value for NO_2 is breached for large areas of Greater London.

The majority of air pollution in major cities originates from road transport and commercial and domestic heating. The greatest sources of air pollution at ground level are from road transport and construction machinery. Contributions from commercial and domestic heating are an important factor but are often emitted from elevated positions.

Although there have been some improvements in the levels of pollution emitted by vehicles since the introduction of Euro emission standards in 1992, a substantial body of evidence as highlighted by the recent diesel emission scandal has demonstrated significant failures in compliance with the Euro emission standards (1-6). Given the rate at which vehicles emissions are falling, air pollution is an ongoing issue. The concerns surrounding air pollution in London are clear given the response to a WSP | Parsons Brinckerhoff survey undertaken by polling and research consultancy ComRes.

The survey questioned over 1,000 adults currently living in London and the two key findings were:

- Air pollution (16%) is the highest day-to-day problem Londoners face after crime levels and costs of living; and
- One in four Londoners (25%) have seriously considered moving out of London because of air (and noise) pollution.

CHAPTER 2 -

DOES CITY AIR QUALITY IMPROVE WITH HEIGHT?

Growing upwards

In recent years, given the pressures on the UK housing supply, issues such as the provision of high rise development schemes and the growing trend of building upwards instead of outwards have come to the forefront. Often new development sites in urban environments are in areas of existing poor air quality and consideration of this has to be given when introducing new occupants to these areas.

Air quality at ground floor level is reasonably well documented as there has been extensive research undertaken (both monitoring and modelling) into this. Local authorities regularly complete annual air quality monitoring and modelling exercises to understand the air quality hot spots within their respective boundaries and submit annual reports detailing their findings, recommendations and proposed approach to improve local air quality to Defra.

Consequently, as the focus has been on air quality at ground floor level and how air pollution disperses laterally, the reduction in pollution with height has been neglected and is not particularly well understood. With recent trends of building upwards in densely populated urban environments, the impact on future occupants at height is unclear and requires further study.

With the rise of tall buildings, the creation and worsening of street canyons has become more prominent. The definition of a street canyon is 'the deep, narrow, valley-like spaces created when a road is enclosed by tall buildings on both sides' (illustrated by Figure 4 below).

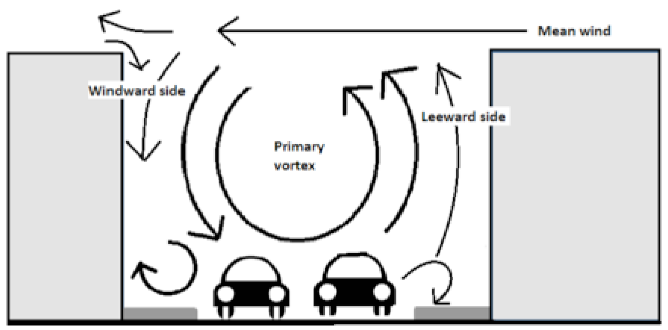

Figure 4: Pollutants within a street canyon are often recirculated and trapped within the street canyon, therefore reducing the rate of dispersion and causing variable concentrations at different heights.

AIR QUALITY WITH HEIGHT - THE CLASSIC MODELLED CONCENTRATION PROFILE

This study has focused on NO_2 as the pollutant of most concern, other pollutants including particulates may exhibit different concentration profiles with height. The classic air quality modelling concentration profile for NO_2 with height is illustrated in Figure 5 below.

