Impact of green screens on concentrations of particulate matter and oxides of nitrogen in near road environments

Prepared for the Royal Borough of Kensington and Chelsea

February 2015

Anja H. Tremper, David C. Green, Davene Chatter-Singh and Kyri Eleftheriou-Vaus

Environmental Research Group

King's College London

Title	Impact of green screens on concentrations of particulate matter and oxides of nitrogen in near road environments

Customer	The Royal Borough of Kensington and Chelsea

Customer Ref	

File Reference	

Report Number	

Environmental Research Group
King's College London
4th Floor
Franklin-Wilkins Building
150 Stamford St
London SE1 9NH
Tel 020 7848 4044
Fax 020 7848 4045

	Name	Signature	Date
Lead Author	Anja Tremper		
Reviewed by	David Green		
Approved by	Gary Fuller		

Summary

Research on urban vegetation suggests that it can help reduce the impact of pollution on people and buildings by acting as a pollution sink, especially for particles. 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 St. Cuthbert with St. Matthias Primary School in the Royal Borough of Kensington and Chelsea. NO_X and PM_{10} were then measured immediately either side of the screen using two standard chemiluminescence NO_X analysers and two Turnkey Osiris light scattering PM analysers, respectively. The difference in concentration between the roadside side and playground side of the screen was assessed as it matured.

To quantify the measurement uncertainty, the instruments were co-located at the start and the end of the programme. This data was used to correct for systemic biases and to calculate a daily between sampler uncertainty, which was 7.2% for NO_2 and 15.2% for PM_{10}.

Highest concentration could be observed during September for NO_2 and in March and September/October for PM_{10}. Annual mean air quality objective would not have been met on either side of the screen for NO_2 assuming that the analysis period is representative of the entire year. The average PM_{10} concentration was below the annual mean objective; this is with the significant caveat that the PM_{10} measurement methodology is not equivalent. NO_2 and PM_{10} concentrations rise during morning rush hour and remain elevated throughout the day. The concentration difference between the sites also remains highest throughout the daytime period.

NO_2 and PM_{10} source directions are aligned with the road axes suggesting that pollution levels were generally highest when emissions were either recirculated from the A3220 (northbound) or blown along the road from sources on northbound A3220, old Brompton Road and southbound A3220.

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. The ivy screen led to a decrease in the pollution concentrations on the playground side of the screen by 24% for NO_2 and 38% for PM_{10}; both were higher than the measurement uncertainty and thus significant. Comparing school hours independently a reduction in concentrations of up to 36% and 41% were found for NO_2 and PM_{10}, respectively. This demonstrates that the screen is very effective during daytime hours, when both emissions and exposure are highest.

Although it is clear that the screen has a significant effect in preventing the transport of pollution from the roadside into the playground, further work would be required to assess the impact of the screen at greater distances from the road.

This page is left intentionally blank

Contents

1 Introduction

The concentration of toxic air pollutants such as nitrogen dioxide and particulate matter are elevated close to roads in London, these have been shown to have detrimental health effects including increased cardio-pulmonary and lung cancer mortality and increased risk of respiratory symptoms (WHO, 2003). Many of these effects are more enhanced in sensitive populations, such as children. Indeed, exposure to PM has been shown to negatively affect the development of the lung function in elementary schoolchildren (Horak Jr. et al. 2002). Many schools in London and in the Royal Borough of Kensington and Chelsea (RBKC) 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 nitrogen dioxide, remain high close to roads. Alternative methods to reduce human exposure, in particular for the sensitive populations such as children, are therefore being sought.

One such method is the installation of green screens to act as a barrier to the transfer of polluted air. Research on urban vegetation suggests that it can help reduce the impact of pollution on people and buildings by acting as a pollution sink, especially for particles. 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 hypothesis was that a green screen will have a beneficial effect on the PM and NO_X concentrations inside the school grounds. To assess the efficacy of a green screen to prevent the transport of vehicle emissions from the nearby road into the playground, 51m of ivy screen were installed at St. Cuthbert with St. Matthias Primary School in the London Borough of Kensington and Chelsea (Figure 1). This had the effect of increasing the existing roadside barrier from around 2m to 2.7m high. The primary school was chosen due to its location close to a busy road (A3220), with the main playground area adjacent to that road (Figure 3). PM_{10} and NO_X were then measured immediately either side of the screen. Data was collected as the screen was growing and thus the impact of the screen could be monitored during the maturing of the ivy screen.

2 Methods

2.1 Measurement configuration

The primary data source for this study were the temporary monitoring stations at St. Cuthbert with St. Matthias primary school (Figure 2, Figure 3). The stations were installed for the duration of one year (November 2013-November2014) and were situated along Warwick Road (A3220), either side of an ivy screen. One set of analysers was inside the school grounds in order to measure the concentrations on the playground side of the screen and the other set of analysers was situated on the outside of the green screen to measure the roadside concentrations.

Figure 2: Locations of the Earl's Court Road kerbside monitoring station and the North Kensington background monitoring site.

Additionally, in order to provide a comparison, North Kensington and Earl's Court Road monitoring site data were used as comparison sites .The North Kensington monitoring station, a background site, is situated in a school yard in the north of the borough. The Earl's Court Road monitoring station, a kerbside site, is situated on the southern end of Earl's Court Road, between the Braham Gardens and Bolton Gardens (Figure 2).

