The impact of a green screen on concentrations of nitrogen dioxide at Bowes Primary School, Enfield

Prepared for the London Borough of Enfield

January 2018

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Customer	Enfield Council

Customer Ref	

File Reference	

Report Number	

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Summary

City Hall data revealed that many schools within London are currently located in areas exceeding legal air quality limits. In a new scheme by the GLA/Mayor of London to protect school children from the effects of air pollution, audits will be carried out to review ways of lowering the exposure to pollution in and around Schools, one of which could be the use of “'green infrastructure' such as ‘barrier bushes’ along busy roads and in playgrounds to ‘block’ out toxic fumes.

Research on urban vegetation suggests that it can help reduce the impact of pollution on people and buildings by acting as a pollution sink. Furthermore, the transport of pollutants from nearby traffic sources in urban areas can be effectively reduced by using green barriers. Thus, green infrastructure might be a cost effective and easy way to reduce the impact of pollution in near road environments. This is especially important for vulnerable members of the population, such as children, whose lung growth is slowed in areas with high pollutant concentrations. Therefore, a measure to reduce pollution levels at schools situated at roadsides will be of particular benefit.

To assess the efficacy of a green screen to prevent the transport of vehicle emissions from the nearby road into the playground, an ivy screen was installed at Bowes Primary School in the London Borough of Enfield. Nitrogen dioxide (NO_2) was then measured either side of the screen and the difference in concentration between the roadside side and playground side of the screen was assessed as it matured.

The screen was found to be an effective pollution barrier and a significant impact could be seen once the screen had matured. It led to a decrease in the mean daily pollution concentrations on the playground side of the screen by 22%; this was higher than the measurement uncertainty and thus significant. Comparing school hours independently a mean reduction in concentrations of up to 23% was found for NO_2. This demonstrates that the screen is very effective in reducing pollution concentrations during daytime hours, when both emissions and exposure are highest.

Unfortunately, the annual mean air quality objective would not have been met on either side of the screen for NO_2; assuming that the analysis periods were representative of an entire year. Therefore, further vehicle emissions abatement, in addition to these local measures, would be required to reduce concentrations below the EU Limit Value at the playground.

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Contents

1 Introduction

City Hall data revealed that within London 360 primary schools are currently located in areas exceeding legal air quality limits (GLA, 2017). In cities, like London, the concentration of air pollutants such as nitrogen dioxide (NO_2) and particulate matter are elevated close to roads and many schools in London are located close to roads, with classrooms and playgrounds only a few meters from heavy traffic. Despite many years of investment in exhaust emission abatement technology, moving from Euro 4 to 5 etc. (EC Regulation 715/2007/EC), and policy interventions such as the London Low Emission Zone, the concentrations of pollutants, especially NO_2, remain high close to roads.

Toxic air pollutants, such as NO_2 have been shown to have detrimental health effects including increased cardio-pulmonary and lung cancer mortality and increased risk of respiratory symptoms (WHO, 2003) and children are particularly vulnerable to the effects of poor air quality. Indeed, exposure to NO_2, nitrogen oxides (NO_X), and particles below 2.5µm in size ($PM_{2.5}$) has been shown to negatively affect the lung function in schoolchildren (Gehring et al., 2013).

In a new scheme by the GLA/Mayor of London to protect school children from the effects of air pollution, detailed audits will be carried out to review ways of lowering the exposure to pollution in and around Schools (GLA, 2017). One of the recommendations of such an audit could be the use of "'green infrastructure' such as 'barrier bushes' along busy roads and in playgrounds to 'block' out toxic fumes (GLA, 2017).

Research on urban vegetation suggests that it can help reduce the impact of pollution on people and buildings by acting as a pollution sink. Furthermore, the transport of pollutants from nearby traffic sources in urban areas can be effectively reduced by using green barriers (Sternberg et al, 2010; Hill, 1971). Thus, green infrastructure might be a cost effective and easy way to reduce the impact of pollution in near road environments. As mentioned above this is especially important for vulnerable members of the population, such as children, whose lung growth is slowed in areas with high pollutant concentrations (Kelly and Fussel, 2011). Therefore, a measure to reduce pollution levels at schools situated at roadsides will be of particular benefit.

Figure 1: Playground area with and without ivy screen

The efficacy of an ivy screen was assessed in a study in the Royal Borough of Kensington and Chelsea. The screen was found to be an effective pollution barrier once the ivy had started growing and a significant impact could be seen once the screen had matured (Tremper et al., 2015). However, the measurements were taken immediately either side of the screen and thus may not reflect the pollutant concentrations further away from the screen.

In the current study, 12 m of ivy screen were installed in the nursery entrance area of Bowes Primary School in the London Borough of Enfield (Figure 1). The green screen was designed to fill gaps in the existing barrier and reached 2.4 m in height as shown in Figure 1. Data was collected before and after the screen was installed and a follow up study was carried out after the screen had matured. NO_2 was monitored on the roadside and playground side of the screen to assess the efficacy of the screen in reducing exposure in this area of the school.

Bowes Primary School was chosen as it is located on the North Circular Road, a busy four lane road. The school has hosted a London Air Quality Network (LAQN) measurement station since 2004 and recent concentrations are shown in Figure 2. Compared to the London Mean Roadside (see Methods section for explanation), concentrations found at Bowes Primary School are lower and have been dropping more noticeably over recent years. Despite of this, the concentrations measured in this location still exceed the annual EU Limit Value for NO_2. There has been significant variability in the trend of NO_2 concentrations at different sites in London due to different vehicle mixtures; this has been reviewed in Font et al (2017).