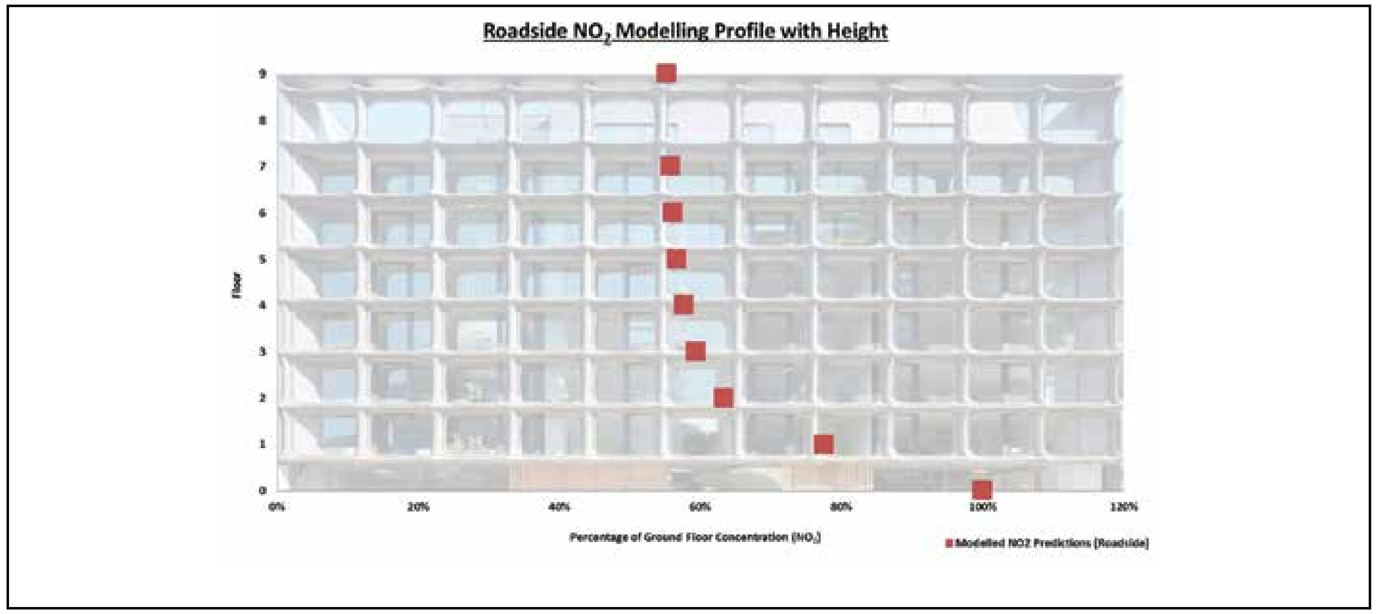

Figure 5: A typical NO_2 concentration profile using ADMS Roads dispersion model. The profile illustrated above includes 2016 Defra background concentrations taken from a typical central London Street in Westminster.

NB: Data from the eighth floor was excluded from the modelling profile to ensure a direct comparison with 'roadside' monitoring at height data collected.

The classic modelled concentration profile indicates that between the ground and fourth floor (~1.5-13.5m) the greatest reduction in NO_2 concentrations occurs (approximately 40%). However, beyond the fourth floor the reduction in NO_2 concentrations on a floor by floor basis is significantly less (approximately 10% between the fourth and ninth floor). The curve reflecting the modelled reduction in pollutant concentrations with height is an indicative representation of what are very complex real world conditions.

CHAPTER 3 - OUR MEASUREMENTS SHOW AIR QUALITY IMPROVES WITH HEIGHT, BUT IT'S A VARIABLE PICTURE

With the uncertainty surrounding how NO_2 concentrations reduce with height, and the potential uncertainties associated with the classic modelled concentration profile, WSP | Parsons Brinckerhoff collated data from air quality monitoring undertaken at height from local authorities in London. To supplement this WSP | Parsons Brinckerhoff deployed a number of NO_2 diffusion tubes at height at various locations in London and Cardiff.

The air quality monitoring survey, which is one of the largest known surveys of variation in air quality with height, was undertaken at twenty six locations for a periods ranging from three to twelve months. The measurement locations were at sites that are classified as 'roadside' and 'urban background' locations:

- Roadside – Sites with sample inlets between one and five metres from the edge of a busy road ; and
- Urban Background – Sites in urban locations which are located away from specific emission sources, usually at a distance of more than twenty metres. These locations broadly represent city-wide background concentrations.

Figure 6 and 7 below provide graphical representations of the 'roadside' and 'urban background' monitoring data collected.

