A comparison of diffusion tube–measured nitrogen dioxide concentrations at child and adult breathing heights in a pre-school setting

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By

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I have no objection with this work being considered by the CIEH panel for the Environmental Health research award, nor any subsequent publication.

Contents

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Abstract

The aim of this study was to critically evaluate concentrations of NO_2 measured at different heights within a children's nursery in South Shields, UK. DEFRA guidelines recommend that diffusion tubes are installed at a height of no lower than 2 metres to protect from vandalism and tampering. However, emerging evidence from similar studies has shown that this may result in a significant underestimation of concentrations at the breathing height of children and adults. Palmes-type diffusion tubes were installed over a period of four months in the outdoor setting of a children's nursery at heights of 0.7m and 1.7m to replicate children's and adults breathing heights respectively, an addition diffusion tube was sited at 2.7m to allow for comparison with an existing diffusion tube located close to the nursery as part of the Local Authorities monitoring regime. Contrary to similar studies identified, concentrations at the 0.7m and 1.7m tubes were very similar, with a four-month average of 18.83 at the 0.7m tube compared to 19.05 at the 1.7m tube. A number of variables have been considered as to why these results contrast to the similar studies. Wind, distance from the road, intervening physical structures and tree cover are considered to be the principal factors. The NO_2 concentrations at 2.7m showed good consistency with the Local Authority monitoring results. Recommendations have been provided to the nursery and Local Authority following a critical literature review of current knowledge of health impact and possible mitigation methods, however in this instance, confidence has been gained in the methods undertaken by the Local Authority to measure NO_2 emissions in this area, with all results being well under the current objective levels required.

List of tables and figures

1. Introduction

1.1 Air pollution

The World Health Organisation (WHO, 2022) describes air pollution as the contamination of the indoor or outdoor environment by any chemical physical or biological agent that modifies the natural characteristics of the atmosphere (WHO, 2022). The understanding of the impact of poor air quality on individuals and communities is strengthening with poor air quality recently being described as the largest environmental risk to public health in the UK (Public Health England, 2022).

1.2 Sources of air pollution

Road transport is a major source of air pollution, in 2020, 70% of European Union (EU) transport emissions came from road traffic (European Environment Agency, 2023). The combustion process in a vehicle engine emits several gases and air pollutants including Carbon Dioxide, Hydrocarbons, Carbon monoxide, particulate matter, and nitrogen oxides (NO_x). The focus of this study is NOx, which are a group of chemicals that are formed by the reaction of nitrogen and oxygen.

At locations adjacent to roads, 80% of the total NOx emissions are contributed from road sources (DEFRA, 2019). Nitrogen Dioxide NO_2 is both a primary and a secondary pollutant. Primary NO_2 refers to the fraction of NO_x emitted directly from a vehicles exhaust that is already in the form of NO_2, this is a result of emission control techniques which oxidise the gases and air pollutants involved in the combustion process. Secondary NO_2 occurs following a chemical reaction between NO and Oxygen in the atmosphere. Zang, et al. (2018) found this chemical conversion process of NO_x to NO_2 to occur rapidly.

1.3 Health impact of NO_2

NO_2 is an irritant of the respiratory system as it penetrates deep in the lung which can bring about respiratory diseases, coughing wheezing and other adverse effects (Paulin & Hansel, 2016). Air pollution is known to disproportionately affect vulnerable groups such as the young, elderly or those with underlying disease (Grey, et al., 2018). Many schools and early years nursery settings are in areas that breach air quality guidelines for NO_2 (Salonen , et al., 2019) and therefore these settings should be a priority for mitigation and understanding of emission levels.

1.4 South Tyneside Council Air quality monitoring

South Tyneside is a metropolitan borough in the North East of England as shown in figure 1.

Figure 1 Map of South Tyneside

The Local Authorities Environmental Health team is responsible for discharging the statutory duty that exists on all Local Authorities to fulfil Part IV of the Environment Act 1995 Local Air Quality Management as amended by the Environment Act 2021.

This duty requires all Local Authorities to review the air quality within its area, both now and any likely impacts in the future and to set this out in an annual status report which is submitted to the Department of Food and Rural Affairs (DEFRA) for appraisal, once approved it can then be published.

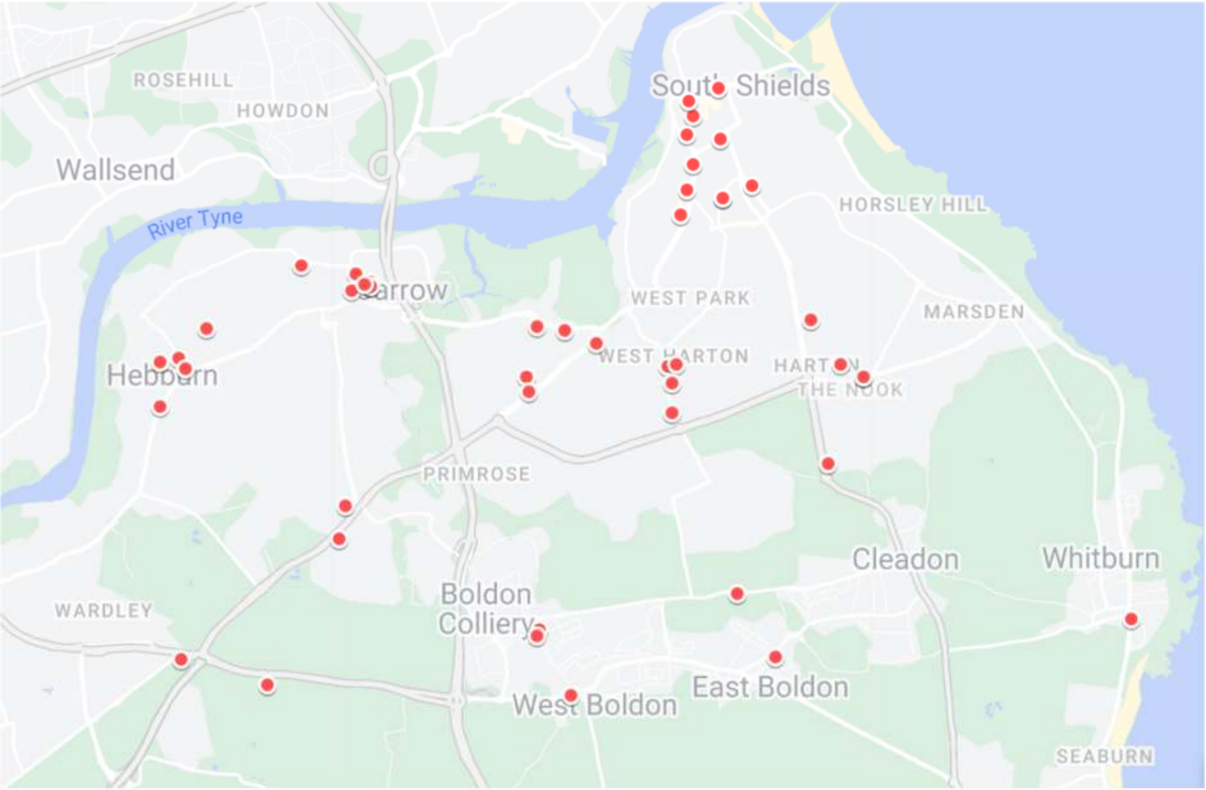
Air pollution in South Tyneside is monitored by using a combination of automatic and non-automatic techniques.

1.4.1 Non-Automatic monitoring

Diffusion tubes use the principle of molecular diffusion to determine NO_2 concentrations. Palmes type diffusion tubes are one of the most common methods of non-automatic, passive monitoring of NO_2 used by Local Authorities (Targa & Loader, 2008). They are small plastic tubes which have one open end to allow for air to flow in and at the capped end, contain two stainless steel grids which are coated in triethanolamine (TEA) which absorbs NO_2 from the air.

Exposure takes place over a 4- or 5-week period, with DEFRA providing an exposure calendar that must be adhered to. South Tyneside Council deploy 43 tubes across the borough, placed in accordance with the appropriate guidance (Local Air Quality management – Technical Guidance (TG22)) (DEFRA, 2022). Figure 2 shows the locations of the diffusion tube monitoring regime within the South Tyneside Council area.

Figure 2 Diffusion tube locations in South Tyneside



1.5 Air pollution impact - guidelines and legislation

To protect human health, ambient concentrations of NO_2 have been regulated throughout Europe by EC Directive 85/203, since 1985. This directive was superseded by the first EC Daughter Directive (1999/30/EC), which came into force in January 2000, and which set Limit Values for $NO_{2,}$ to be achieved by 2010. Directive 85/203 remained in force until 2001. The recommendations for NO_2 objectives set out by the Air Quality Strategy have been formally made part of UK legislation by the Air Quality Regulations 2000 for England, Scotland, and Wales.

The Air Quality Strategy for England, Scotland, Wales, and Northern Ireland defines the objectives for nitrogen dioxide as follows:

• Objective: 1-hour mean of 200 $\mu g\ m^{-3}$ (maximum of 18 exceedance).