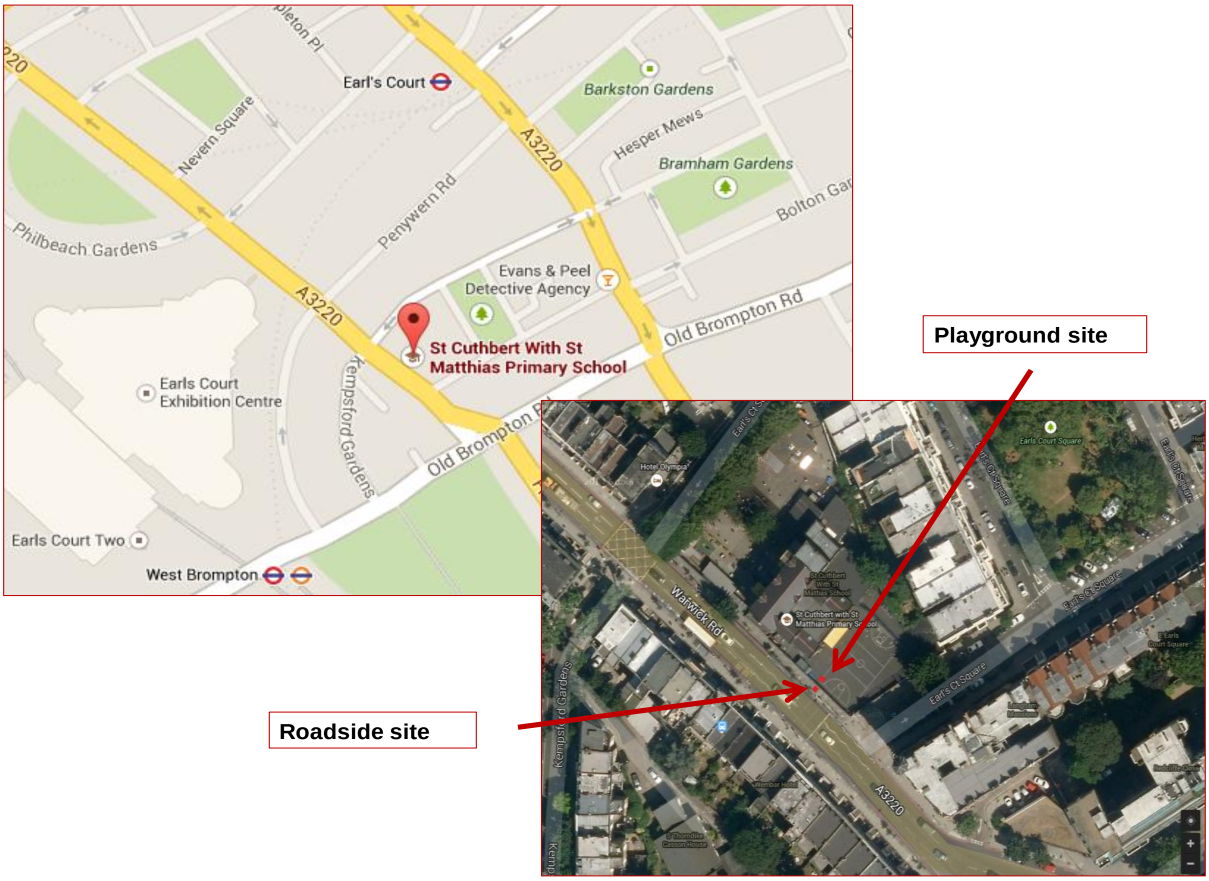

Figure 3: Location of St. Cuthbert with St. Matthias primary school and the location of the monitoring sites in the school

Two standard chemiluminescence NO_X analysers (ML9841) and two Turnkey Osiris light scattering PM analysers were used to assess the difference in concentration between the roadside side and playground side of the screen as it matured. The Osiris instrument was chosen as space was limited and the experimental design dictated that the inlets were placed either side of the screen; however this instrument is indicative and is not equivalent to the EU reference measurement for either PM_{10} or $PM_{2.5}$. Nevertheless, as percentage differences are used to analyse the impact of the green screen, this does not detract from the final conclusions. NO_X data were ratified to LAQN and AURN QA/QC standards and PM data were ratified using instrument calibration and regular flow checks. The North Kensington and Earl's Court Road data were preliminary and not yet fully ratified.

All data analysis was undertaken on hourly mean concentrations containing at least 3 valid fifteen-minute means. "London Mean" 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 (Carslaw, 2013). At the start (NO_X only) and end of the measurement programme the analysers were co-located so that a between instrument uncertainty could be calculated. Orthogonal regression analysis was undertaken and graphed using MS-Excel 2010. Other analyses utilised R statistical software and the Openair function package within it (Carslaw et al, 2013).

Figure 4: Osiris analyser and NO_X inlet situated on the playground side of the green screen

3 Results and Discussion

The instruments were installed in November 2013, however, it took some time to undertake a co-location exercise and ensure that both pairs of instruments were working correctly. The main time periods considered for the data analysis were between the 1st Feb 14 to 22nd Sep 14 for the NO_2 and between 1st Jan 14 to 30th Oct 14 for PM_{10}.The first three months of the year were considered as a "pre-growth" period, during which the impact of the ivy screen was considered to be low.

3.1 Co-location and analyser comparison

As stated in the methods section the instruments were co-located for a short period of time in order to quantify the measurement uncertainty. Figure 5 shows the results of orthogonal regression analysis on the daily mean measurements from the two analysers for NO_2 and PM_{10}. The NO_X analyser co-location analysis contained measurements from co-locations undertaken both before and after the trial; the consistency between the pre and post periods offers a great deal of confidence in this result. PM_{10} co-location data was only available for a period after the study.