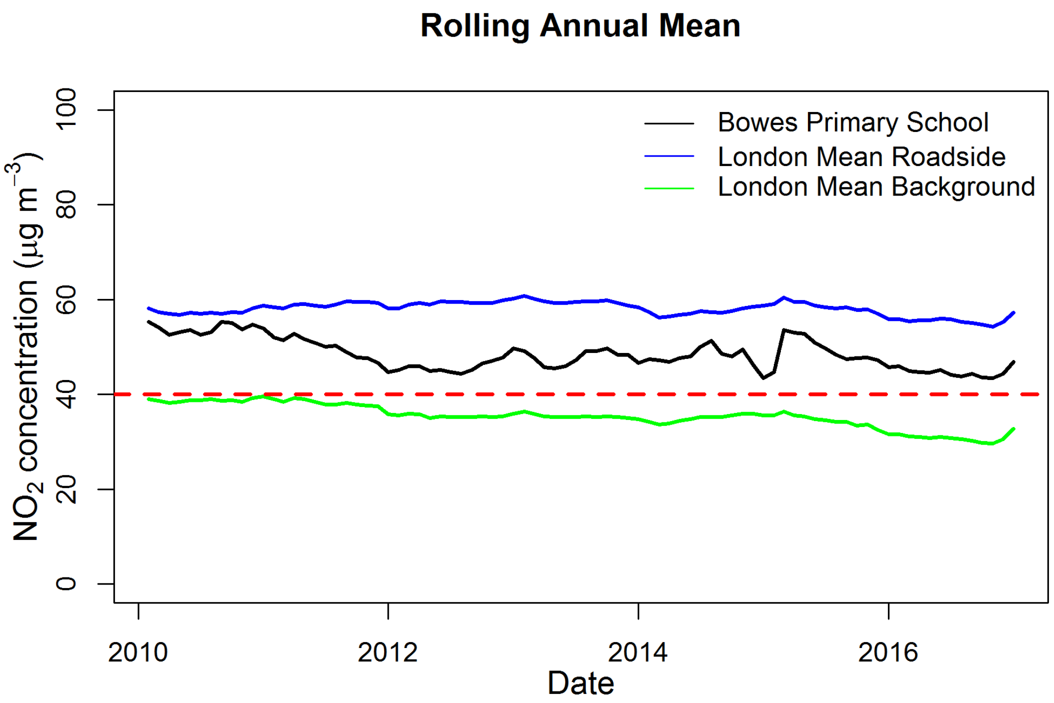

Figure 2: Rolling annual mean NO_2 concentrations (μgm^{-3}) at Bowes Primary School (includes periods of low data capture) in comparison to London Mean Roadside and London Mean Background concentrations

2 Methods

2.1 Measurement configuration

The primary data source were two air pollution monitors installed at Bowes Primary School (Figure 3 and Figure 4) for the duration of this study. The monitors were installed for four months in 2014 (21st Jul to 21st Nov) and again for 8 months in 2016/17 (5th Aug to 6th Apr). One station was located on the North Circular Road side of the screen to measure the roadside concentrations; the second station was located 1 m away from the screen inside the school grounds in order to measure the concentration in an area used by the school and nursery children.

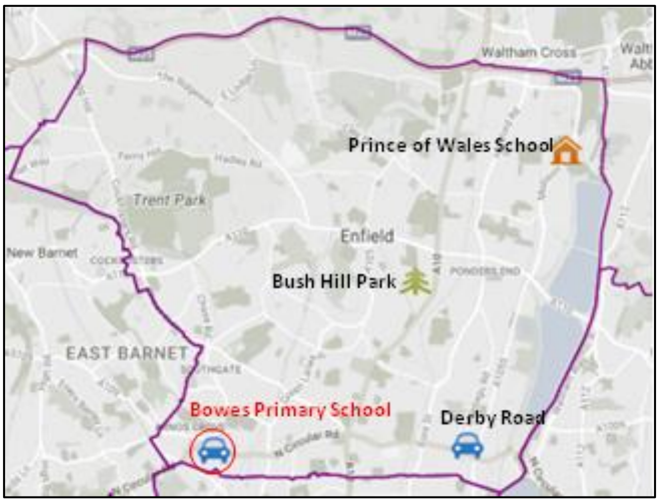

Figure 3: Locations of the Bowes Primary school monitoring stations and further stations in Enfield (Derby Road, Prince of Wales School and Bush Hill Park)

Additionally, in order to provide a comparison, the mean roadside and mean background concentrations are used. These mean concentrations are calculated using all roadside and background monitoring stations available on the LAQN and therefore serve as a general guide to current concentrations found within London.

Two chemiluminescence NO_X analysers (ML9841B) were used to assess the difference in NO_2 concentration between the roadside and playground as the screen matured. NO_2 data were ratified to LAQN and AURN quality assurance and quality control standards using calibration standards traceable to national and international standards and employing independent audits by the National Physical Laboratory.