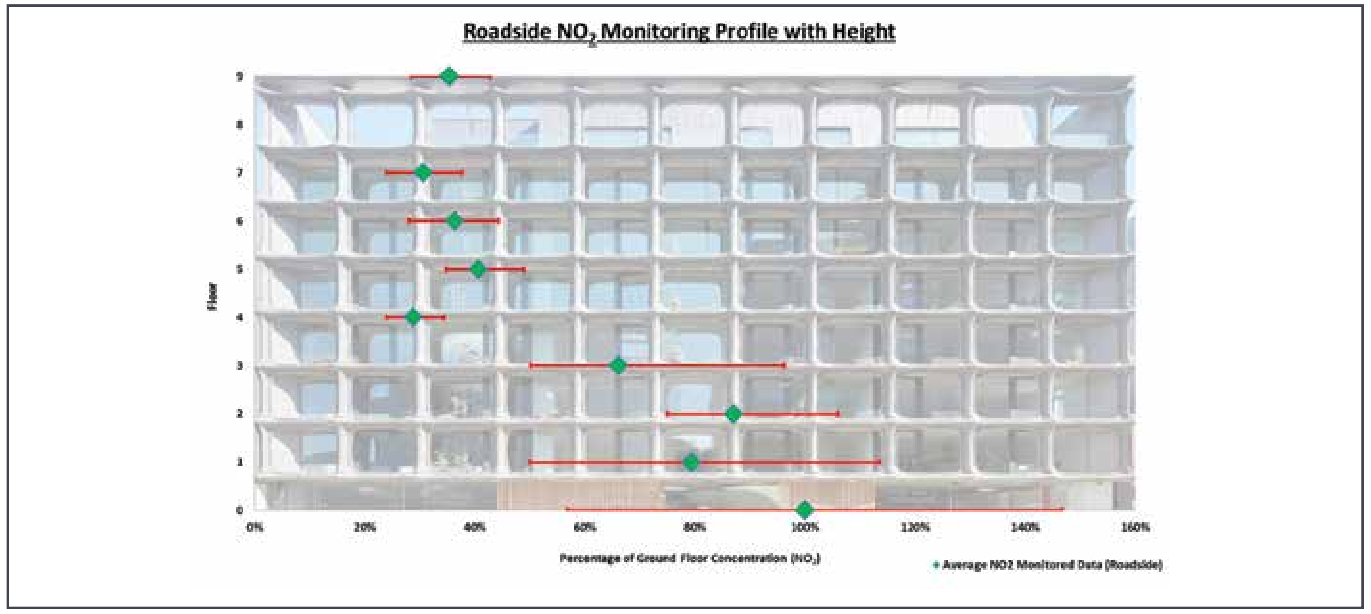

Figure 6: Roadside NO_2 diffusion tube monitoring with height in London and Cardiff. Each green point indicates the average monitored NO_2 concentration for each floor and the red error bars indicate the minimum (left) and maximum (right) NO_2 concentrations measured at each floor.

Summary: Average NO_2 concentrations at monitored 'roadside' locations indicated a reduction with height of approximately 50% to 60% between the ground and fourth floor. Beyond the fourth floor the data indicates that there is no further significant reduction in NO_2 concentrations with height.

Furthermore, between the ground and fourth floor there is a large variability in 'roadside' NO_2 concentrations given the range of the data measured between the minimum and maximum NO_2 concentrations (approximately 10-40% plus or minus the average NO_2 concentration measured). The variability in the monitored NO_2 concentrations between the fourth and ninth floor is significantly lower (approximately 5-10% plus or minus the average NO_2 concentration measured). The large variability in measured NO_2 concentrations at the lower floors indicates how complex real world conditions in combination with the proximity to the primary source of emissions (road traffic) can effect NO2 concentrations.

NB: No 'roadside' monitoring was undertaken at the eighth floor.