The co-location exercise and orthogonal regression of the data revealed that there was a systematic over-read of the roadside NO_X analyser in comparison with the background. The analysis for NO_2 results in a slope of 0.83 (±0.02), and an intercept of +0.75 (±0.4) ppb. The regression analysis for PM_{10} results in a slope of 1.08 (±0.06), and an intercept of -1.15 (±1.52) μgm^{-3}. Hence, in the case of the Osiris analysers there was a small systematic under-read of the roadside instrument compared to the background instrument.

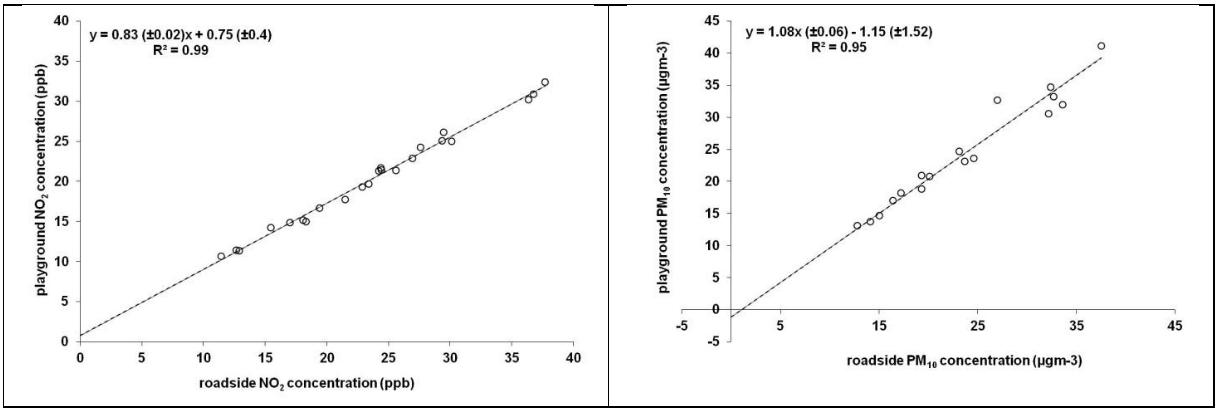

Figure 5: Scatter plot for NO_2 (left) and PM_{10} (right) concentration from the two analysers

The coefficient of determination (R^2) is very high for both (0.99 for NO_2 and 0.95 for PM_{10}) and ensures a great deal of confidence in correcting for these systematic biases. To do this, the concentrations of the instruments were corrected using factors derived from orthogonal regression of the 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.

	NO_2 (%)	PM_{10} (%)
Hourly Between Sampler Expanded Uncertainty	8.1	16.4
Daily Between Sampler Expanded Uncertainty	7.2	15.2

Table 1: Between sampler uncertainties for hourly and daily mean concentration from the paired analysers at St. Cuthbert with St. Matthias primary School

3.2 Overview of monitoring data

When comparing between instruments of the same type, the data were analysed only for periods where both of the paired instruments were producing valid data. Therefore NO_2 data were analysed between the 1st Feb and 22nd Sep 14 and PM_{10} data were analysed between 1st Jan and 31st Oct 14. The mean and median concentrations of NO_2 and PM_{10} are given in Table 2 and show that the mean, as well as the median roadside concentrations were higher for both pollutants. 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.

Pollutant	Site	Concentration	
		Median	Mean
NO_2 in ppb (µgm^{-3})	**Roadside**	34.2 (65.2)	34.7 (66.3)
	Playground	28.2 (53.9)	29.2 (55.8)
PM_{10} in µgm^{-3}	**Roadside**	28.8	32.1
	Playground	20.5	22.3

Table 2: Summary of pollution concentrations at St. Cuthbert with St. Matthias primary school

Assuming that the analysis period is representative of the entire year, the annual mean air quality objective would not have been met on either side of the screen for NO2 but was consistently below the annual mean objective for PM10. A significant caveat is that the PM10 measurement methodology is not equivalent and should therefore not be compared to the regulatory limit value.

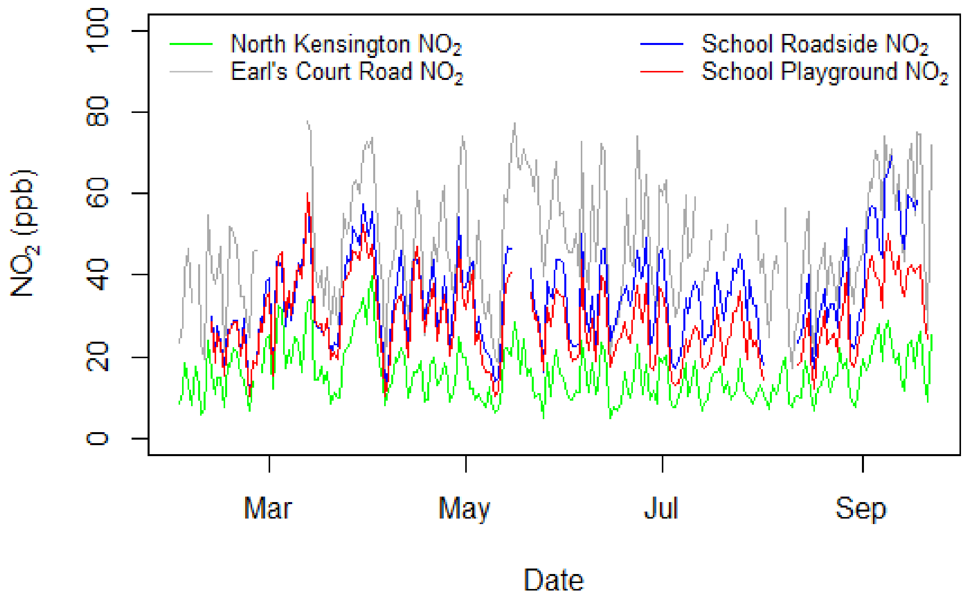

Figure 6: Time series plot of NO_2 (ppb) concentrations at the roadside and playground side of the green screen in comparison to the North Kensington background site and Earl's Court Road roadside site