• Objective: Annual mean of 40 $\mu g\ m^{-3}$

The Daughter Directive provides two limits for nitrogen dioxide as follows:

• The hourly average concentration must not exceed 200 $\mu g\ m^{-3}$ (105 ppb) on more than 18 occasions per calendar year.

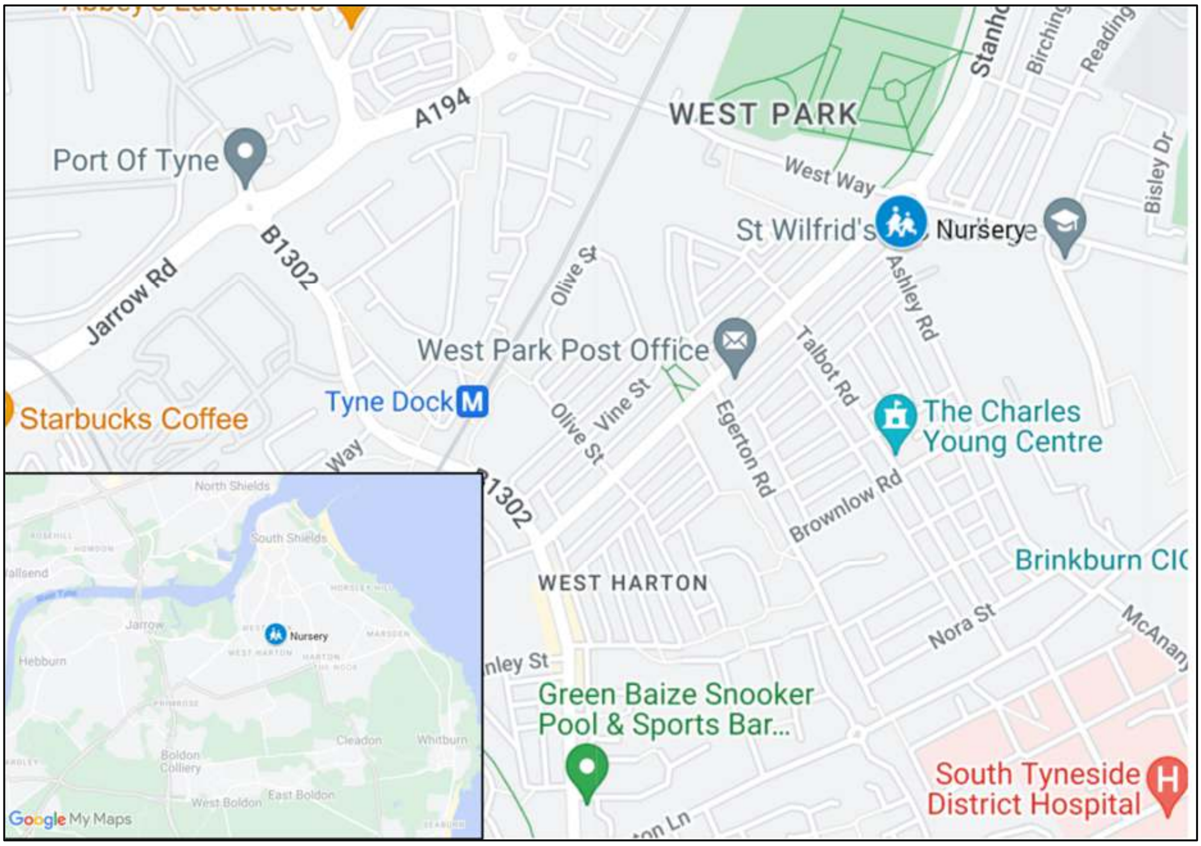
• The annual average concentration must not exceed 40 $\mu g\ m^{-3}$ (21ppb)

South Tyneside air quality levels do not breach the current annual national objective at any of its locations (South Tyneside Council, 2023).

1.6 Nursery setting

A children's nursery in South Shields is located next to a roundabout which serves an important function within the strategic road network of the town. The immediate area also includes a primary school, secondary school, and shopping area. Several bus services operate in this area because of the number of uses in the immediate vicinity, and due to its prominent location within South Shields as shown in figure 3.

Figure 3 Location of nursery within South Tyneside



The nursery was opened in 2018, and as it did not reach the validation requirements of the Tyne and Wear validation protocol (Local Planning Authorities, 2019), did not need planning consent under the town and country planning act due to its previous use, therefore the Local Authority were unable to request an assessment of the local air quality and its potential impact on the users of the nursery prior to its opening. Therefore, to characterise the area further a diffusion tube was installed in the vicinity of the nursery. The diffusion tube was sited using the official guidance provided by DEFRA.

1.7 Diffusion tube placement guidelines

DEFRA recommends diffusion tubes are installed on street furniture at a height of no lower than 2m to reduce the risk of vandalism or theft, however even the guidance for the placement of diffusions tubes acknowledges that tubes placed above breathing height may underestimate the actual concentrations to which the public are exposed (Targa & Loader, 2008). Studies by Rowell, et al., (2020) and Kenagy, et al., (2016) have highlighted the possible misrepresentation of emissions which impact on human health because of diffusion tubes being located higher than both adult and child breathing height. This therefore raises the hypothesis, is the measurement methodology that is provided by DEFRA assessing the true levels of emissions in communities, and furthermore, does this monitoring methodology underestimate the levels of air pollution which children are exposed to.

1.8 Rationale for study

As identified above, there is a scarcity of research relating to the relationship between concentration levels of NO_2 at breathing heights of children, adults and the recommended practice provided by DEFRA. Given the current increasing knowledge around the subject of the impact of poor air quality on human health, especially the vulnerable population, including children, this study Is beneficial to further understanding of the relationship between height of monitoring and concentration levels, and also provide a critical insight into current work being carried out to mitigate poor air quality levels, specifically at children's settings.

1.9 Aims

The aim of this study is to critically evaluate variations in levels of NO_2 depending on the height of diffusion tubes located at a children's nursery in South Shields, Tyne and Wear. Additionally, if it is proven that the levels within the nursery setting are harmful to human health, what interventions can be considered to mitigate and potentially reduce the level of emissions that the children are exposed to.

1.10 Objectives

1. A critical literature review of current research on the specific detail of NO_2 levels measured at differing heights of diffusion tube siting.

2. A Critical literature review of current understanding of the impact on poor air quality on children

3. A critical evaluation of current research into possible mitigation that could be put in place to minimise the risk to children from poor air quality when in educational settings.

4. To critically analyse diffusion tube measured nitrogen dioxide concentrations at adult and breathing height in a school nursery.

5. Recommendations to the nursery based on the analysis and research above.

2 Literature Review

2.1 Introduction

The purpose of this chapter is to present a critical literature review of related factors of the impact of air pollution on children's health to meet objectives 1 -3 of this thesis.

2.2 Health impact

2.2.1 Impact on respiratory function

The effects of road traffic related air pollution on health are very complex, several different sources such as NO_2, particulate matter, and Benzene, and their individual effects, may vary from one to another (gov.uk, 2018). What is clear however, is that poor air pollution has a causal effect on human health, principally, but not limited to, the respiratory function (National institute of Environmental Health Sciences, 2024).

Recent research by the Lancet has shown that globally, respiratory disease is the third leading cause of death globally, with air pollution being the second biggest risk factor, only behind smoking, and causing the death of 1.3 million people worldwide (Lancet, 2023). In London alone, poor air quality was the cause of more than 1700 hospital admissions between 2017 and 2019 for Asthma and Chronic obstructive pulmonary disease (COPD). 700 of these admissions were for children under the age of 14 (London.gov.uk, 2022)

Lung development occurs rapidly from birth to two years old, (Rao, et al., 2010) and then continues through adolescence until the age of 18 in girls, and into the mid 20's for males. Therefore, children are particularly vulnerable to the impacts of poor air quality for several reasons. NO_2 as a result of road traffic is an irritant of the respiratory system and it invades deeply into the lung (Tiotiu, et al., 2020), introducing respiratory diseases such as asthma and COPD. Additionally, children, especially preschool children, are considerably more physically active than teenagers and adults (Sigmund, et al., 2007) and they also breath quicker than adults, and therefore breathe in more air (Fleming, et al., 2011)

Extensive publicity surrounding the death and subsequent coroner's report of Ella Kissi-Debrah resulted in an increased public awareness of the impact of poor air quality on children. Ella died just after her 9th birthday from respiratory illness, an initial inquest did not mention the impact of the poor air quality where she lived in London, close to one of the areas with the highest air pollution, however following experts in the field of respiratory illnesses reviewing the case, a new inquest took place resulting in the coroner declaring that Ella died of respiratory failure, severe asthma and air pollution exposure (Dyer, 2020)

2.2.2 Asthma

Iskander, et al (2012) studied the number of children hospital admissions for asthma in close proximity to areas of high air pollution in Copenhagen, Denmark and found a strong association, especially with regards to pollution caused by road traffic. Veremchuk, et al (2018) identified that the link between asthma onset and air pollution was stronger in children than in adults. This hypothesis is supported by such as those from Sheffied & Landigran (2011) and Kelishadi & Poursafa (2010) who identified that the late onset effects of air pollution exposure in early life may be related to chronic diseases later in life.