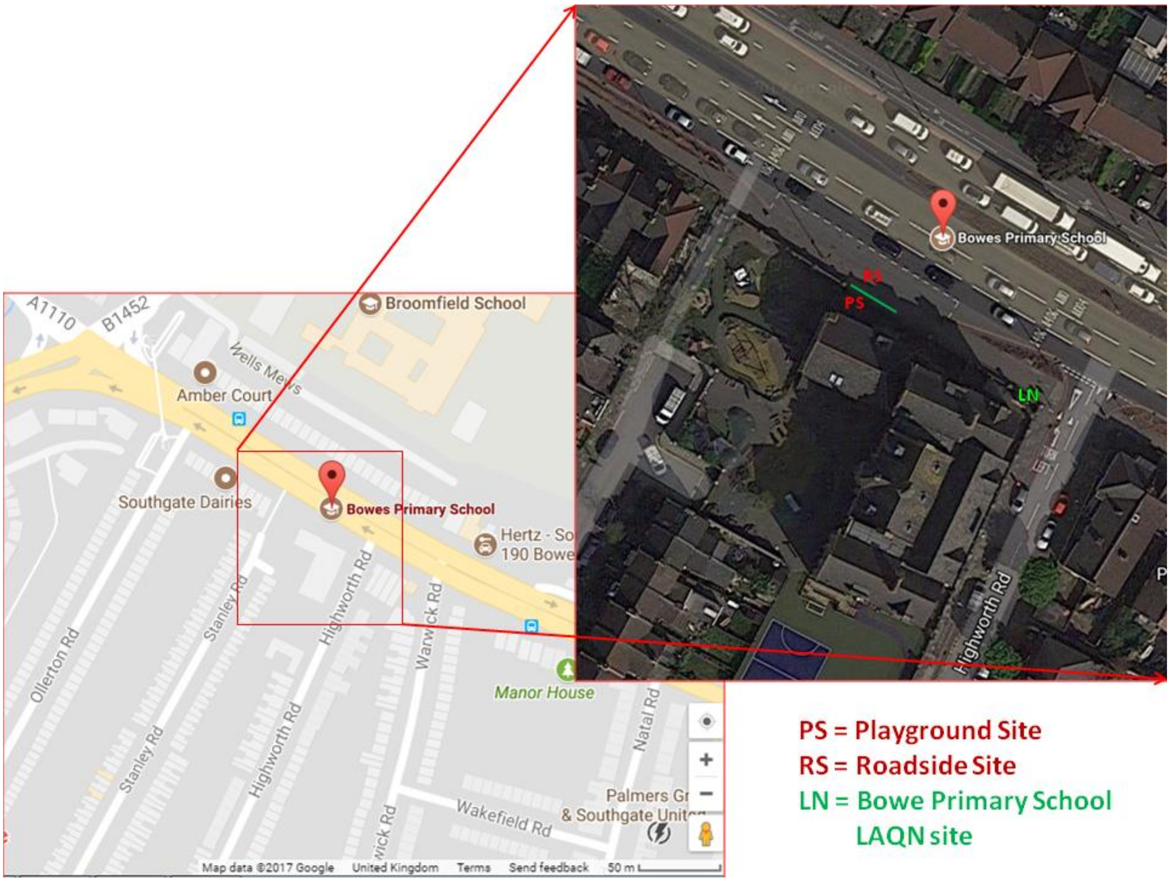

Figure 4: Location of Bowes Primary School and the location of the green screen monitoring sites and LAQN site in the school

Data analysis was undertaken on hourly mean concentrations; a valid hourly concentration was only calculated when 3 valid fifteen-minute means were available. The pollution increment was calculated by subtracting the playground concentrations from the roadside concentrations measured at the same time. Synoptic London meteorological data was used in the analysis; this is a "typical" meteorological data set representing London, which is a composite of data from several instruments co-located with air pollution monitoring sites in the LAQN (Carslaw, 2013). At the start and end of the measurement programmes, and additionally once during the 2016/17 measurement programme, the sample inlets were co-located at the roadside location. This enabled a comparison of the performance relative to each other so that their relative measurement uncertainty could be calculated. Reduced major axis regression analysis (RMA) was undertaken in MS-Excel 2010 using Model 2- Reduced Major Axis. Other analyses used R and the Openair function package within R (Carslaw et al, 2013).

Figure 5: Monitoring station and inlets situated on the playground side of the green screen (left) and the roadside of the screen (right)

3 Results and Discussion

The instruments were first installed in July 2014 and operated until November 2014. However, due the co-location of the monitors for quality assurance, the measurement data spanned 7th Aug 14 to 30th Oct 14. The first 3 weeks were considered a “pre-screen” period as the ivy was installed at the end of August. 1st Sep to 3rd Oct was considered “pre-growth” period during which the impact of the ivy screen was considered to be present but low.

A follow up study was carried out between 5th Aug 14 and 6th Apr 17 when the ivy screen had matured. As in the previous period co-location exercises were carried out at the start and end of the measurement period and additionally in Jan/Feb 2017. During the follow up study the analysers had to be switched off for a period of time due to the breakdown of the air-conditioning unit in the cabinet. Thus the time considered for data analysis were 11th to 18th Aug 2016, 06th Dec 16 to 15th Jan 17 and 07th of Feb to 28th Mar 17.

3.1 Co-location and analyser comparison

As stated in the methods section the instruments were co-located for periods of time in order to quantify the measurement uncertainty. Figure 6 shows the results of regression analysis on the daily mean measurements from the two analysers for NO_2. The co-location exercise and regression of the data revealed that there was a small systematic under-read of the roadside NO_X analyser in comparison with the background. The analysis for NO_2 resulted in a slope of 1.05 (±0.04), and an intercept of +0.14 (±1.25) ppb.