The timeseries of the NO_2 and PM_{10} data are shown in Figure 6 and Figure 7, respectively. The highest NO_2 concentrations could be observed at the roadside site in September and the lowest concentrations were seen at the start of the monitoring period. Comparing the concentrations measured at the school to the North Kensington background site and Earl's Court Road roadside site, it was found that the concentrations at the school were between those measured at the background station and that measured at the roadside station.

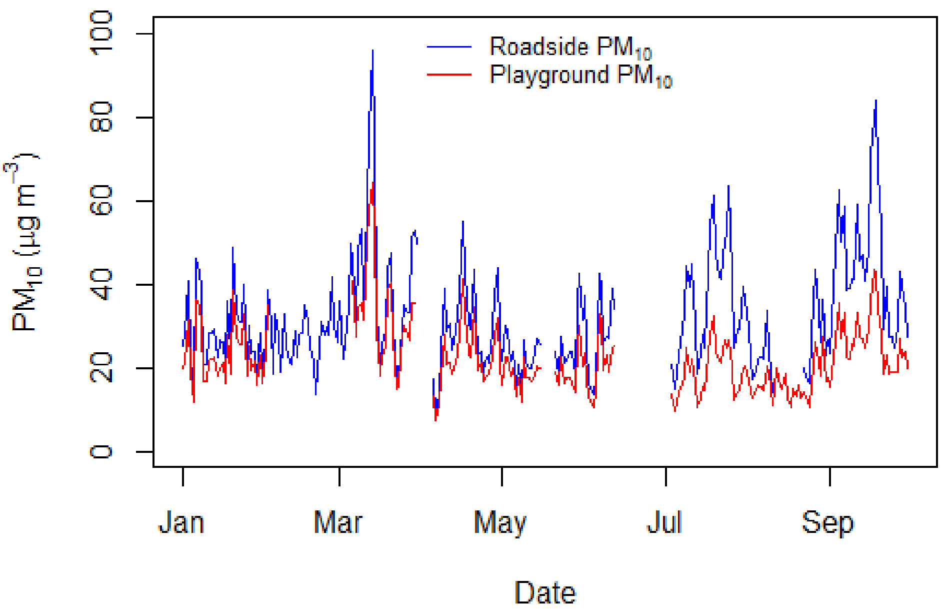

Figure 7: Timeseries plot of PM_{10} (μgm^{-3}) concentrations at the roadside and playground side of the green screen

For the PM_{10} there were clear episodes in March and September/ October and as with NO_2 the roadside concentrations were generally higher than the background concentrations. These data were not compared to other borough PM_{10} measurements as the data measured by Osiris is used for indicative purposes and it not equivalent to the EU reference measurement.

3.3 Influence of wind speed and wind direction

Bivariate polar plots were produced using the openair analysis package in R (http://www.openair-project.org/). They show a smoothed concentration surface in relation to wind speed (radial axis) and wind direction (polar axis) and were used to highlight the relative influence of local sources to pollution. Their use in characterising ambient air pollution sources is described in Carslaw *et al.* (2006).

Polar plots for both sites were produced for the NO_2 and PM_{10}. When interpreting such plots it is important to consider that the predominant wind direction for this site is south-westerly (Barratt et al., 2012), thus sources from this direction will have a much greater impact than other sources.

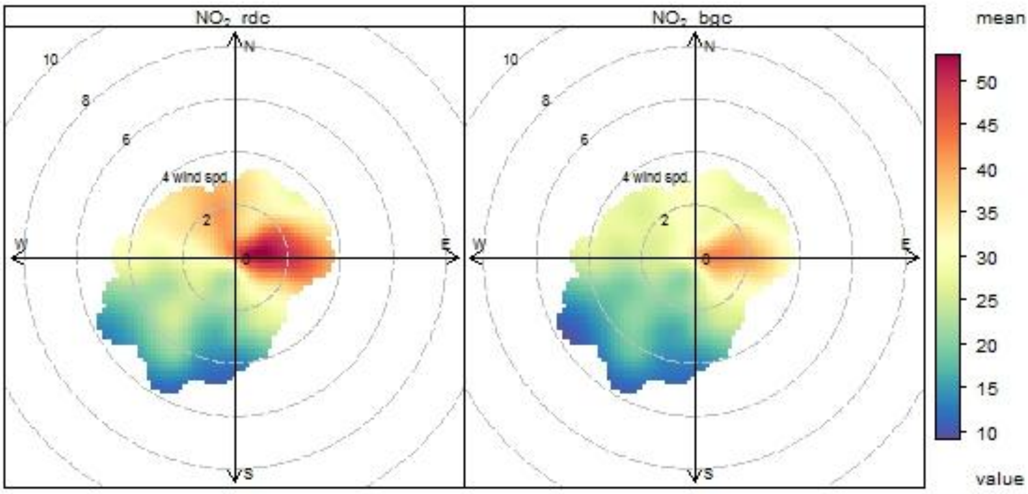

Figure 8 shows that NO_2 concentrations were highest during north-easterly and easterly winds at both sites. A secondary source could be observed for the roadside NO_2 in north-north-westerly wind direction. These directions are aligned with the road axes suggesting that pollution levels were generally highest when emissions were either recirculated from the A3220 (northbound) or blown along the road from sources on northbound A3220, old Brompton Road and southbound A3220.