A study that was carried out that did not find the same consistent association between air pollution exposure and hospital admissions for asthma in children was carried out by the Pollution Effects on Asthmatic Children in Europe (PEACE) project (Roemer, et al., 1999). It is possible that the results of this study were influenced by the shorter observation period of two months, whereas research such as Sunyer, et al (1997), Morgan et al (1998) and Lee et al (2006) show that with longer study timeframes, a common trend appears for poor air pollution impacting on childhood asthma admissions to hospital.

2.2.3 Allergies

Studies have been undertaken finding links to air quality and health impacts in children that are not related to respiratory diseases. Chan, et al (2023) recently considered the impact of poor air quality on the development of childhood allergies and found a strong correlation between increased air pollution exposure and allergy symptoms. Work by Zhang, et al (2023) substantiated this hypothesis that poor air quality is also a likely causal link to some food allergies, concluding that alongside stomach and skin, airways are another potential route for the early onset of food allergy. However, evidence gathered by Gehring, et al (2010) and Nordling, et al (2008) was not able to prove a link between air pollution and food allergy. It is possible that the reason for these different findings is because of the methodologies used in these studies, where air pollution was considered from inside subjects' properties rather than outdoor air pollution, it is clear that this research did not include exposure in alternative setting such as schools.

2.2.4 Vitamin D deficiency

Argalwhal, et al (2002) identified a strong association between elevated air pollution levels and Vitamin D deficiency in children in Delhi, India, and found children living in highly polluted areas to be more vulnerable to this disease. Vitamin D deficiency is associated with deteriorating bone health, and In severe cases this can cause diseases such as rickets in young children (Misra, et al., 2008)

Notably, Bose, et al (2019) found that higher vitamin D levels in asthmatic children mitigated against adverse asthmatic symptoms during times of daytime elevated air pollution.

2.2.5 Secondary confounders

Ferguson, et al (2020) Studied the effect of indoor levels of N02 because of road traffic and found a similar consistent relationship between poor air quality and respiratory disease in children. This study also considers secondary confounders which are intrinsically linked to the ambient air quality in an area and also links increases the likelihood of poor health such as the socio-economic status. Mehta, et al (2014) studied the personal exposure of residents of a number of areas in Vietnam and found a strong correlation between poverty and higher exposure levels to poor air quality. Children of lower economic status are disproportionately exposed to higher rates of outdoor air pollution (Mathiarasan & Huls, 2021). Potential reasons for this include children of families with financial pressures are more likely to walk to school and therefore be more vulnerable to higher levels of road traffic (Su, et al., 2013) , they may live closer to busier roads or industrial areas and therefore more susceptible to higher levels of air pollution (Bel, et al., 2005).

2.2.6 Depression

A further health impact that has been associated with poor air quality exposure in children is the impacts on mental health matters such as anxiety and depression. Recent research identifies exposure to traffic related pollution being a risk factor for neurodevelopment deceleration in children (Sunyer, et al., 2015). In their study of 284 children aged 12 years old in the UK, Roberts, et al (2019) found that those who lived in the top 25% of the areas with highest ambient level so fair pollution were found to be four times more likely to be diagnosed with depression at the age of 18. Interestingly, this study did not find a significant link between exposure and immediate diagnosis of mental health illness at the age of 12, indicating that, as with the slower onset of respiratory symptoms discussed above, this is likely due to the brain still developing at this age and therefore symptoms may not be fully present until an older age. This can be corroborated by studies such as Rice & Barone, (2000) who confirm that there are critical periods of vulnerability for the development of the nervous system and children's brains are still developing at this age and are therefore vulnerable to neurologic injury from air pollution. Notably for this study, within a children's nursery setting, Guxens, et al (2022) identified in their research that the first years of life are extremely sensitive periods for exposure to air pollution for brain functional connectivity. In a recent, substantial piece of research of just under 2,000 children, Crooijmans et al (2024) found that the higher exposure to NO_2 greatly impacted the attentional function of children from 4 to 8 years old.

2.3 Comparison of similar studies

There is a growing body of evidence such as that presented by Vardoulakis, et al (2011) and Violante, et al (2006) that suggests population exposure is not being accurately measured by the methodologies that exist for assessing air quality as a result of road traffic emissions.

2.3.1 Adult versus child breathing height

There are several studies that have considered the impact of the function of height measured NO_2 concentrations, with three studies found that have specifically looked at the difference between measurements found at child breathing height compared with adult breathing height in the same location. Rowell, et al (2020) studied the difference is diffusion tube concentrations at 0.7m, 1.7 and 2.7m to replicate child breathing height, adult breathing height and DEFRA guidelines respectively. The outcome of this study showed no statistical difference between 1.7m and 2.7m, however the research did show a significant statistical difference of 5.9% between emissions measured at 0.7m and 2.7m. A significant detail of this research is that the diffusion tubes were placed 7m away from the highway, showing that even with a considerable spatial distance from the road to receptor, a significant difference in measured emissions exists. This contrasts however with the work carried out by Kenagy, et al (2016). In this study, diffusion tubes were again sited at child breathing height (0.8m in this instance) and 2.0m in several locations throughout the city of Edinburgh, Scotland. This study found differences of between 5 – 15% between the two diffusion tube heights at the same location. However, in contrast to the work carried out by Rowell et al (2020), this study concluded that the difference in measured concentrations did not persist at distances of further than 2.5m away from the roadside. Similar work was carried out in an air quality study by the Scottish Government (2015) however the NO_2 measurements were captured using an AQ mesh sensor, this is a low-cost sensor as opposed to the Diffusion tubes used in the studies considered above. This sensor was mounted to a bespoke trolley and pushed around pavements in the centre of Glasgow, Scotland. This research found that in areas of lower ambient NO_2 concentrations, there was no consistent influence on measured concentrations, however at in areas of higher concentrations, the study found a significantly higher levels measured at adult breathing height compared to a child's. The author of this study discusses these findings and suggests that they may be as a result of road traffic emissions as the hot exhaust emissions disperse widely into the environment on leaving the exhaust. However, these findings are not consistent with the outcome of the two studies discussed earlier. It is possible that the difference in monitoring technique may have some impact on the contrasting results.

2.3.2 Comparing horizontal concentrations.

These studies considered the relationship between emissions found at child breathing height compared to adult breathing height, there are further studies which assess emissions measured at a selection of heights higher than these. A summary of the findings of these studies, where diffusion tubes were used in all assessments, is as follows.

Vardoulakis et al (2011) measured NO_2 emissions at 2.5m and 9.5m on a multi storey building and found emissions to be 24% lower at the higher tube. Amato, et al (2019) reported a 10% reduction in emissions at diffusion tubes at 15m compared to emissions recorded at 3m. Eeftens, et al (2019) considered the difference in height with additional assessment given to a comparison between summer and winter levels. A clear reduction in levels was found in both seasons, the median decrease between levels measured at Ground floor and compared with 10m above street level being 8.1% in winter and 10.4% in the summer. The study found that the decrease in emissions was sharper at areas with high ambient concentrations at ground level. A similar conclusion was found by Sajani, et al (2018) who found a 17% decrease in emissions at 15m vs 2m in concentrations measured in the summer, and a 11% decrease in the winter at the same heights. These studies show a consistent pattern of a decrease in emissions when assessing vertical variances in diffusion tube locations, with the seasonal variation clearly influencing results. The combustion process in vehicle engines results in Nitrogen Oxide (NO) being formed through a series of complex chemical reactions. When NO is emitted into the atmosphere, NO mixes with oxygen to form NO_2. In the summer months, there is an abundance of oxygen in the lower atmosphere and therefore significant mixing occurs which could explain the sharper decrease in measured emissions in the summer months as opposed to winter. Notably, Monn, et al., (1997) found a significant disparity in concentrations measured in both Winter and Summer seasons, comparing emissions at 20m and 3.5, reporting a 40% difference in the summer, but no notable difference between levels in the winter.

There are further studies that can be considered which show variations in findings compared to those above. In their study of exposures at varying height and distance from the roadside, Laxen & Noordally (1987) found an increase in the summer consistent with the findings laid out above, with a 15% - 30% decrease noted in the summer at a diffusion tube height of 18.5m compared to a tube located at 2.5m. However, this study also found a slight increase in concentrations at the same heights in the winter. One potential explanation for this is that the study was carried out over a small time period, with tubes only exposed for a one-week period. Similarly, Cheong, et al (2012) found an increase in concentrations a diffusion tube located 17.5m high on an apartment block compared to tubes located at ground level This study found an increase in concentrations of between 12% and 16%. The findings in this work highlight further possible explanations for the inaccuracies that can be associated with the use of diffusion tubes to measure air quality. The study took place in a significantly built-up area in Singapore, and this may introduce the street canyon effect. A street canyon can refer to a narrow street with buildings lined up on both sides (Nicholson, 1975) and pollutants within a street canyon are found to often be recirculated and trapped and therefore reduce the rate of dispersion and cause variable concentrations at differing heights (Camden.gov.uk, 2020).