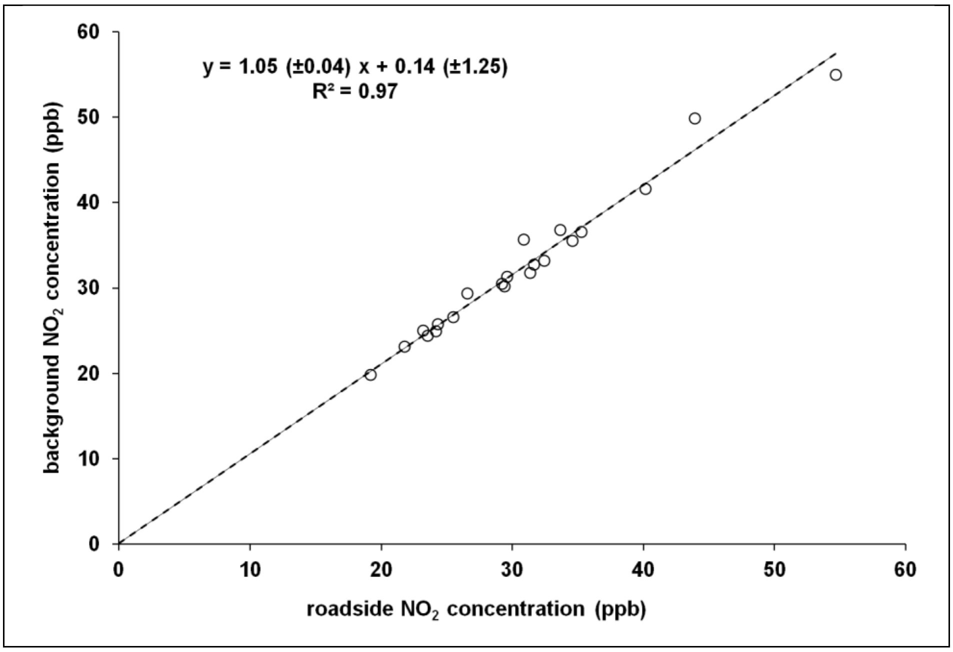

Figure 6: Scatter plot for daily NO_2 concentration from the two analysers

The co-location analysis contained measurements from all co-locations undertaken and the consistency between the periods and resulting high coefficient of determination (R^2=0.97) ensures a great deal of confidence in correcting for the systematic bias. To do this, the concentrations of the instruments were corrected using the regression slope and intercept of the hourly instrument measurements in comparison to the mean of the two co-located measurements. All further analysis was carried out on these corrected concentrations.

The calculated between sampler uncertainties are given in Table 1 and are a measure of the sensitivity / detection limit of the experiment. Therefore, when comparing measurements between the analysers, any change induced by the ivy screen would need to be greater than the relevant expanded between analyser uncertainty to be considered significant.

Table 1: Between sampler uncertainties for hourly and daily mean concentration from the paired analysers at Bowes Primary School

	NO_2 (%)
Hourly Between Sampler Expanded Uncertainty	5.7
Daily Between Sampler Expanded Uncertainty	4.8

3.2 Overview of monitoring data

The data were analysed only for periods where both of the paired instruments were producing valid data. The mean and median concentrations of NO_2 in the 2014 (pre and post screen installation) and 2016/17 monitoring periods are given in Table 2 and show that the mean, as well as the median roadside concentrations were higher in all cases. This is probably due to the distance of the road and the resulting gradual decrease of concentrations due to dispersion and dilution; even without the screen.

Means provide the information necessary to assess regulatory targets (e.g. the 40 µg m^{-3} annual mean limit value) but can be heavily influenced by a small number of high concentrations. However, medians provide a better descriptor of the data populations that are log normally distributed; like air pollution concentrations.

	Site	NO_2 Concentration (µgm^{-3}) Median	Mean
2014 (pre screen)	Roadside	53.6	53.5
	Background	50.6	51.5
	Increment	*1.9*	*2.1*
2014 (pre growth)	Roadside	64.3	64.4
	Background	60.3	60.0
	Increment	*3.9*	*4.3*
2016/17 (mature screen)	Roadside	66.8	68.2
	Background	51.3	53.2
	Increment	*14.0*	*15.0*

Table 2: Summary of pollution concentrations at Bowes Primary school

Assuming the analysis periods were representative of the entire year, the annual mean air quality objective would not have been met for any of the periods and locations for NO_2. The measurement periods were relatively short and thus may not be representative of a whole year. However, exceedance of the annual mean would be expected as the Bowes Primary School LAQN monitoring site has measured NO_2 concentrations above the annual limit value for the last 5 years (see Figure 2). The hourly mean limit value cannot be assessed using short term measurement as produced in this project.