There were initial concerns that the boiler within the school grounds might be a substantial source of NO_2 and, with increasing growth of the ivy screen, led to an increase in concentrations within the playground area. There is no evidence of this as the concentrations on the playground side of the screen are consistently lower than the roadside concentrations.

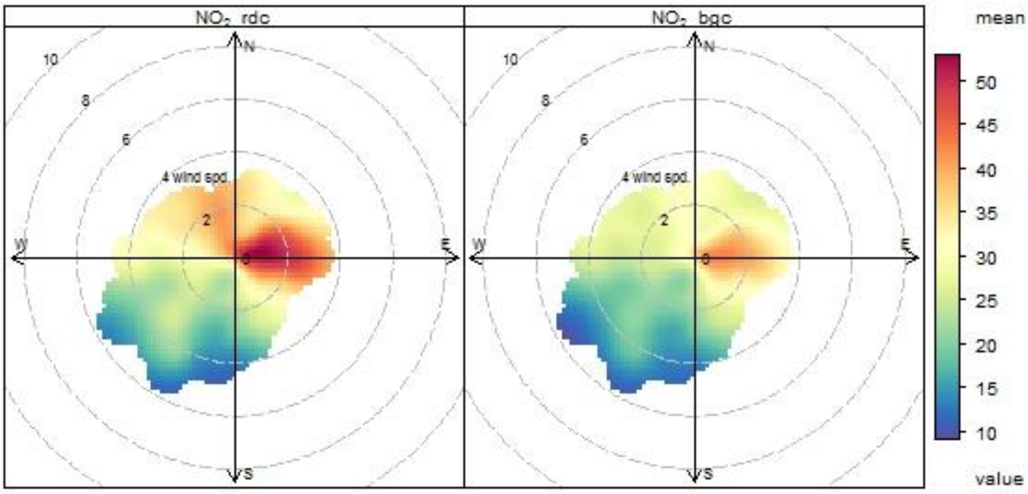

Figure 8: Bivariate polar plot of the NO_2 (ppb) concentrations at the roadside site (rd) and playground site (bg) by wind speed and direction

The pattern for PM_{10} was more complex with sources evident to the east/north-east at mostly lower wind speeds and an additional source to the south-west at high wind speeds. The source to the east/north-east is likely to be the same as for NO_2 and hence due to traffic emissions from the various roads that surround the monitoring stations. The source seen to the south-west at higher wind speeds is due to emissions a further distance away. This could possibly be also due to traffic emissions from the Old Brompton Road, other PM_{10} generation activity such as construction work or sea salt from marine sources often associated with these high wind speeds from the south west.

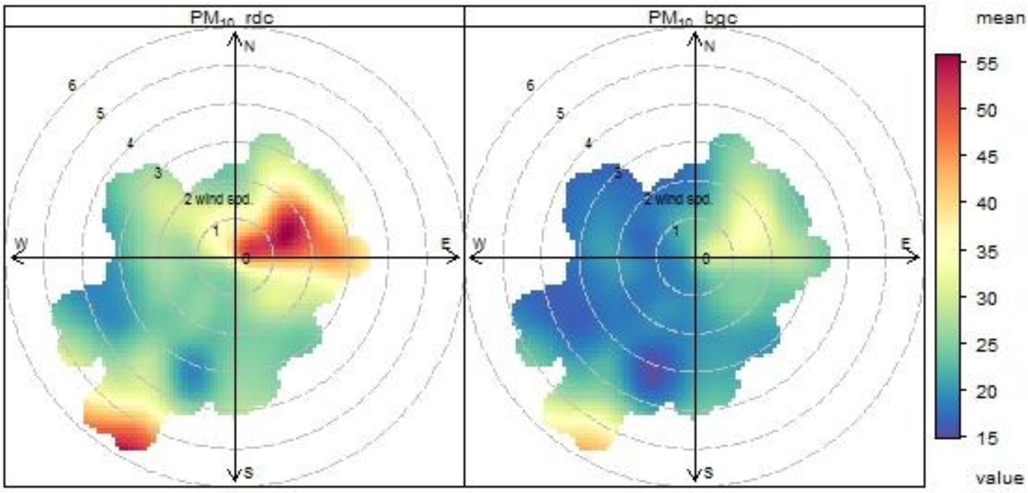

Figure 9: Bivariate polar plot of the PM_{10} ($\mu g/m^3$) concentrations at the roadside site (rd) and playground site (bg) by wind speed and direction

3.4 Concentration difference between roadside and playground

Figure 10 shows monthly box and whisker plots of the daily mean concentration difference in % for NO_2 and PM_{10}, respectively. Also indicated is the between sampler uncertainty calculated using the co-location data.