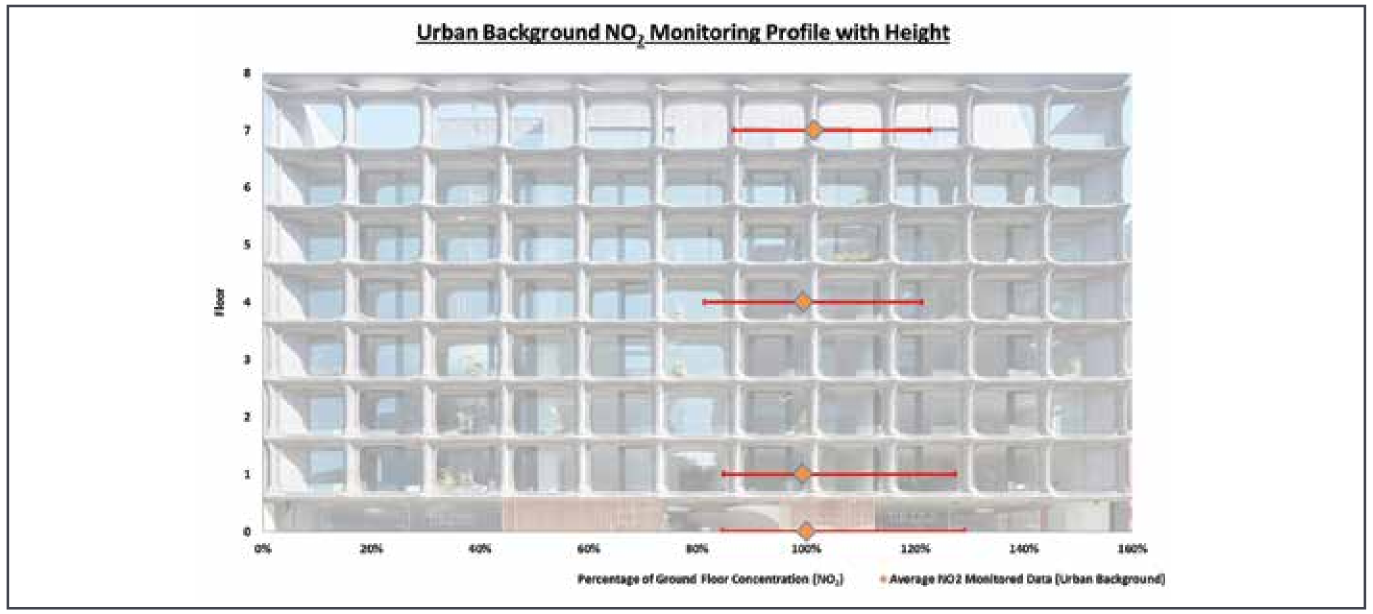

Figure 7: Urban background NO_2 diffusion tube monitoring with height in London and Cardiff. Each orange point indicates the average monitored NO_2 concentration for each floor and the red error bars indicate the minimum (left) and maximum (right) NO2 concentrations measured at each floor.

Summary: Average NO_2 concentrations at monitored 'urban background' locations indicated no significant reduction with height. The variability in 'urban background' NO_2 concentrations is approximately 20-25% plus or minus the average NO_2 concentration measured at all floors. Therefore, the data indicates that in 'urban background' locations little to no difference in measured NO_2 concentrations is evident between the ground and eighth floor.

NB: No 'urban background' monitoring was undertaken at the second, third, fifth, sixth and eighth floors, and therefore is not included in this figure.