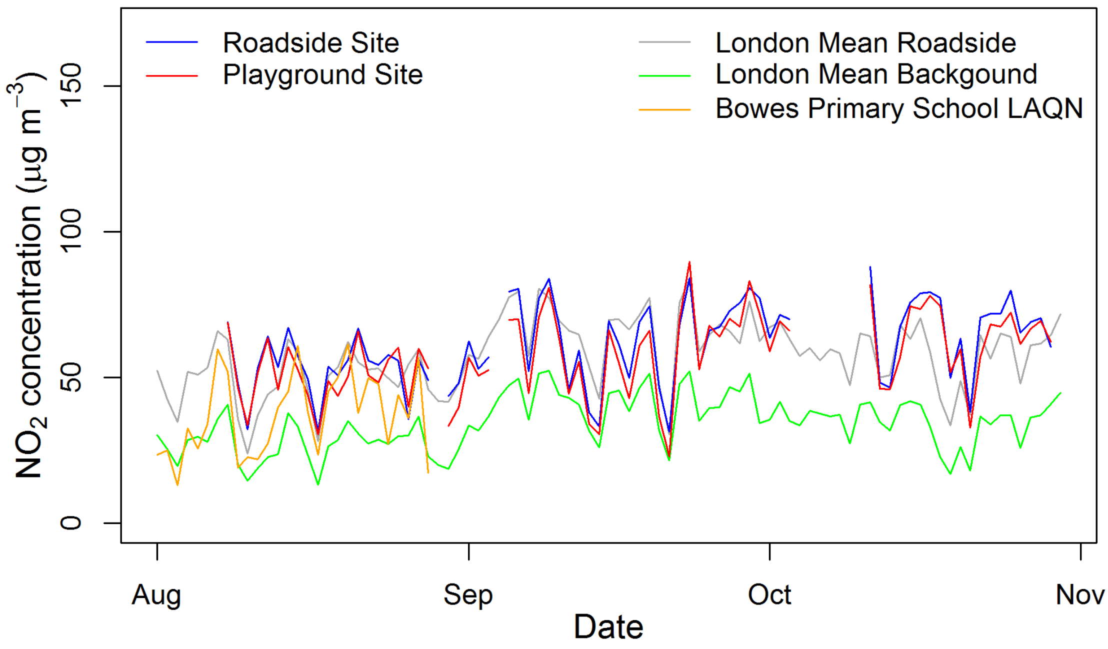

Figure 7: Time series plot of NO_2 (ppb) concentrations at the roadside and playground side of the green screen in comparison to London Mean Background and London Mean Roadside in 2014

The time series of the NO_2 data are shown in Figure 7 and Figure 8 for 2014 and 2016/17, respectively. The highest NO_2 concentrations could be observed at the roadside site in episodes in December 2016/January 2017. The lowest concentrations were seen at the start of the monitoring period in 2014 and the final period in 2017. Higher concentrations are generally observed during winter periods due to a lack of dispersion caused by colder weather.

Comparing the playground and roadside concentrations measured at the school to the London Mean Roadside and London Mean Background, it was found that the concentrations at the Bowes Primary School were comparable to the London Mean Roadside concentrations for the measurement periods in 2014. In the period 2016/17 the Bowes Primary School roadside concentration was above the London Mean Roadside concentration for most periods, whereas the Bowes Primary School background concentration remained comparable to the London Mean Roadside concentration.

It was difficult compare the playground and roadside concentrations to the Bowes Primary School LAQN site as during the 2014 sampling period data from the Bowes Primary School LAQN site were only available for the pre-screen period, during which the LAQN site concentrations were lower than those found at either of the green screen sites. During the 2016/17 period, the Bowes Primary School playground site was comparable to the Bowes Primary School LAQN site, but the roadside concentration was higher than both. The differences seen from the green screen site to the LAQN site are likely due to the different locations.

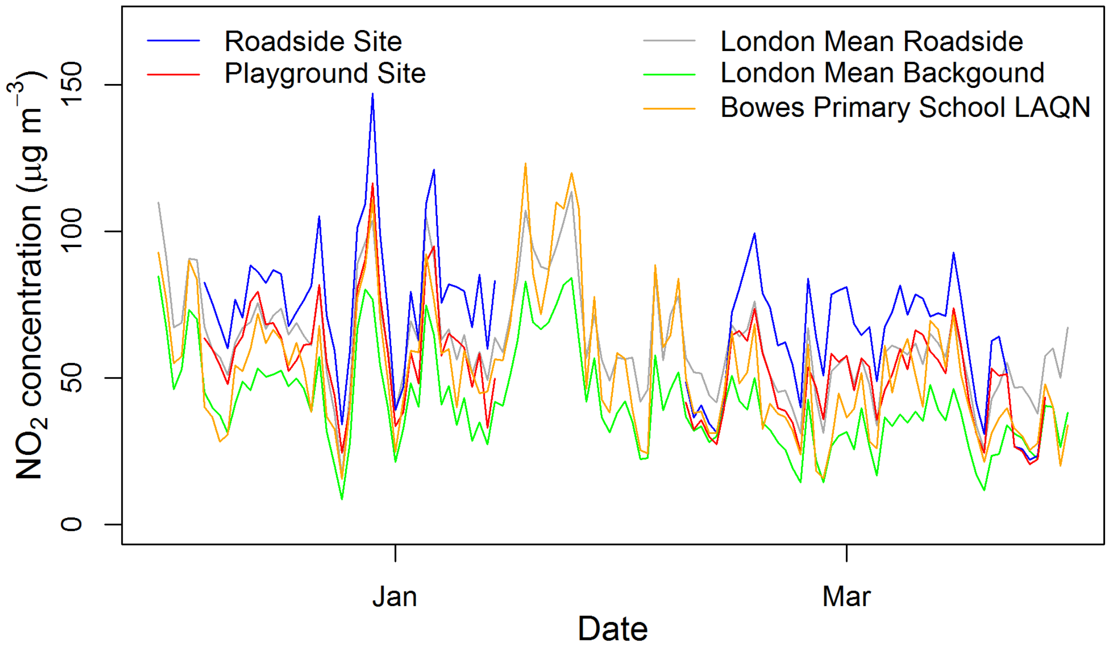

Figure 8: Time series plot of NO_2 (ppb) concentrations at the roadside and playground side of the green screen in comparison to London Mean Background and London Mean Roadside in 2016/17 (plot does not include August 2016)

3.3 Influence of wind speed and wind direction

Bivariate polar plots are used to highlight the relative influence of local sources to pollution; they show a smoothed concentration surface in relation to wind speed (radial axis) and wind direction (polar axis). Their use in characterising ambient air pollution sources is described in Carslaw *et al.* (2006). Polar plots for both sites were produced for the median NO_2 concentrations. When interpreting such plots it is important to consider that the predominant wind direction (Barratt et al., 2012) for this site is south-westerly as shown in Figure 9, thus sources from this direction will have a much greater impact than other sources.