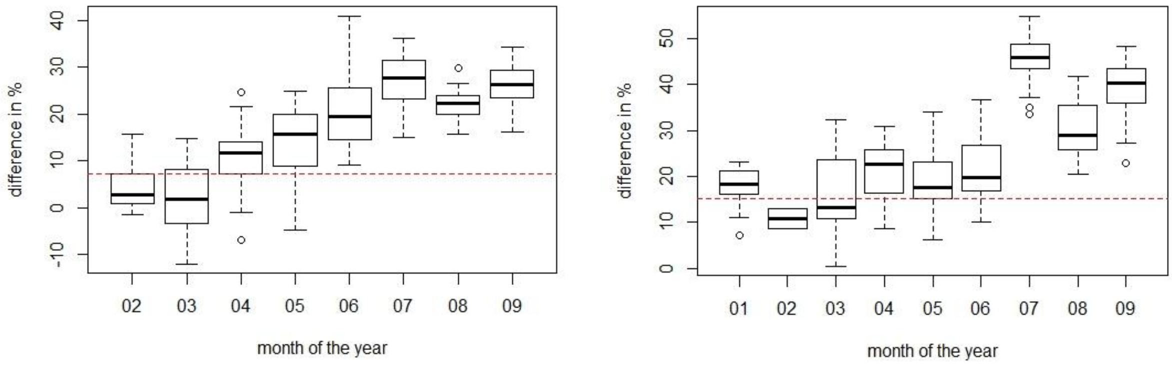

Figure 10: Monthly box and whisker plot of daily mean NO_2 (left) and PM_{10} (right) concentration difference (%) in comparison to the daily between analyser uncertainty (dashed line)

For the first two months the NO_2 concentration difference between the two sites was on average 3% and increased to 10% in April. For PM_{10}, the initial three months showed an average difference of 16%. This difference likely reflects the slightly greater distance from the traffic emissions of the playground instruments as well as the immature green screen which blocked the transport of some of the pollutants into the playground (Figure 11). Importantly, this was smaller than or around the instrument uncertainties for both pollutants, which was 7.2% for NO_2 and 15.2% for PM_{10}.

As the ivy starts to grow, however, the concentration difference between the two sites increases above level of instrument uncertainty to an average of 24% for NO_2 and 38% for PM_{10} from July to September 2014. The trend in the effect of the ivy growth is clear in the NO_2, increasing at approximately 5% per month. The trend is less clear in PM_{10}, suddenly increasing in July. PM_{10} is likely to be influenced more strongly by background concentrations which in turn are influenced by episodic event. The resuspension of material from the ivy screen itself may at times impact on PM_{10} concentrations measured on both sides of the screen. It is also possible that the effect on PM_{10} is higher as the ivy screen filters. Encouragingly, the effect of the screen is broadly similar for both NO_2 and PM_{10}.

Figure 11: Green screen on installation (left) and after growth period has started (right)

3.5 Temporal variation in NO_2 and PM_{10} concentrations

The diurnal and weekly variation of the pollution concentrations were plotted for the spring term period, which was before a significant concentration difference was found due to the ivy screen (07-01 to 11-04), the summer term, which was after a significant concentration difference was found (28-04 to 22-07) and during the period when the ivy screen had fully matured (23-07 to 30-09; Figure 12 and Figure 13).

The NO_2 concentrations show a clear diurnal cycle with a pronounced morning and evening rush hour, especially during the first period of analysis. The concentrations remain elevated throughout the day. The lowest concentrations can be found in the early morning hours. There is also a clear weekly pattern with Saturday and Sunday showing lower concentrations than weekdays.

When comparing the three periods, it is noticeable that the NO_2 concentration difference between the sites increases as the screen matures. Initially, during the summer term, the background concentration drops as the screen thickens and only increases slightly even though the roadside concentration increases during summer.