2.3.4 Fall off with distance.

A further uncertainty which can influence air quality levels is the factor of the fall off with distance between the diffusion tube and the receptor. The guidance provided by DEFRA (2018) for the siting of diffusion tubes for air quality monitoring indicates that the most appropriate location is one which is open to the sky, with no overhanging vegetation or buildings, and away from service equipment such as air conditioning units or extractor vents. With these considerations in place, and also acknowledging possible access issues when siting at residential properties, this leads to the majority of Local Authorities siting diffusion tubes on street furniture such as lamp posts. It is recognised by DEFRA that in areas such as residential estates, these tubes may not be representative of community exposure, and therefore provide a tool in the form of an excel spreadsheet which allows for the prediction of concentrations at measured distances away from a diffusion tube location. The methodology found in this prediction methodology can be assessed against a number of studies which have been undertaken to assess the relationship between distance and NO_2 drop off. Laxen and Noordally (1987), Hickman et al (2002), Green and Fuller (2023), Laxen and Marner (2003) and the Highways Agency (2007) are all studies which looked at the relationship and found a consistent reduction in concentration with distance from the kerb.

2.4 Mitigation

2.4.1 Green walls

There is emerging evidence that green walls/living walls can have significant impact in mitigating air pollution. A green wall is foliage that can be wrapped around a purpose-built lattice or and existing fence with the aim of absorbing and blocking pollution, in this instance from road traffic. Tremper & Green (2018) found extremely promising results when comparing emissions in a school playground where a green wall made of ivy was implemented between the road side and the playground and found reduction of up to 7% in emissions at the playground two months after installation of the screen, and a reduction of up to 24% once the ivy had matured. This followed on from a similar experiment by in 2015 where the researchers found a similarly substantial reduction in road traffic emissions of 24% (Tremper & Green, 2015). Both studies also showed a significant decrease in levels of particulate matter from the roadside to the children's playground with a green screen intervening. A report that came to a different viewpoint, namely that green walls have little to no impact on air pollution mitigation is by Paull , et al (2020). Paull surmised that previous studies showing a consistent reduction because of green screens are likely to be based on computer modelling and over exaggerating results. This is not the case for the two studies highlighted above, where measurements have been taken in the field and no computer modelling used. The methodology of Paull's study included taking measurements adjacent to a green wall, and then comparing these measurements to ones taken at a reference wall in nearby vicinity. This could be a reason for the difference in results, as air quality can be influenced by localised variables which may result in differing levels at locations in proximity to each other.

2.4.2 Internal green screens

Some studies have also shown the benefits of installing similar green screens within the classroom itself. Reports such as those by Ghazalli, et al., (2018) and Suarez-Caceres & Perez-Urrestarzu (2021) have considered the impact of green walls within the classroom settings and found reductions in measured emissions similar to those outlined above. Additional benefits of internal green walls such as improved internal temperature (Fonseca, et al., 2023) reduced noise ingress (Scamoni et al, 2022) and reduced demand on internal ventilation systems (Parzikhar, et al., 2020) all enhance the benefits of increased use of indoor green walls.

2.5 Behaviour change

2.5.1 School streets

However, in addition to approaches that incorporate green technology such as green walls, solutions that engage the public have also been the subject of significant growth in recent years as it is believed that behaviour change initiatives are a key element of reducing air pollution. One such initiative is school streets.

A school street is a road outside a school with a temporary restriction on motorised traffic at school drop off and pick up times. The inception of the school streets initiative can be traced back to Italy in the early 1990's, when communities in Bolzano city became overwhelmed with traffic around schools and restricted vehicles. Since then, its approach has been used throughout the world, with a significant increase in the UK in the last ten years. There are now more than 500 schemes in London alone (London.gov.uk, 2022) . In the UK, school streets initiatives are generally administered by the Local Authority, usually with support from third parties such as SUSTRANS or CAPITA. Reducing road traffic emissions around schools is seen as a significant priority now, as further studies come forward showing the impact of poor air quality on the human population, especially children. By restricting access to the specific roads involved in the scheme, participants are given no option but to consider a modal shift in their approach to journeys to school. Unfortunately, this aspect is also perhaps the most controversial and a barrier to success of schemes as Heloise, (2019) found in a case study of a scheme in London. Education is a key behaviour change intervention behind the school streets initiative. The positives from an education intervention are multi-faceted and are crucial to the success of schemes (Hunter, 2015). In their analysis of successful or otherwise school streets initiatives, Smith, et al., (2022) found that the level of awareness in the locality was an important element that facilitated the success of a scheme and Hung, et al., (2019) found that educational campaigns targeting air pollution reduction should be a top priority in policy communication. Embedding an active travel conversation in children at nursery and school age is a significant positive and the implementation of a school streets initiative is normally accompanied by an educational programme at the same time. In their study of successful schemes. Gidney (2017) found that engaging participants in initiatives in terms of taking messages home around the opportunity of active travel within the school setting. One potential barrier to the overall success of the school streets initiatives is that of emissions monitoring during the times of day that the scheme is in operation. As the most common method of recording air quality levels is the use of non-automatic diffusion tubes, they do not show peaks and troughs of emissions during hourly resolutions, rather monthly averages (DEFRA, 2023). As technology around monitoring advances, we are starting to see more devices that are a reasonable cost and can provide minute by minute emission levels. As Fonseca & Whitney (2019) suggested, new methods of monitoring can be useful in raising awareness, and therefore the use of these new technologies will allow participants the opportunity to see in fine detail, how their participation in the scheme influences a decrease in emissions and potentially increase the likelihood of increased buy-in to initiatives. Any data received throughout the monitoring could also be used to explore incentivisation, for example by giving participants the opportunity to try and reach specific emissions levels for their school.

3 Methodology

3.1 Introduction

This chapter Introduces the methodology for the thesis. It sets out the purpose, aims and objectives of the thesis. It will justify the choice of nursery and explain why only one nursery was used in the final thesis. The method of study is the combination of primary data collection with a desktop literature review to meet the aims and objectives. Ethical approval was obtained from the College of Science and Engineering Ethics Committee

3.2 Primary data

3.2.1 Choice of setting

To achieve the central aim of this study, it was necessary to choose a suitable setting to carry out the primary data collection. A preschool nursery setting was chosen above primary schools and senior schools due to the knowledge obtained during the prereading process of choosing a dissertation topic, research such as Sheffied PE, et al (2011), Kelishadi et al (2010) and Poursafa et al (2011) all indicate that it is the youngest children who are the most impacted by poor air quality .

3.2.2 Nursery selection process

Currently, there are twelve preschool nurseries within the South Tyneside Council area. Therefore, a process was undertaken to select the most appropriate nursery. Selection requirements were based on the following criteria:

- Operational children’s nursery within South Tyneside Council area
- Access to a location within the outdoor area of the nursery where diffusion tubes could be installed. To ensure the safety of the users of the outdoor area, the diffusion tubes must be located away from where children are able to access, however still representative of children’s exposure within the outdoor setting.
- Positive communication with management.
- Located on a busy road network to ensure that road traffic emissions will be representative of exposure throughout an urban area.
- In proximity to an existing diffusion tube located as part of the South Tyneside Council LAQM regime.

By following this process, two nurseries were appropriate for the purpose of this study. By choosing two nurseries this would allow for a critical comparison of the findings at two separate locations within the borough, however, as detailed in the limitations section of this chapter, the study progressed with only one nursery.

3.2.3 Method of data collection

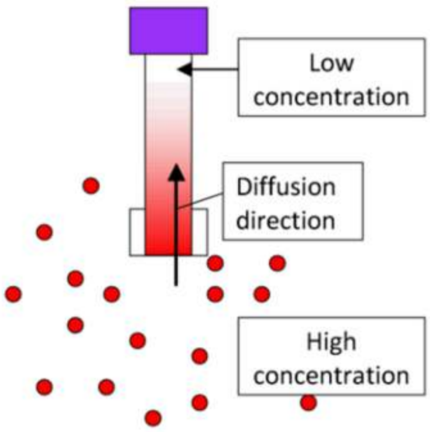
There are a number of possible methods to consider when determining the most appropriate way to gather road traffic emissions data. Diffusion tubes, continuous monitoring stations or low-cost sensors could all be employed for this purpose (Munir, et al., 2019). For this study, diffusion tubes were considered the most appropriate, as this allows for comparison with current health guidelines, comparable emissions data in the area and comparison with similar studies, Rowell, et al., (2021) and Kenagy, et al., (2016).

3.3 Diffusion tubes

3.3.1 Molecular diffusion.

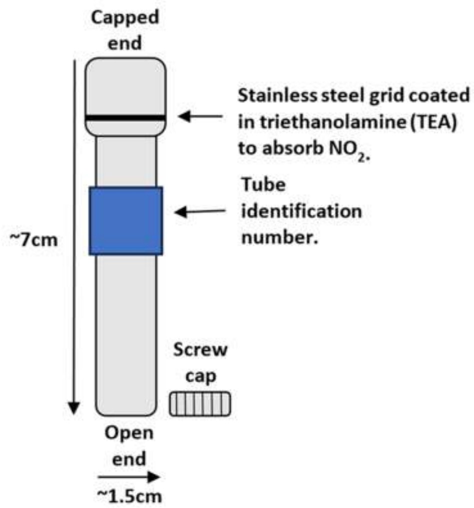
Diffusion tubes work by a process called molecular diffusion (AEA Energy and Environment, 2008). As figure 4 illustrates, molecular diffusion involves compounds moving from an area of high concentration to low concentration (Gradko, 2020).