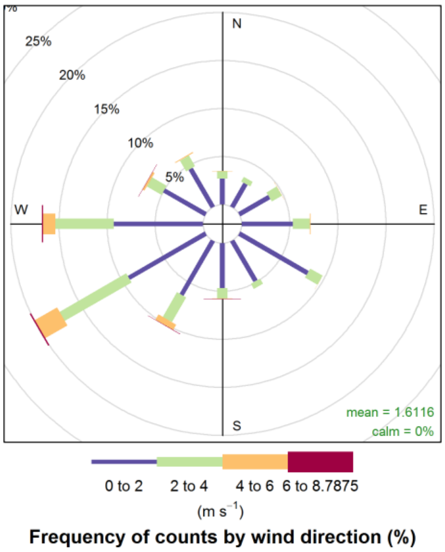

Figure 9: Wind rose for London mean meteorological data between 2014 and 2017

The bivariate polar plots of NO_2 concentrations measured by both instruments are shown in Figure 10. This demonstrates that the NO_2 concentrations were highest during south-south-westerly winds for both instruments rather than from the road, which runs along the north-west/south-east transect. This may be due to local micro-meteorological conditions recirculating wind from the road back onto the measurement site. Closer examination of the roadside polar plot in the areas close to the centre shows higher concentrations to the north-west and south-east. These directions are perpendicular to the road axes suggesting that pollution levels were generally highest when emissions were blown from the North Circular towards the school. The impact of these sources, especially that from the north west, were diminished in the playground instrument.

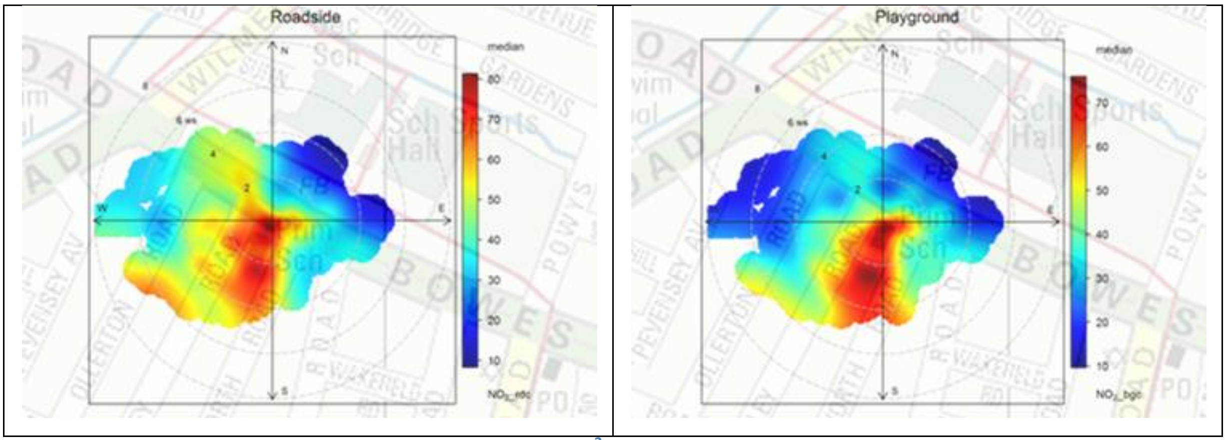

Figure 10: Bivariate polar plot of the median NO_2 (μgm^{-3}) concentrations at the roadside site and playground site by wind speed and direction for all monitoring periods

To illustrate how the green screen influenced the impact of the local pollution sources in more detail, the pollution increment was calculated by subtracting the playground concentrations from the roadside concentrations and bivariate polar plots were produced for the sampling periods in 2014 and 2016/17 (Figure 11).

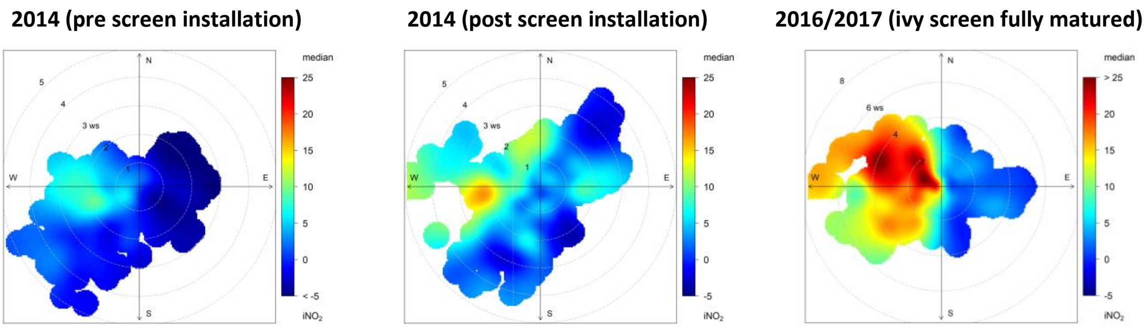

Figure 11: Bivariate polar plot of the median NO_2 (μgm^{-3}) concentration increment by wind speed and direction for 2014 pre screen installation (left), 2014 post screen installation (centre) and 2016/2017 (right) monitoring periods

Before the ivy screen was installed the increment was relatively uniform in all directions (± 5µg m^{-3}) although an overall positive increment was observed due to the dilution and dispersion effects of measuring further away from the road. This was enhanced during westerly winds, possibly due the sheltering effect of a nearby wall on the playground instrument. After the screen installation there was a positive increment in from westerly and northerly winds at all wind speeds, at wind speeds about $1ms^{-1}$ from easterly winds and at very low wind speeds ($<1ms^{-1}$) from all wind directions. After the screen has matured (2016/2017) this increment was more pronounced, thus showing the positive effect of the screen.