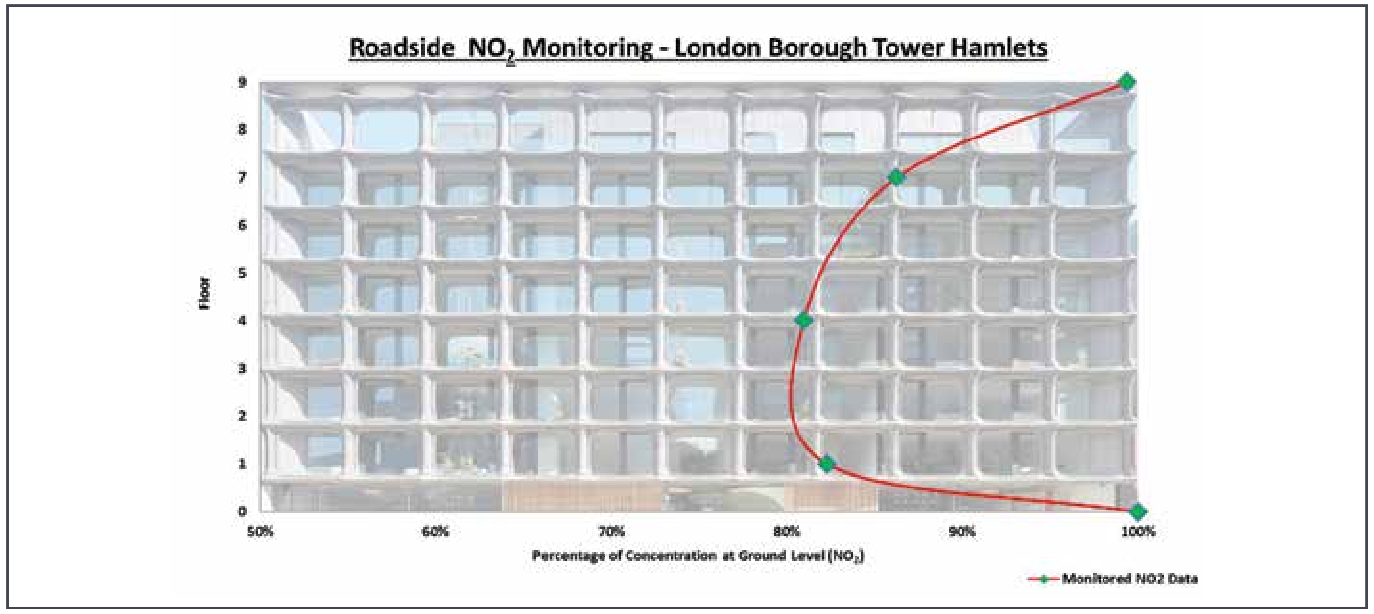

Figure 8: Roadside NO_2 diffusion tube monitoring with height in the London Borough Tower Hamlets (London).

Summary: Average NO_2 concentrations at the monitored 'roadside' location indicated a reduction with height of approximately 20% between the ground and fourth floor. Beyond the fourth floor the data indicated increasing concentrations with height up to the ninth floor where concentrations were almost equivalent to those at ground level. The emissions from the energy plant offset the reduction in NO_2 with height above street level (the degree to which this occurs will depend on the relative strengths of the street level and roof level sources).