Figure 4 Molecular Diffusion (Gradko, 2020)



The compounds in the air are at a higher concentration than those in the tube, therefore the compounds diffuse into the tube and collect on an absorbent that is secured between two gauze layers as shown in figure 5.

Figure 5 Diffusion tube schematic (Rowell, et al., 2021)



Because the compounds are absorbed, the low concentration in the tube is maintained and therefore diffusion continues.

3.3.2 Diffusion tube positioning

Diffusion tubes were mounted onto a drainpipe using a cable tie with a 5cm spacer unit to ensure that air can flow around the open end of the tube. One tube was located within the nursery playground, parallel to the diffusion tube that is located by STC as part of its borough wide monitoring. It was located 2.5m in height. The purpose of this diffusion tube location is to critically analyse the fall off rate with which emissions recede, as the literature review has shown, there are differing outcomes depending on distance from road, therefore the comparison of this tube with the existing located tube will be useful. Additionally, by comparing concentration levels at these two tubes, it will be possible to consider if the location as currently used by the Local Authority is appropriate for the objective of understanding concentrations at the nursery itself.

Due to safety concerns, two additional diffusion tubes were located out of reach of children, however they were be located within the playground area. The diffusion tubes were located at 0.7m and 1.7m to replicate breathing height of the children at the nursery (Rivas, et al., 2016) and the breathing height of adults (Kenagy, et al., 2016).

3.3.3 Exposure period

Diffusion tubes were collected and replaced with new as part of the monthly process conducted by the Local Authority. The tubes were collected in accordance with the DEFRA LAQM calendar

(DEFRA.gov.uk, 2024). Tubes were exposed over a four monthly period between November 2023 and February 2024.

3.3.4 Laboratory analysis

Monitoring was conducted as part of South Tyneside Councils monthly monitoring regime. The tubes were stored in a refrigerator before and after deployment, and sent to Gradko international, a United Kingdom Accreditation Service (UKAS) certified laboratory for analysis. When diffusion tubes are returned to the laboratory to be analysed, the lab determines the concentration of compounds in the layers of the stainless-steel grid. This is then used in a calculation to return the average concentration of compounds that were present in the air during the monitoring period.

3.3.5 Data analysis

The analysis report provided by the GRADKO laboratory lists -

- The amount of NO_2 on the tube in ug which is the analytically derived value.
- The gaseous ug/m3 at the sampling location, the parameter used to allow for comparison with health guidelines.
- Parts per billion NO_2

On receipt, the analysis reports were stored in a secure personal folder. The data ug/m3 data was logged on an Excel spreadsheet.

When all four monthly analysis reports were received, the UG/m3 data was analysed using the descriptive statistical method. This method was preferred to inferential statistics as the objective was to compare emission levels both at differing heights of diffusion tube, and with similar studies found in the critical literature review. Therefore, using the descriptive method facilitates the use of graphs and tables to effectively describe and summarise the datasets.

3.4 Secondary data

3.4.1 Literature review methodology

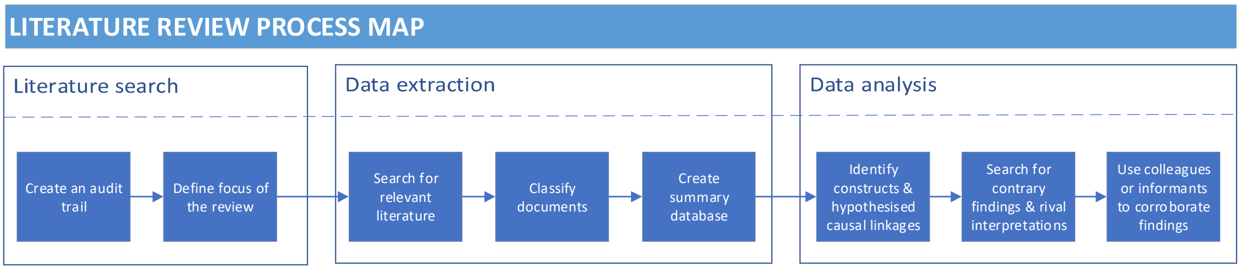
The focus of the critical literature review in this study is divided into three distinct sections –

- Identifying comparable research and critically appraising outcomes.
- Critical review of current understanding of health impact of air quality on children.
- Critical consideration of mitigation strategies, both theoretical and practical.

3.4.2 Literature review process

The literature review process for this thesis broadly followed the work set out by Borg et al (1996) which followed on from Malen (1991). The process is set out in Figure 6.

Figure 6 Literature review process map



In June – September 2023, information was collated using systematic searches of internet resources such as Science Direct, online journal resources such as Wiley online library, JSTOR, Springer online library and the University of Derby online library.

The following requirements for results were specified:

- Full text available
- Written in English
- Titles screened for relevance.
- Duplicates removed.
- No date restriction was applied, however during the extraction process articles and reports sorted by date to ensure most recent research prioritised.

For the literature review which focused on any comparable research into analysis of differing diffusion tube heights, no geographical restrictions were applied, however during the extraction process research was sorted by location to allow UK research to be prioritised in the review, however research from further afield was also identified and critically discussed.

Finally, the method known as snowballing and reverse snowballing was used on relevant academic research. Snowballing refers to the process of retrieving any relevant articles cited in an appropriate research paper, and then retrieving and checking the new article for any pertinent literature (Sayers, 2007).

3.5 Limitations of methodology

3.5.1 Primary data - Exposure time period

The foremost limitation of the methodology used in this work relates to the time period for which the diffusion tubes were exposed. As ethical approval was required before data collection could begin, it was not possible to begin data collection until September 2023. Therefore, four months of data have been obtained. Although the yearly average is not achieved from exposure rather a calculation method, it is appropriate to note that TG2022 states that any monitoring programme should as a minimum be over a period where emissions are likely to be highest. Therefore, given that tail pipe emissions contribute to poorer air quality over the winter period Wine et al. (2022) concluded that cold temperatures for example may contribute to substantial increase in emissions, it can be considered that this is an appropriate and justifiable monitoring period.

3.5.2 Primary data - Diffusion tubes as a measuring tool

The use of diffusion tubes as the method of measuring emissions of road traffic comes with inherent uncertainty (Butterfield, et al., 2021). Diffusion tubes may over or underestimate for a number of reasons such as seasonal variations or nearby emissions such as diesel generators or boiler flues in the vicinity. Alternative methods include low-cost sensors or Continuous monitoring stations. Whilst these alternatives may potentially offer more confidence in terms of the accuracy of measurements, they are also expensive and require a constant electricity source. Therefore, it was considered justifiable to employ the diffusion tube assessment method.

4. Results and discussion

4.1 Introduction

The purpose of this chapter is to report and critically evaluate the findings of the primary data collection undertaken, ensuring that the principle aim of the study and objective 4 are met. The discussion will look at the variables that may have led to the results being as they are, and in addition will consider the implications for public health, a comparison with similar studies found in the critical literature review and a comparison with results found in the Local Authority monitoring regime. The chapter will conclude with a series of recommendations for the Local Authority and the nursery, to meet objective 5. Limitations of the study and considerations for wider research will also be identified.

4.2 Results

This results in table 1 report the results of the primary data collection. Diffusion tubes at 2.7m, 1.7m and 0.7m were installed as part of this study, the West Park diffusion tube data is retrieved from the Local Authorities monthly monitoring regime and the Local Authority average from the same is added for comparison. It is the numerical average of concentrations measured at 43 diffusion tubes installed across the borough.

All results are shown in µg/m3.