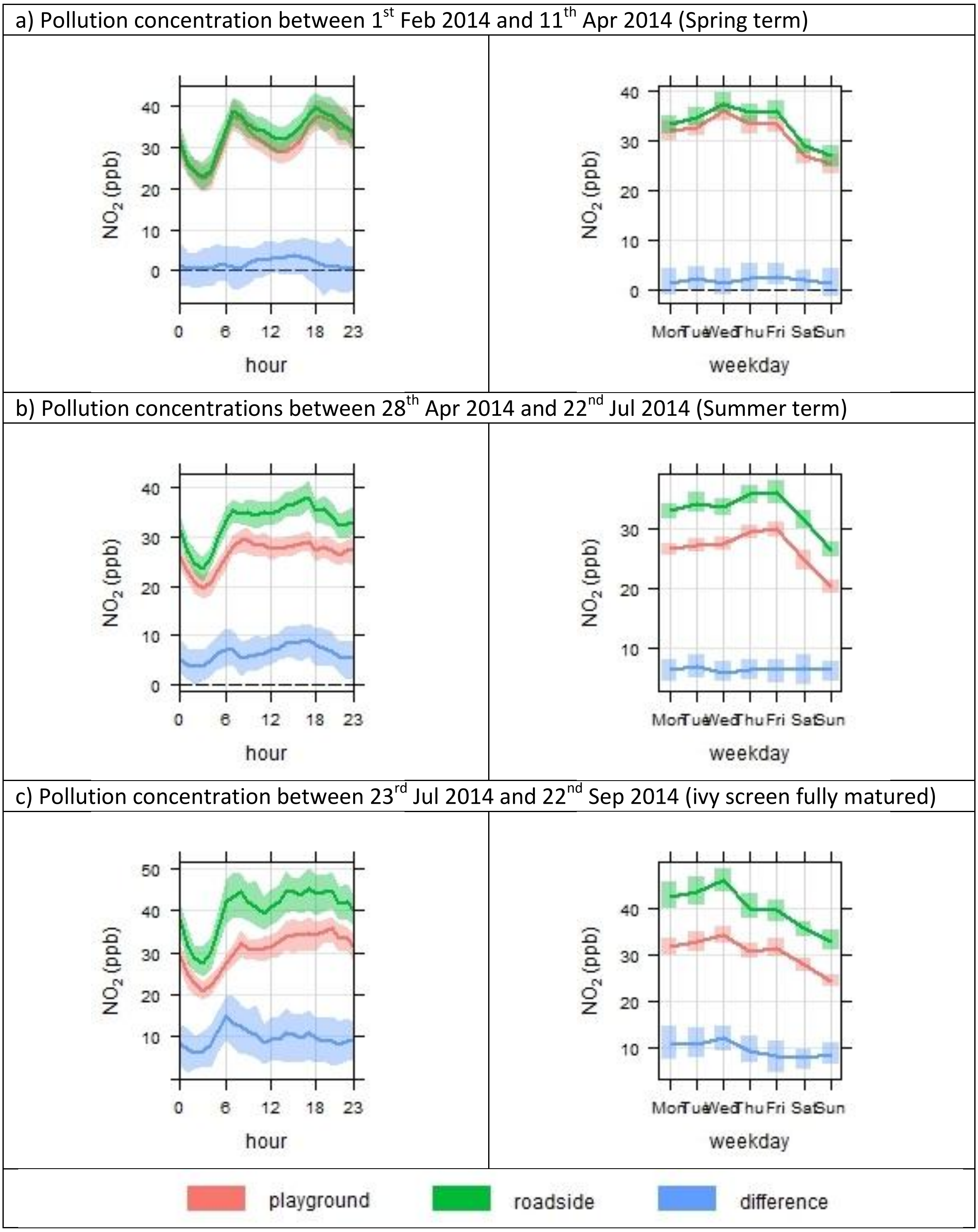

Figure 12: NO_2 diurnal and day of week plots

The diurnal pattern of PM_{10} is less pronounced than that of NO_2. There is a clear rise during the morning rush hour and then the concentration stays elevated during the day. There is no clear pattern over the weekly cycle as they seem to differ in each period analysed. It is possible that a few days with high concentration have a marked effect on the concentrations overall.

When comparing the three periods a similar pattern can be seen for PM_{10} compared to NO_2, with the background concentrations initially dropping compared to the roadside and staying lower in summer when concentration increase at the roadside.