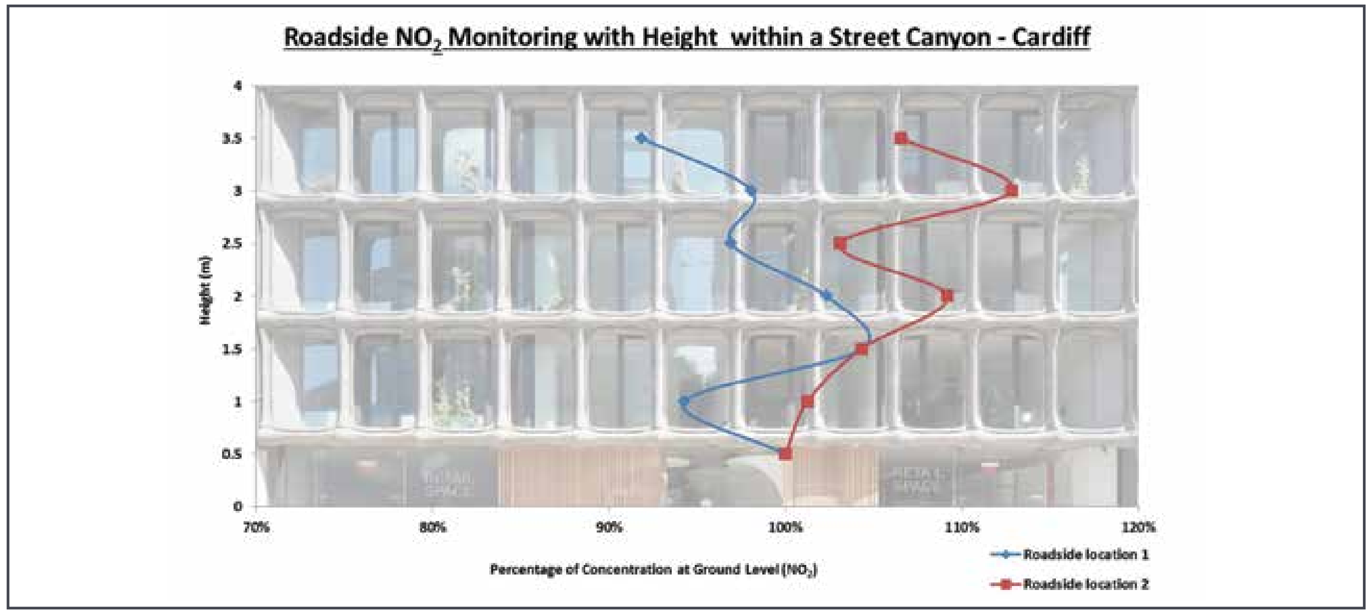

Figure 9: Roadside NO_2 diffusion tube monitoring at height within a street canyon (Cardiff).

Summary: Average NO_2 concentrations at monitored 'roadside' locations within a street canyon in Cardiff indicated a significant amount of variability between the ground (0m) and first floor (~4m). The large variability in measured NO_2 concentrations within the street canyon indicates how complex real world conditions such as road width and building height in combination with the close proximity to road traffic emissions can effect NO_2 concentrations. Unlike the reduction in roadside' NO_2 concentrations seen in Figures 6 and 8 between the ground and first floor of approximately 20%, data indicates no definitive upward or downward trend.

Figure 10: Comparison of roadside NO_2 diffusion tube monitoring and typical modelled concentration profile for NO_2. The green points indicate the average monitored NO_2 concentration for each floor and the red bars indicate the minimum (left) and maximum (right) NO_2 concentrations measured at each floor. The red points indicate the modelled NO_2 concentrations predicted at each floor

Summary: Between the ground and third floor the modelled concentration profile slightly under-predicts NO_2 concentrations by approximately 5-15% compared to the monitoring data. From the fourth to ninth floor the modelled concentration profile over-predicts NO_2 concentrations by approximately 20-30% compared to the monitoring data.

The graph highlights that air quality dispersion in urban environments is complex and variable. These complexities are evident from the differences between the modelled and monitored NO_2 concentration profiles. The modelled profile is based on formulated simplistic parameters and therefore the reduction in NO_2 concentrations with height may not necessarily be realistic. Monitoring provides a more specific and accurate understanding of variations in concentrations with height at a particular location.

A separate study by the City of London of NO_2 concentrations at the Barbican indicates that concentrations above 9th floor level (up to level 34) may not be dissimilar to those at lower levels, particularly at background locations. The implication is that concentrations at high rise levels should not simply be assumed to be substantially lower than ground floor background concentrations.

SUMMARY – AIR QUALITY MONITORING WITH HEIGHT

The 'roadside' NO_2 monitoring data and the classic modelled concentration profile indicate that between the ground and fourth floor the greatest reduction in NO_2 concentrations occurs (between 40-60%). However, beyond the fourth floor both the monitored and modelled NO_2 concentration profiles do not indicate any further significant reductions (approximately 10%). The greatest variability (up to 40%) in NO_2 concentrations is evident in the first 10 metres; beyond the first 10 metres variability is significant lower (approximately 5-10%). The large variability in measured NO_2 concentrations at the lower floors indicates the complexity of real world conditions.

The 'urban background' NO_2 monitoring data indicated no significant reduction in NO_2 concentrations between the ground and eighth floor.

The 'roadside' NO_2 monitoring data collected in the London Borough of Tower Hamlets indicated a reduction in NO_2 concentrations between the ground and fourth floor. Based on the typical 'roadside' curve (Figure 6) we would expect to see this reduction plateau. However, the monitored data indicated an increase in NO_2 concentrations which is likely caused by the emissions from the onsite energy centre at roof level. The reduction in NO_2 concentrations with height is offset by the roof top energy centre contributions.

The 'roadside' NO_2 monitoring within a street canyon in Cardiff indicated a significant amount of variability between the ground (0m) and first floor (~4m). The variability in concentrations indicates the complexity of the built environment, which monitoring can illustrate reasonably well.