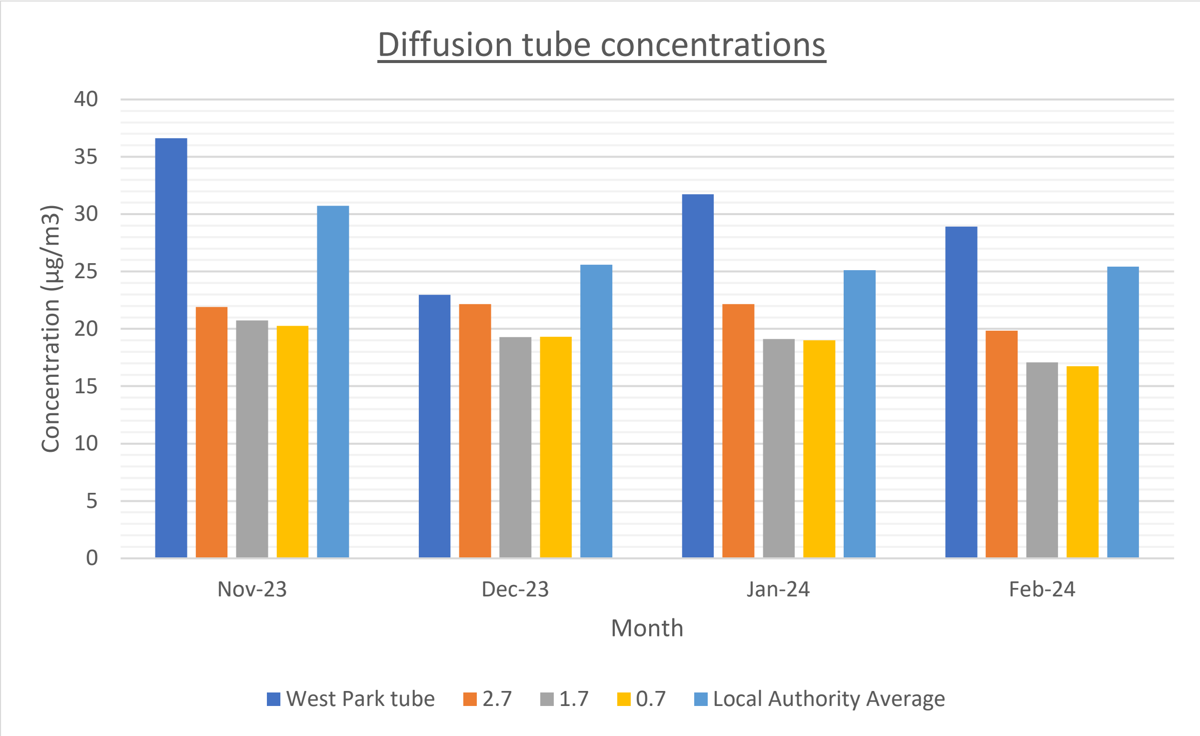
Table 1 Diffusion tube concentrations

	West Park tube (LAQM)	**2.7m**	1.7m	0.7m	Local Authority Average
November	36.63	21.92	20.74	20.26	30.73
December	22.97*	22.15	19.27	19.31	25.6
January	31.73	22.16	19.13	19.01	25.13
February	28.91	19.85	17.07	16.75	25.42

* *Analysis provided by laboratory for the West Park Tubes December concentration identified that the concentration of NO_2 on the diffusion tube may have been compromised by water droplets. This would likely dilute the concentration of NO_2 and provide an inaccurate reading for the month in question. This is discussed further in the analysis of results, and the limitations section.*

These results can be displayed in chart form for a visual reference, as shown in figure 7.

Figure 7 Diffusion tube concentrations bar chart



4.3 Initial analysis

There is a clear trend in the results detailed here, indicating that there is no significant statistical difference in measured concentrations at the three diffusion tubes that have been installed for the purposes of this survey. All months measured show a minimal difference between the tubes measured at 0.7m and 1.7m and a consistent though very small increase to the tube measured at 2.7m. These findings are notable as they contradict the findings of Kenargy et al (2018) and Rowell et al (2021) as discussed in the literature review and this is considered further later in this chapter.

Concentrations are showing a gradual decrease as we move out of winter as expected. The November and January concentrations at the West Park are relatively high compared to the Local Authority average and the tubes installed for this work, this is not unusual given the traffic levels in the location. However, although the concentration fluctuates between 36.63 µg/m3 and 28.91 µg/m3, which is consistent with a similar decrease shown in the LA average, there is no such fluctuations in the tubes installed for this study, where the concentrations remain steady over the full monitoring period of the four months. The potential reasons for this are discussed further in this chapter. This chapter will also critically consider the notable drop of in emissions with distance that can be seen when comparing the West Park tube to the tube that was installed at 2.7m on the façade of the building for the purpose of comparing the two.

4.4 Implications for public health

To allow for comparison with relevant guidelines, it is necessary to calculate the annual mean concentration. This involves a process of annualisation and bias adjustment as descried here.

4.4.1 Annualisation

The process of annualisation is provided by DEFRA (2020) and allows for an annual mean average to be predicted where data collection has been carried out for less than nine months. The methodology uses NO_2 data from nearby continuous monitoring stations to estimate concentrations.

4.4.2 Bias adjustment

To investigate diffusion tube accuracy, a bias adjustment can be calculated in one of two ways, either the local bias adjustment which is derived from an accuracy procedure where a monitoring station results are compared against diffusion tubes installed at the monitoring station, or a national method, where a spreadsheet is provided by DEFRA (2023)to allow for a factor to be derived from results provided by other Local Authorities. Table 2 details these results for each tube.

All results are shown in µg/m3.

Table 2 Diffusion tube annual concentrations

Tube height	Monitoring period (Months)	Raw data	Annualised	Bias Adjust
0.7	4	18.83	17.1	16.58
1.7	4	19.05	17.2	16.70
2.7	4	21.52	20.0	18.46

The annual average for all three diffusion tubes involved in the study is well below the EU annual guideline level of 40 µg/m3, which is consistent with the Local Authority monitoring data for all 43 diffusion tubes and monitoring stations across South Tyneside. In addition, the technical guidance (TG2022) shows that a study carried out on behalf of DEFRA identified that exceedances of the 1 hour mean objective of 200 µg/m3 not to be exceeded more than 18 times a year is unlikely to have been breached where the annual mean is below 60 µg/m3. This indicates that the outdoor setting where the children are spending time is not in breach of any current EU air quality objectives for NO_2.

In 2021, the WHO updated its air quality guidelines with more stringent values for selected pollutants, including NO_2 (WHO, 2021). The new recommendations reflect recent evidence, such as that identified in the critical literature review on the impact of air quality on health, and advocate for much lower guideline values, with a new NO_2 limit value of 10 µg/m3.

In February of 2024, the European parliament and the European Council reached a political agreement to introduce legislation that will set new air quality standards which will align more closely with the WHO's guidelines than current objective levels (European Commission, 2024). The proposal to revise the Ambient Air Quality directive (AAQD) will set a new limit value of 20 µg/m3 by 2030, with the final aim of aligning fully with the WHO guidelines by 2035. Therefore, alongside interventions at a national level required to drive down air quality emissions, interventions such as those identified in the critical literature review on mitigation methods, will be required at the nursery location as and when these recommendations are brought forward into law.

4.5 Comparing tube at nursery with tube STC local monitoring tube.

A further aspect of this study was to locate a diffusion tube within the nursery outdoor setting at a height of 2.7m. This was to allow for direct comparison of emissions recorded with the diffusion tube that is located within the locality of the nursery as part of the Local Authorities monitoring regime. This diffusion tube was sited at the nearest point to the roadside next to the nursery in response to concerns raised by the Environmental Health team relating to the proximity of the nursery to the busy road network. A comparison of results is identified in table 1.

The table shows a consistent decrease from the tube located 1m away from the roadside to the tube at the façade of the nursery, 12.5m away from the roadside. This result is to be expected and is consistent with current evidence. There is substantial research, as highlighted in the critical literature review (section 2.3.4) that indicates there is a causal relationship between NO_2 drop off with distance from the road.

Technical guidance provided by DEFRA (2016) allows for a calculation to take place to predict the NO_2 concentrations at distances away from the roadside where a number of variables are known. Therefore, using the emissions measured at the roadside using the LAQM monitoring regime, the prediction methodology can be used to compare with the emissions measured at the façade of the nursery.

Figure 8 shows the inputs used for this calculation. The input for the NO_2 background level has been derived from the data provided by DEFRA's background concentrations (DEFRA, 2024). The results for November have been applied.

Figure 8 Fall off with distance inputs.