Before the screen had matured a negative increment could be detected for about a quarter of the measurements (26%), thus during these periods the concentrations were higher in the playground site than the roadside site. This was mainly the case when the wind direction was from the north east or south east. After the screen had matured this negative increment was only experienced during 2% of the measurements, thus further showing a clear benefit of the screen.

3.4 Concentration difference between roadside and playground

Figure 12 shows monthly box and whisker plots of the daily mean concentration difference in % for NO_2. Also indicated is the between sampler uncertainty calculated using the co-location data.

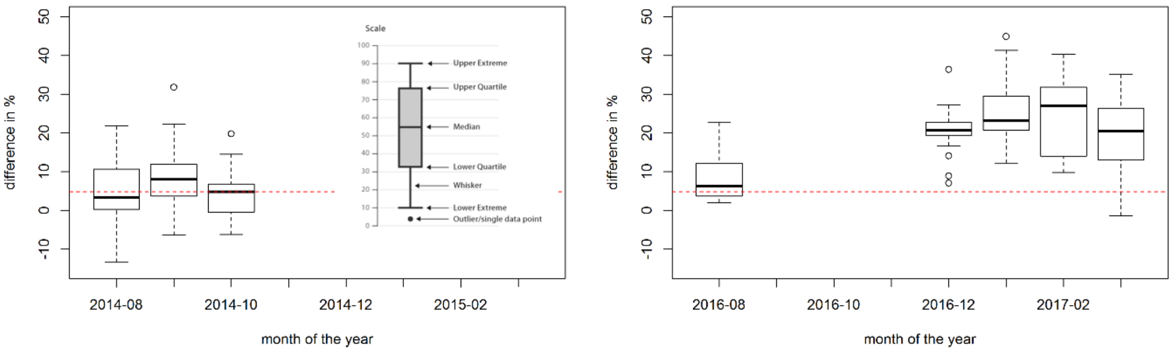

Figure 12: Monthly box and whisker plots of daily mean NO_2 concentration difference (%) in 2014 (left) and 2016/17 (right) in comparison to the daily between analyser uncertainty (dashed line) with general box and whisker plot inset.

For the first month in 2014 the daily NO_2 concentration difference between the two sites was on average 4.6% (median 3.3%). As this was the period before the screen was installed, this can be attributed to dilution caused by the difference in the distance from the road. After the screen was installed the daily mean concentration difference was 8.1% (median 8.0%) for September and 4.2 % (median 4.8%) for October. This difference likely reflects the effect of the immature green screen, which blocked the transport of some of the pollutants into the playground, plus the distance from the traffic emissions of the background instrument (Figure 13). After the ivy matured, the daily mean concentration difference between the two sites increased to 9.9% (median 7.7%) in August 2016. From December 2016 to March 2017 the daily mean NO_2 concentration difference increased to an average of 21.8% (median 21.3%).

Figure 13: Green screen on installation (left) and after growth period has started (right)

At the start of the study, the mean difference between the instruments was generally less than the instrument uncertainty. It was not until the second period of study, when the screen had matured, where the majority of the measurements were greater than the instrument uncertainty.

3.5 Temporal variation in NO_2

The diurnal and weekly variation of the pollution concentrations were plotted for the pre screen period, which was before the ivy screen was installed (1st Aug to 28th Aug), the post installation period in 2014, which was after the screen was installed but still not matured (28th Aug to 30th Oct) and during the period when the ivy screen had fully matured (7th Aug'16 to 30th Mar'17; Figure 14).

The NO_2 concentrations showed a clear diurnal cycle with pronounced morning and evening rush hour peaks. The highest concentrations were during the morning rush hour in the pre-screen period and during the evening rush hour in both post screen installation periods with concentrations remaining elevated throughout the day in all periods. The lowest concentrations can be found in the early morning hours. There is also a weekly pattern with Sunday showing lower concentrations than weekdays and Saturdays.