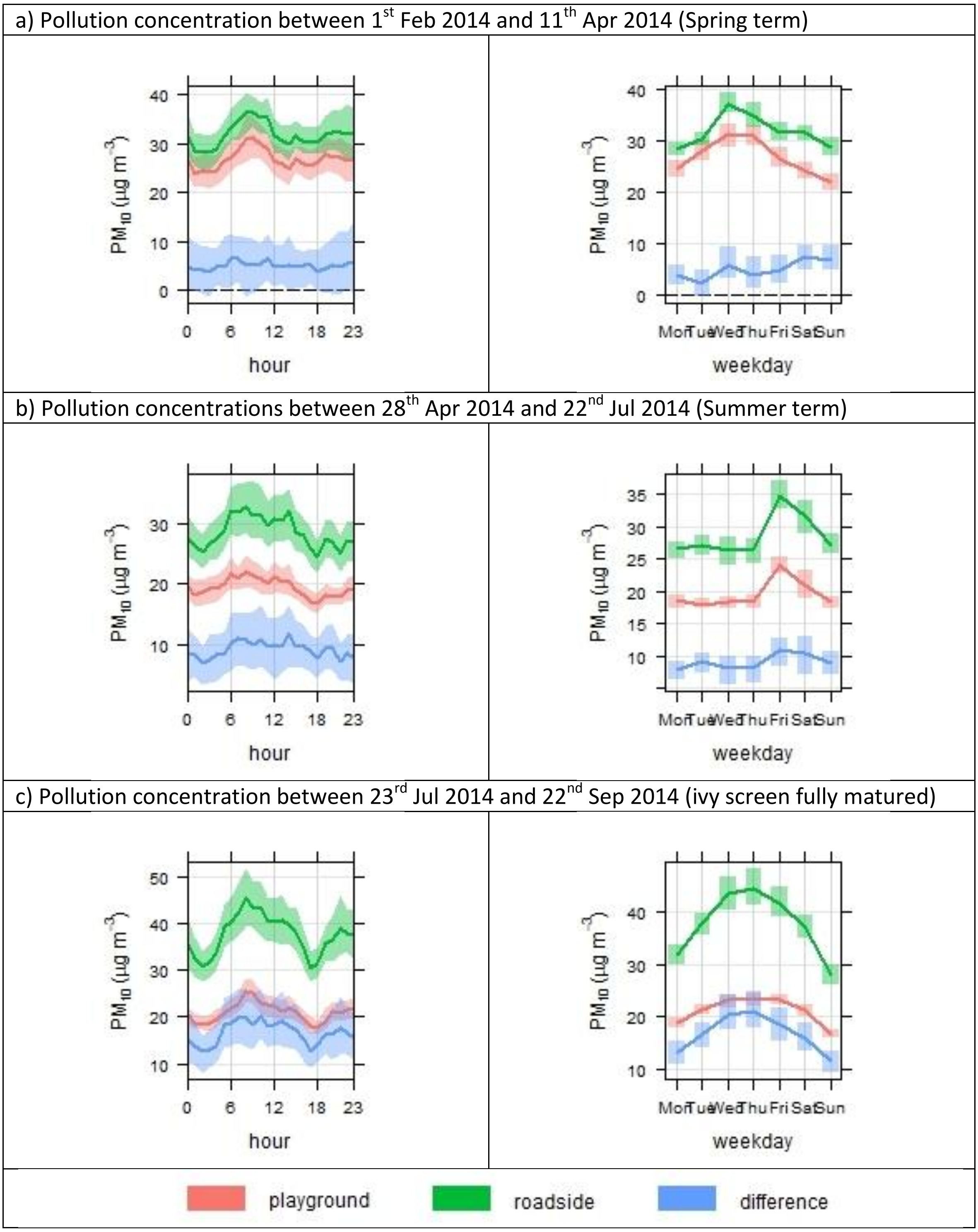

Figure 13: NO_2 diurnal and day of week plots

Examining the diurnal variations, it is clear that both NO_2 and PM_{10} concentrations are higher during the daytime when children are in the school and playground. In order to quantify the effects the screen has on the exposure of the children, the pollutant concentrations in the three periods were calculated for daytime hours (09:00-16:00) of weekdays only (Table 3). A clear trend can be seen to the concentration difference as the screen matures, with a fully matured screen leading to a concentration decrease of 36% and 41% for NO_2 and PM_{10}, respectively, at the playground side of the screen. Again these are broadly consistent with each other, showing that NO_2 and PM_{10} are reduced to a similar but slightly greater degree for PM_{10}, possibly due to the filtration effects.

	Roadside Site	Playground Site	Difference	
NO_2 in ppb (μgm^{-3})				
spring term	39.7 (75.8)	31.1 (59.4)	8.6 (16.4)	22%
summer term	41.5 (79.3)	28.1 (53.7)	13.4 (25.6)	32%
mature screen	50.3 (96.1)	32.3 (61.7	18 (34.4)	36%
PM_{10} in μgm^{-3}				
spring term	37.1	31	6.1	16%
summer term	30.4	21.1	9.3	31%
mature screen	43.1	25.5	17.6	41%

Table 3: Roadside and playground pollution concentrations during school hours (09:00-16:00) for the spring term, summer term and after the ivy screen has fully matured

4 Conclusions

PM_{10} and NO_2 were measured either side 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 both an assessment of 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 pre and post trial co-location assessments and the high correlation of determination values demonstrated that this was a robust approach.

Highest NO_2 concentration could be observed during September and overall the annual mean air quality objective would not have been met on either side of the screen for NO_2 assuming that the analysis period is representative of the entire year. There are PM_{10} episodes in March and September/October with the average concentration being below the annual mean objective; this is with the significant caveat that the PM10 measurement methodology is not equivalent.

NO_2 and PM_{10} source directions are aligned with the road axes suggesting that pollution levels were generally highest when emissions were either recirculated from the A3220 (northbound) or blown along the road from sources on northbound A3220, old Brompton Road and southbound A3220. There was an additional source in south-westerly direction at high wind speeds for PM_{10}.

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. The ivy screen led to a decrease in the NO_2 concentrations on the playground side of the screen by 24%, this was higher than the measurement uncertainty of 7% and was therefore significant. The decrease in the PM_{10} concentrations on the playground side of the screen was 38%; this was higher than the measurement uncertainty of 15% and was therefore significant.

Comparing school hours independently a reduction in NO_2 concentrations of up to 36% and a reduction the PM_{10} concentrations of up to 41% was found. This demonstrates that the screen is very effective during daytime hours, when both emissions and exposure are highest.

The reductions in NO_2 and PM_{10} concentrations are broadly similar; the PM_{10} reductions are slightly higher than those for NO_2 once the green screen has fully matured. This may illustrate slightly different effects that the screen is having on gases or particles. As the NO_2 concentration is lower than the PM_{10} the gas may be passing through the screen while the particles are being filtered by the increased foliage.

Although it is clear that the screen has a significant effect in preventing the transport of pollution from the roadside into the playground, further work would be required to assess the impact of the screen at greater distances from the road.

5 References

Barratt B., Carslaw D.C., Fuller G., (2012). Characterisation & trends in air quality within the Royal Borough of Kensington & Chelsea. Client: Royal Borough of Kensington & Chelsea

Carslaw D.C., Beevers S.D., Ropkins K., Bell M.C., (2006). Detecting and quantifying aircraft and other on-airport contributions to ambient nitrogen oxides in the vicinity of a large international airport. *Atmospheric Environment*, 40(28), 5424-5434.

Carslaw D.C., (2013). *The openair manual*; open-source tools for analysing airpollution data.

European Parliament and Council, (2007). Regulation (EC) No 715/2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information.

Hill A. C. (1971). Vegetation: a sink for atmospheric pollutants. *Journal of the Air Pollution Control Association*, 21, 341–346.

Horak Jr., F, Studnicka, M., Gartner, C., Spengler, J.D., Tauber, E., Urbanek, R., Veiter, A., Frischer, T., (2002). Particulate matter and lung function growth in children: a 3-yr follow-up study in Austrian schoolchildren. *European Respiratory Journal*, 19, 838–845

Kelly, F. J., & Fussell, J. C. (2011). Air pollution and airway disease. *Clinical and Experimental Allergy*, *41*(8), 1059 – 1071

Sternberg, T., Viles, H., Carthersides, A., Edwards, M., (2010). Dust particulate absorption by Ivy (Hedera Helix L.) on historic walls in urban environments. *Science of the Total Environment*, 409, 162-168.

WHO, (2003). Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide. Copenhagen, World Health Organization.