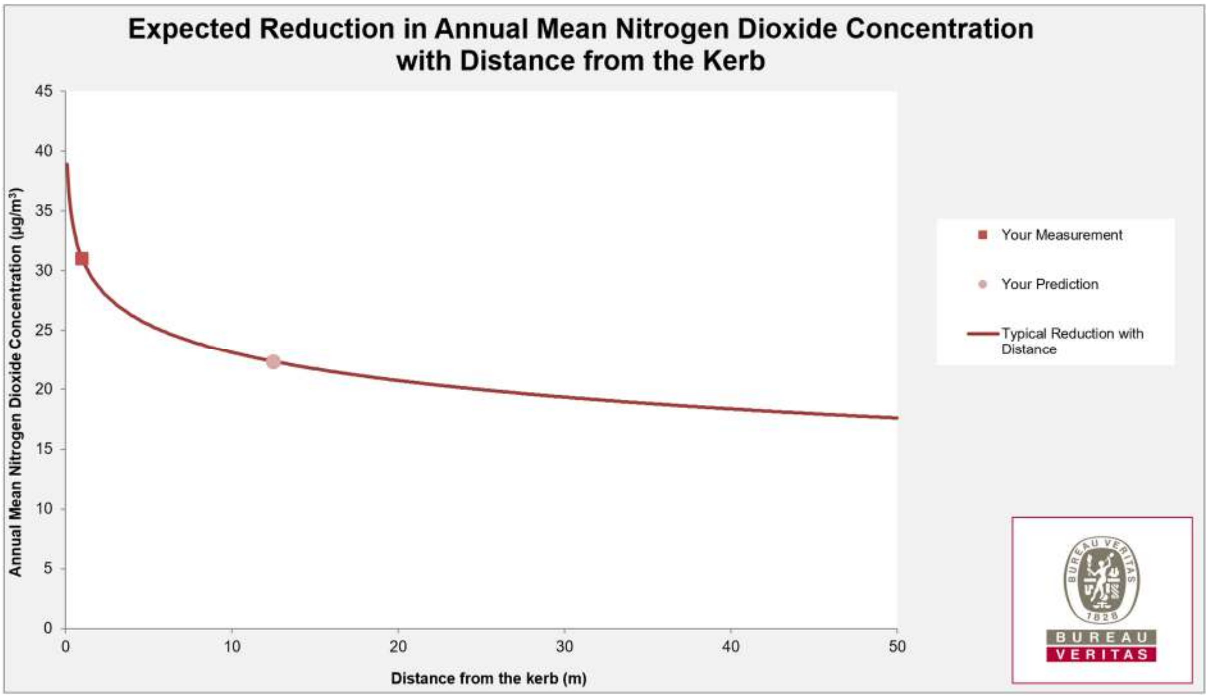
Enter data into the pink cells

Step 1	How far from the KERB was your measurement made (in metres)?	1	metres
Step 2	How far from the KERB is your receptor (in metres)?	12.5	metres
Step 3	What is the local annual mean background NO_2 concentration (in $\mu g/m^3$)?	14	$\mu g/m^3$
Step 4	What is your measured annual mean NO_2 concentration (in $\mu g/m^3$)?	31	$\mu g/m^3$
Result	The predicted annual mean NO_2 concentration (in $\mu g/m^3$) at your receptor	22.3	$\mu g/m^3$

The predicted concentration of 22.3 µg/m3 is almost identical to the measured concentration of 22.16 µg/m3.

Figure 9 shows the expected reduction in graph form and starkly identifies the sharp fall off from the roadside to a steady level at around 10m away from the road. Reference found that background levels are realised at around from the roadside.

Figure 9 Expected reduction.



This has proved to be a useful comparison and will allow for the Local Authority to confidently predict emission levels at the nursery at any point in time by using the concentrations found at the roadside tube. This gives confidence that the prediction methodology used here is sound and allows for accurate emission levels at distances away from the diffusion tubes used in the Local Authority regime.

4.6 Comparison with other studies

Table 3 identifies the studies discussed in the critical literature review and highlights pertinent details of the methodology of the studies. The table compares the outcomes of analysis of emission levels at a child's breathing height compared to levels at adult breathing height. Similar to this study, the work by Rowell et al (2021) also compared emissions at 2.7m, however it is not completely comparable to the work in this study as the tube is located in a slightly different area of the outdoor setting, whereas in Rowells work the tube is located on the same drainpipe allowing for direct comparison in their study.

Table 3 Comparison of similar studies

Location	Method of analysis	Height – (m)	Distance from kerb (m)	Outcome	Reference
South Shields	Diffusion tube	0.7 and 1.7	12.5	**No** statistical difference.	This study
Newcastle	Diffusion tube	0.7 and 1.7	7	7.1% - 11.4% **lower** at 1.7m vs 0.7m	Rowell, et al., (2021)
Edinburgh	Diffusion tube	0.8 and 2.0	0.4 – 4.7	8.7% **lower** at 2.0m v 0.8m	Kenagy, et al., (2016).
			>5	**No** statistical difference	
Glasgow	Low-cost sensor	0.8 and 1.68	0 (kerbside monitoring)	15% **higher** at 1.68m v 0.8m	Scottish Government (2015)

As can be clearly identified in the table 3, the outcome of this study is not consistent with the principal conclusions of the similar studies carried out. The table shows that the two similar studies in Newcastle and Edinburgh are in agreement with each other, namely that there is a significant increase in emission levels at 0.7m as opposed to 1.7m. This study has identified no such increase between the two heights. The Glasgow research is not consistent with any of the identified studies, including this work, however this was undertaken using a different methodology of measurement, a portable sensor pushed around busy city centre streets on a trolly, the proximity of this trolly to the road potentially explains the difference between the Glasgow study and others, as the literature review identified, the chemical reactions occur over the duration of a few seconds at the road. One of the critical differences of this study with Glasgow and Newcastle is the distance from the roadside to the diffusion tube. This was necessary to ensure that he outdoor setting of the nursery was appropriately characterised by the monitoring. However, it is further away from roadside traffic than the comparable studies. Notably, the study in Edinburgh carried out further assessment of results at locations over 5 metres away from the curb and, agreed with the results of this study, showing no significant statistical difference of diffusion tubes at 0.8m and 2.0m.

The studies detailed in the critical literature review, specifically in section 2.3.2, have highlighted a trend found in research, such as that by Sajani et al (2018) and Eeftens et al (2019) that shows a reduction in concentrations at higher heights on buildings. This is also not consistent with the findings of this study, where a slight increase in concentrations is found between the tubes at 0.7m and 1.7m and the tube at 2.7m. These findings however are consistent with the outcome of a similar study carried out by Monn et al, who, has detailed in the literature review, found that there spatial gradients in the Winter were significantly less in the winter than in the summer. In their recent review of over 170 research papers into the influencing factors of airflow and pollutant dispersal around buildings, Wu, et al (2022) concluded that their remains a key gap in knowledge regarding how the complexities of the real world affect the behaviour and flow of pollutants.

The following critical discussion examines the local factors that may have influenced the results that have been detailed in section 4.2.

4.6.1 Distance from the road.

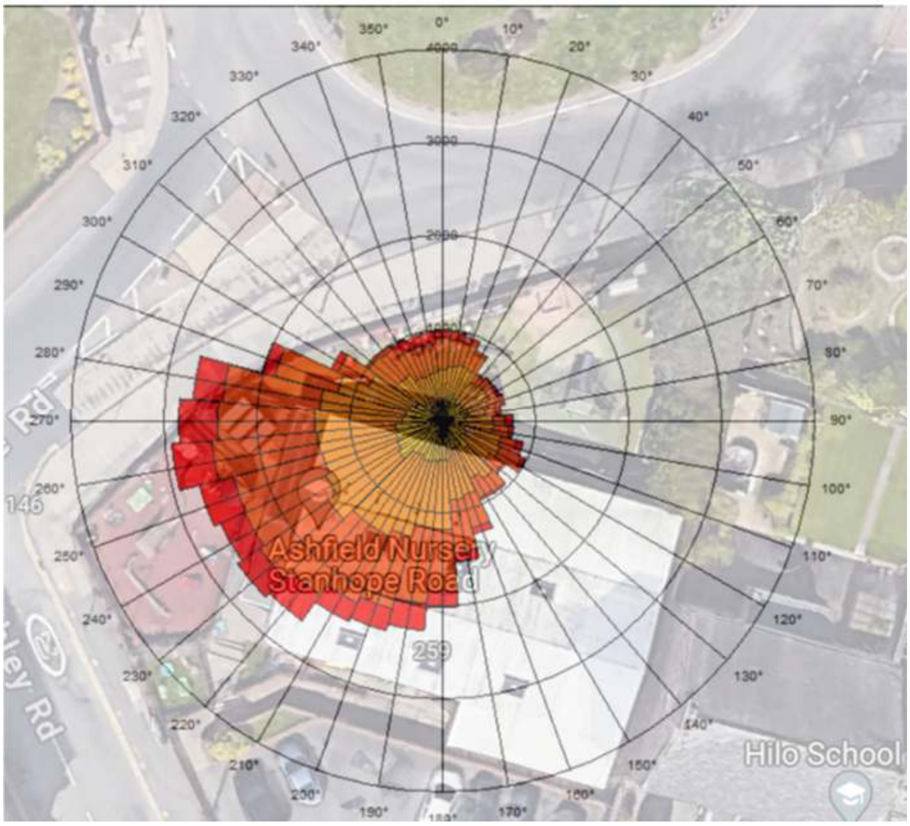
When considering the studies found in the literture review, this work is unique in that it considers concentrations at a greater distance from the road than all similar studies. It is well known that there is a relationship between the distance from the roadside and NO_2 concentrations at a given point (DEFRA, 2008). This will be critically discussed later in this section when comparing our results to the existing diffusion tube that is in the vicinity for exisiting Local Authority monitoring. However, it is also likely to be a critial factor when given that all concentrations measured within the outdoor setting are a very similar and consistent level over the monitoring period. Given that the concentrations are similar to those provided by DEFRA for background concentrations (Defra.gov.uk, 2024), it is possible that the impact of road traffic emissions at this distance from the road is reduced and background levels as a result of pollutants transported into the area from further away.

4.6.2 Wind speed and wind direction

Variations in weather conditions on scales of metres to many kilometres can be shown to impact on spatial and temporal variations of NO_2 concentrations (DEFRA, 2022).

In their research into the behaviour of pollutants as a result of road traffic, Hwang et al (2015) showed that pollutant concentrations can be significantly influenced by the prevailing wind direction. The wind rose below in figure 10 has been obtained from recent data (Environment Agency, 2020) and shows the prevailing wind direction, overlayed on a google maps image of the nursery.

Figure 10 Prevailing wind direction wind rose



As can be seen, it shows a strong trend of wind coming from the South Westerly direction. This could potentially have the impact of influencing dispersion of air flow by blowing towards the tree lining and screening that is in place at the nursery as can be seen in figure 11.