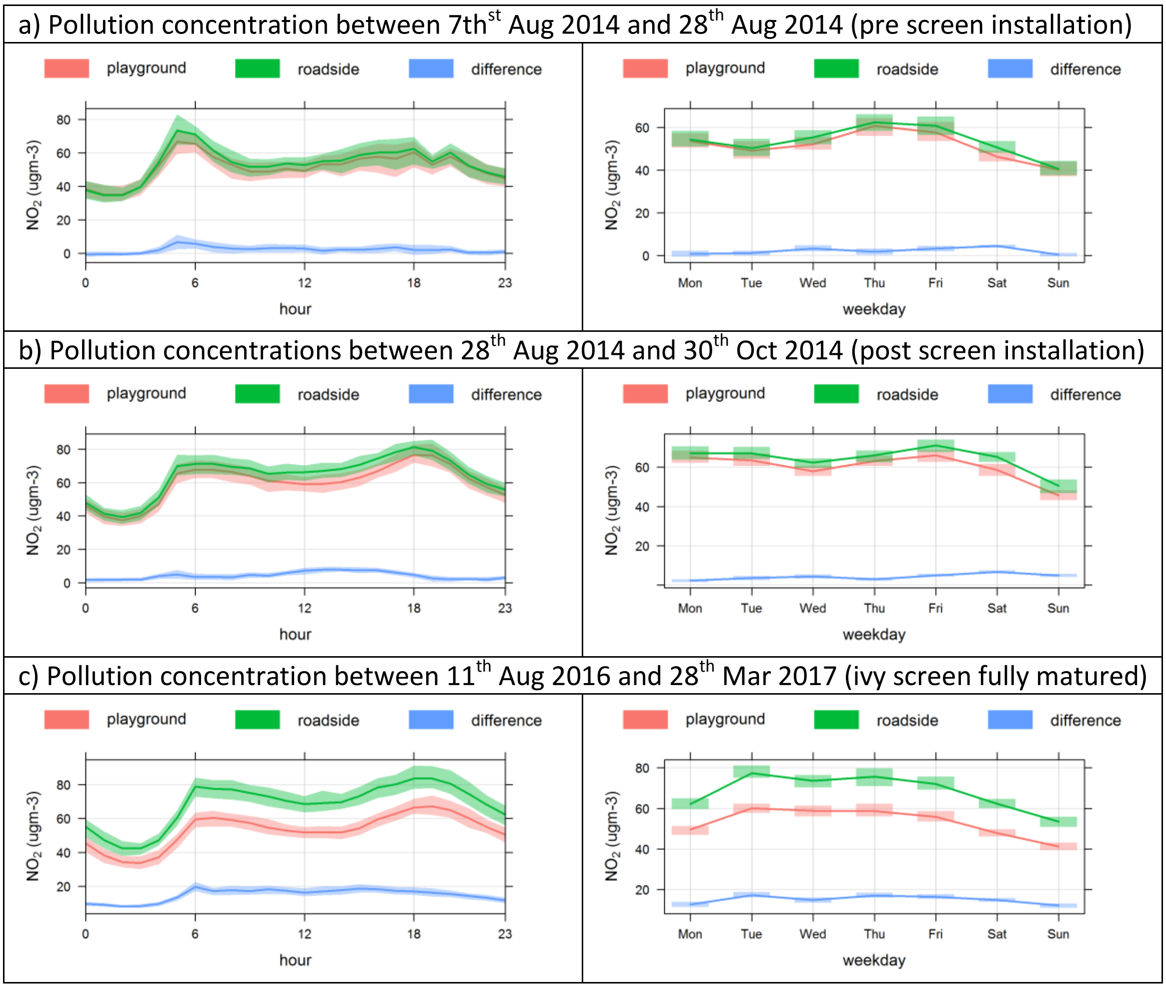

Figure 14: NO_2 diurnal and day of week plots

When comparing the three periods, it is noticeable that the NO_2 concentration difference between the sites increased markedly after the screen matured.

Examining the diurnal variations, NO_2 concentrations were higher during the daytime when children were in the school. To quantify the effect the screen had on the exposure of the children, the pollutant concentrations in the three periods were calculated for daytime hours (08:00-16:00) of weekdays only (Table 3). A trend can be seen in the concentration difference as the screen matures, with a fully matured screen leading to an average concentration decrease of 22.5% (median 22.2%) for NO_2 at the background side of the screen.

Time period	Roadside Site	Playground Site	Difference	
	NO_2 in μgm^{-3}		Increment	Mean %
Pre-screen Installation	58.6	58.4	2.5	3.8%
Immature screen	70.6	67.9	5.5	7.8%
Mature screen	75.2	59.6	18.3	22.5%

Table 3: Roadside and background NO_2 pollution concentrations during school hours (09:00-16:00) for the period pre-screen installation, with an immature screen and after the ivy screen has fully matured

4 Conclusions

NO_2 was measured at roadside and playground location at Bowes Primary School, Enfield before and after the installation of an ivy screen to assess the efficacy of a green screen to prevent the transport of vehicle emissions from the nearby road into the playground. The experimental design included periods of co-location which allowed an assessment of the uncertainty in the measurements so that any effect of the ivy screen could be deemed significant, or not. Furthermore, this allowed any biases between instruments to be corrected to ensure that any efficacy derived was independent of individual instrument anomalies. The consistency between all co-location assessments and the high correlation of determination values demonstrated that this was a robust approach.

Overall the concentration at the roadside monitoring site was higher than that measured at the playground monitoring site. The screen was found to be an effective pollution barrier once the ivy had started growing and a significant impact could be seen once the screen had matured. As the ivy screen matured concentrations measured in the playground reduced relative to the roadside at all wind speeds from south-westerly/westerly and north-westerly winds. This led to a decrease in the daily NO_2 concentrations on the playground side of the screen by 15 $\mu g\ m^{-3}$ (21.8 %). Comparing school hours independently a mean reduction in hourly NO_2 concentrations of 18.3 $\mu g\ m^{-3}$ (22.5 %) was found. Both these values were higher than the measurement uncertainty of 4.8% and was therefore significant. This demonstrates that the screen is very effective in reducing pollution, especially during daytime hours, when both emissions and exposure are highest.

Unfortunately, the annual mean air quality objective would not have been met on either side of the screen for NO_2; assuming that the analysis periods were representative of an entire year. Therefore, further vehicle emissions abatement, in addition to these local measures, would be required to reduce concentrations below the EU Limit Value at the playground.

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