CHAPTER 4 - MITIGATION OF POOR AIR QUALITY

According to a study by the European Environment Agency in 2013, people in Europe spend at least 90% of their time indoors. Given the uncertainty in the reduction in NO_2 concentrations with height, building design is important. To manage the level of outdoor air pollution being drawn into buildings there are two options that could be considered: First, natural ventilation and second mechanical ventilation. Mechanical Ventilation with Heat Recovery (MVHR) is most commonly installed in residential or commercial buildings in urban environments where natural ventilation as a standalone ventilation approach is not a practical solution due to the poor air quality.

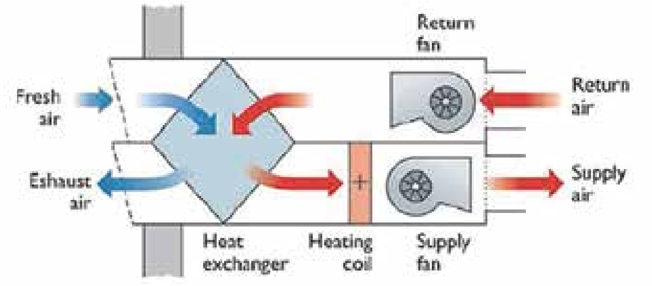

Figure 11: A typical MVHR system. Supply and extract vents are assisted by fans coupled with heating and/or cooling coils.

In areas of poor air quality MVHR systems can incorporate filtration systems to reduce pollution levels drawn in to below EU limit values. If a filtration system is proposed, the following must be considered:

- Installation costs are high;
- Regular maintenance is required to ensure efficient operation;
- Continual operating costs (from the electrical consumption), and
- Who is responsible for the on going maintenance and replacement of filters, and for how long?

Furthermore, centralised heating systems are commonly installed in urban areas, often with flue termination at roof level. In order to reduce the likelihood of exposure of occupants to unacceptable levels of air pollution, consideration

CHAPTER 5 - FIVE PRACTICAL RECOMMENDATIONS

While the long-term solution is to cut emissions, we make five practical recommendations:

- **Consider air quality at an early stage:** A site-specific air quality appraisal should form part of the environmental due diligence process. Depending on the complexity of the situation air quality monitoring and modelling may be appropriate at this stage. By understanding the air quality constraints of a site as early as possible this can benefit the health of occupants, the design and potentially offer cost savings in the long term.

- **Be mindful of air intake locations:** Air intakes should ideally be located on non-road facing facades or if roadside in elevated positions to avoid emissions from roads and other sources (such as exhausts associated with heating facilities from the proposed development and adjacent buildings). This would help minimise the exposure of new occupants to poor air quality and minimise the requirement for costly mitigation.

- **Installation of efficient centralised energy facilities and/or renewable energy sources:** Air quality for residents who live in high-rise buildings are often impacted by emissions from elevated point sources, commonly from centralised energy facilities. Unless the local planning authority has specific requirements, as a rule of thumb it is recommended that these facilities should meet as a minimum the NOx emissions standards detailed in the GLA planning guidance. Where possible, technology that eliminates emissions should be considered.

- **Be aware of developments within a street canyon/ introduction of a street canyon:** Street canyons can limit dispersion under some circumstances and worsen air quality. New developments that create street canyon environments require careful consideration and technical advice should be sought by air quality specialists as early in the development process as possible.

- **Establish a sufficient evidence base to minimise costly mitigation:** Ensure that sufficient evidence is available to be presented at planning submissions stage to minimise the requirement for costly mitigation such as NOx filtration which has ongoing maintenance and cost implications.

ABOUT US

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In the UK and Ireland, 7,100 people (including Mouchel Consulting) provide consultancy services to all aspects of the built and natural environment working across both the public and private sectors, with local and national governments, local authorities, developers, contractors and co-professionals. The combined business has been involved in many high profile UK projects including the Shard, Crossrail, Queen Elizabeth University Hospital, the Bullring shopping centre in Birmingham, the re-development of London Bridge Station, Manchester Metrolink and the London Olympic & Paralympic Route Network.

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