Figure 11 Image of tree line at nursery. Google Maps (2023)

Kenagy, et al (2016) found that greater wind speeds incresased the rate and extent of dilution of road traffic NO_2. Reduced wind speeds are known to reduce dispersion which can cause NO_2 concentrations to accumulate close to its source (Bower, et al., 2004). Wind speed at the Albemarle weather station, the closest weather monitoring station with data recognised by the UK Met Office (Met Office, 2024), was an average of 5.1 knots (Met Office, 2024a) which is classified on the Beaufort scale as a light breeze (Met Office, 2024b), this indicates therefore that the wind over this period was not of significant strength and therefore emissions may have been localised to the outdoor setting area.

4.6.3 Air flow within outdoor setting

The design of buildings can significantly affect air pollution levels, factors such as height, density and material can impact on the air flow within an area (Frederickson, et al., 2024). Diffusion tubes were located within the outdoor setting of a nursery, and therefore there are several play structures such as slides and climbing frames near to the location of the diffusion tubes. There is also a very small boundary wall between the road and the play area, McNabola, et al (2008) demonstrated that a low boundary wall of 0.5m in height can have a significant influence on the air flow close to the roadside and beyond depending on additional factors such as wind speed and direction. Technical guidance provided by DEFRA (2008) states that diffusion tubes should be sited away from vertical surfaces to ensure unimpeded air flow around the diffusion tube. It is therefore possible that the air flow in the outdoor setting and therefore the emissions dispersal is influenced by the structures and low boundary walls that are in the vicinity.

4.6.4 Tree cover

As previously detailed, it was necessary to install the diffusion tubes in an area of the outdoor setting that was not accessible by the children to ensure that the tubes were not removed. The location where the tubes were installed was close to trees and overhanging shrubbery as shown in figure 11. There is considerable conflicting research which has examined the impact of tree cover on the dispersal of pollutants from traffic depending on the level of tree canopy coverage, type of tree etc. As an example of these inconsistent outcomes, Grundstrom & Pleijel (2014) found a small reduction of NO_2 levels due to urban tree vegetation on a traffic route whereas Ylies-Pelkonen, et al (2020) using similar methodology found that NO_2 levels showed no change at all under tree canopies as opposed to treeless areas. The consistently slightly higher concentrations that are found at the 2.7m tube may indicate that the role being played by the trees in this instance is one of mitigation as opposed to a localised increase. However this hypothesis would be contrary to the findings of Deysana, et al (2017) who found that the uptake of NO_2 by vegetation was not as prevalent in the winter months. Salmond, et al (2023) concluded that the role of vegetation is likely to be determined by factors such as type, density, climate conditions, street geometry and emission rates. Therefore, more detailed work would be required in this location to determine the extent to which the tree line influences the dispersal of pollutants in this localised area.

4.7.1 Wider implications of results

Although this study has provided confidence that air quality at this particular nursery is consistent with concentrations found in locations as part of the LA monitoring regime, and furthermore well within the concentration guidelines provided for health impact (at this time), given the disparity between results with similar studies that are geographically close to our monitoring location, it is not clear what wider implications this study may have for local or national air quality policy. Further research, such as that identified in the conclusion, would help to understand further the relationship between diffusion tube heights and concentrations and adult and child breathing heights. The knowledge detailed in the critical literature review, particularly with regards to health impact, proves that this type of research is greatly relevant and needed at this time.

4.8 Recommendations

To fulfil objective 5, recommendations can be highlighted to the nursery and the Local Authority as detailed in table 4.

Table 4 Recommendations to nursery and council

Recommendations to nursery
Provide parents with the outcome of this thesis, confidence can be gained from this report that emission levels are within guidelines set and no objective levels are being breached at the nursery.
Consider contacting the Local Authority to see if they are currently undertaking school streets schemes, although it is likely that this would not be feasible due to the location being on a roundabout that holds strategic network importance for the borough, and therefore will not be able to close during peak times, the behaviour change theory can still be considered. One possibility would be to look into obtaining a low-cost sensor, potentially through the Local Authority, or grants, and incorporate into the nursery curriculum with principles similar to school streets, but also will allow for a complete picture of air quality throughout the day and potentially schedule outdoor breaks accordingly.
Investigate the possibility of joining the Schools Air quality Monitoring for Health and Education (SAMHE) project. This is a new initiative which is bringing together a network of air quality monitors inside schools and nurseries in the UK and will provide participants with free sensors.
Explore the possibility of undertaking air quality measurements inside the building, this could be with static diffusion tubes or low-cost sensors, especially in rooms facing onto the roundabout, and use the measurements to consider if an internal green wall would be beneficial in the room given the findings discussed in the literature review.
As discussed in the literature review, green walls have been found to improve air quality in outdoor environments. Therefore, consideration of such mitigation would be beneficial, this might be with bespoke green walls as discussed, or perhaps an initiative with the children to look into how to provide more green vegetation around the boundary of the nursery.
Confidence can be taken from this assessment, caveated with the limitations that have been set out, that in this specific instance, monitoring that is being carried out in the vicinity can provide an accurate depiction of air quality exposure at the children's nursery.
To consider carrying out similar exercises at different nurseries and school settings within the Local Authority to assess whether the results of this assessment are consistent across the area. Investigate any possible streams of revenue to allow for further consideration of green screens or similar practical mitigation schemes at nursery settings.
Continue to promote school streets schemes to embed behaviour change interventions into local communities.

Recommendations to council.
Confidence can be taken from this assessment, caveated with the limitations that have been set out, that in this specific instance, monitoring that is being carried out in the vicinity can provide an accurate depiction of air quality exposure at the children's nursery.
To consider carrying out similar exercises at different nurseries and school settings within the Local Authority to assess whether the results of this assessment are consistent across the area.
Investigate any possible streams of revenue to allow for further consideration of green screens or similar practical mitigation schemes at nursery settings.
Continue to promote school streets schemes to embed behaviour change interventions into local communities.

4.9.1 Limitations.

Table 5 details the limitations that have were unavoidable throughout the period of the work.

Table 5 Limitations of this study

Primary data - Monitoring period
Due to the time limits involved, specifically regarding obtaining ethical approval before being able to commence data collection, the primary data collection took place over a four-month period during the winter months, a time when measured emission levels are at their highest. A full 12 month measuring period would have allowed for a complete analysis of the yearly mean concentration at the nursery, and a more substantial analysis of any potential monthly variations in levels throughout the full monitoring period.
Primary data - Comparison of results
A change in ownership of another nursery in South Tyneside, just before monitoring began resulted in permission being withdrawn for monitoring to take place at that nursery. Consequently, a comparison of results at different nurseries within the local area was not possible.
Primary data - Diffusion tube result
Diffusion tube analysis provided by the laboratory noted that the diffusion tube located next to the nursery as part of the Local Authority monitoring regime may have been compromised by water droplets, and therefore the concentration result may not be accurate. This highlights the uncertainty of diffusion tubes as a monitoring tool.
Secondary data – comparable studies

The outcome of the literature review process for the critical review of comparable studies identified three similar studies. Whilst this low number of similar research limits the comparison analysis possible, this does identify gaps in current research, and therefore justifies the rationale behind this study, in addition, the three comparable studies are geographically close to the location used in this study, giving confidence that robust comparisons can be made.

5. Conclusion

The aim of this dissertation was to critically evaluate any variations in levels of NO_2 depending on the height of diffusion tubes located at a children's nursery. Objectives for this study alongside the central aim were to carry out a critical literature review into any similar research, the current knowledge around the health impacts of air pollution on children and what mitigation exists for areas where air pollution is of concern.

The primary data collected at the outdoor setting of the children's nursery showed no change in levels in NO_2 at diffusion tubes at 0.7m and 1.7m, to replicate children's breathing height and adults respectively. A small increase was found at the diffusion tube located at 2.7m in height, the purpose of this tube location was to replicate Local Authority monitoring practices and to allow for comparison with an existing diffusion tube in the proximity of the nursery. The comparison with the existing tube showed a significant drop off in concentrations due to the distance between the road and the diffusion tube. The results of this study contrasted with studies with three comparable studies identified in the critical literature review, and the possible reasons for this have been critically analysed with wind, distance from the road, intervening physical structures and tree cover the likely reason for this disparity. The measured concentrations have been considered in terms of public health implications and found that levels are well below the current guideline levels however, as discussed in the work, the WHO have recommended newer, more stringent guideline levels due to emerging evidence, such as that discussed in the critical literature review on health impact as a result of air pollution. Recommendations have been formed from the critical literature review for how the nursery can consider mitigating concentration levels using practical methods such as green screens, or by incorporating behaviour change theory such as school streets, both methods have been shown to reduce emission concentrations.

5.1 Recommendations for wider research

Given the disparity between this research and the two similar studies in terms of outcomes, a useful piece of similar research would be to prioritise and further understand the impact of distance from the road and diffusion tubes at different heights at different distance from the road.

A similar piece of research that would be useful would be to carry out a study at areas with low and high traffic to understand further the relationship between background concentrations and diffusion tubes at different heights as considered in this study.

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