UK Health Security Agency

Transport interventions at schools: health impacts and benefits

Summary of international and UK studies

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Executive summary

The UK has made good progress in reducing emissions of all major air pollutants, and air quality has improved significantly over recent years. However, poor air quality in urban areas remains one of the largest environmental risks to public health and reducing air pollution remains one of the persistent public health challenges.

Motor vehicles are a significant source of exhaust and non-exhaust air pollutants and one of the largest contributors to poor air quality. Adverse health effects are a rising concern due to increased urbanisation with increasingly busy roads and emerging health effects which are also associated with inequalities. The Health Effects Institute (HEI) 2022 report (37) found links between adverse health effects and traffic-related air pollution, including effects on children who are at greater risk of air pollution health outcomes. During travel to school, children may be exposed to high levels of traffic-related pollution. As many schools are located close to busy roads, mitigating air pollution in and around schools and exposure during traveling to and from school has the potential to reduce children's exposure to harmful pollution and potential health risks.

A wide range of interventions have been carried out to promote active travel to and from school in the UK and worldwide over the last decades. Such interventions have demonstrated an increase in active travelling but only a few have examined whether this has been associated with less exposure to traffic-related air pollutants or their effectiveness on exposure reduction and/or health outcomes.

Our previous review considered the scientific evidence on people's exposure to air pollutants during transport and identified factors influencing exposure such as transport mode, proximity to motorised transport and ventilation settings for closed vehicles (48). The review helped to better understand how exposure to air pollution changes by mode (driving, cycling, walking, public transport), by route (direct and alternative route) and other factors. In parallel, Osborne and others reviewed studies that reported air pollution concentrations around school environments, as well as interventions that aim to reduce children's exposure to air pollution (54). Following on from the reviews, recommendations were proposed that included supporting active travel choices and use of public transport.

The current work is a step further in reviewing the effectiveness of implemented transport-related interventions around schools at reducing children's exposure to air pollution, any associated health benefits, as well as other co-benefits. Through this summary of evidence, we have identified co-benefits related to increased use of active travel modes and physical exercise, improved road safety and sustainable travel, enhanced socialising, reduced traffic congestion, while in relation to health outcomes, there was reported evidence on respiratory impacts and cardiometabolic health for children.

A range of interventions have been implemented or considered for implementation, which are categorised here related to:

- vehicle technology and driving behaviour
- traffic management
- active travel and behavioural change
- urban planning or school location

In assessing air quality or health improvement, different monitoring and/or modelling methods have been deployed. However, the assessment of interventions can be challenging, and the benefits of interventions are often hard to capture and assess properly, although there are reported cases where benefits have been captured and/or quantified (for example, reduced exposure to air pollution linked to the choice of walking route to school).

The interventions related to school bus technology and fuel were effective for the local environment, but there were concerns around the in-cabin concentrations levels, as they are strongly affected by the air filtration and the vehicle speed. The actions related to closing streets temporarily can lead to reductions in traffic-pollutant concentrations during certain hours of the day, such as school drop-off times, but they offer low to medium air quality improvements in the wider area. The interventions related to active travel and behaviour change appear to be effective when combined with other factors, such as choice of route, affecting the exposure to air pollution; these interventions offer great co-benefits including an increase in physical activity and road safety consideration, and reduction in traffic congestion.

Following the summary of evidence, we propose some interventions that can have a positive impact on climate, air quality and children's health and these include those aiming at:

- preventing emissions – implementation of school streets and anti-idling measures, improvement of pedestrian and cyclist environments, selection of school location at a distance from heavy traffic areas
- mitigating pollutant concentrations – upgrading of public transport vehicles and school buses, use of mechanical or natural ventilation in public transport vehicles, driving behaviour improvements
- avoiding exposure – provision of cycling training and other activities or tools that facilitate shifting to active travel, production of maps for identifying cleaner air routes for travellers

In terms of evaluating the interventions, there is a need to develop and/or adapt approaches that would consistently measure the benefits to health in relation to the different pathways, including air quality improvements, increase in physical activity, and climate change benefits. Therefore, a combination of tools is required to assess interventions and inform the prioritisation of those to be implemented.

Introduction

Background and previous work

Poor air quality is one of the largest environmental risks to public health in the UK. As shown by many epidemiological studies on air pollution, long- and short-term exposure is associated with several health impacts including reduction in life expectancy, exacerbation of asthma and increases in respiratory and cardiovascular hospital admissions (see Health matters: air pollution).

Some people are more at risk of health problems caused by air pollution. These could be children and elderly, individuals with existing cardiovascular or respiratory diseases, pregnant women and people from deprived communities that can either be more susceptible or/and more highly exposed to air pollution.

Children are more exposed to air pollution due to a number of factors including high physical activity and breathing rates, as well as their low breathing zone (closer to traffic fumes). Also, children are growing, and their respiratory and immune systems are still developing, so they are particularly more affected by pollutant exposure (22). For accessibility, many schools are located near main roads, and vehicular emissions can penetrate the school premises, including classrooms.

Exposure to air pollution has a great impact on children's health. For example, nitrogen dioxide (NO_2) and particulate matter (PM) mainly as fine particulate matter ($PM_{2.5}$) and ultrafine particles (UFPs)[1] affect the respiratory system, as well as the cognition and developmental nervous systems (8). The UK Committee on the Medical Effects of Air Pollutants (COMEAP) commented on the evaluation of whether specific populations and life stages are at increased risk from health effects of $PM_{2.5}$ (64). The Committee reported that although the available evidence did not indicate a difference in PM-related health effects between children and adults, studies indicated effects that were specific to growing children, such as impaired lung growth, decrements in lung function and the development of asthma (19).

Traffic-related pollution around schools has been reported to have a significant impact on the pulmonary function and respiratory system especially of primary school children (32) and it has been found that exposure to traffic-related pollutants impacts on children's lung development (12). Some studies have suggested that exposure to traffic related air pollutants may potentially affect children's academic performance, working memory and problem-solving ability (7) (40) (30).

[1] $PM_{2.5}$ is defined as the mass of particulate matter (PM) per unit volume of air passing a size-selective inlet with a 50% cut point efficiency at 2.5µm particle aerodynamic diameter. In practice, $PM_{2.5}$ contains fine particulate matter (PM) with a diameter of less than or equal to 2.5µm. Ultrafine Particles (UFPs), defined as airborne particles with an aerodynamic diameter of 0.1 µm (micrometers) or less.

Children spend a significant proportion of their time at school – in the UK, the proportion is estimated at 25% (28). The BREATHE project[2] reported that children spent on average 6% of the daytime in commuting, which resulted in about 20% of the daily dose of black carbon (58). Hence, mitigating children's exposure to air pollution at schools and during the school run represents an important way by which children's overall exposure to harmful pollutants can be reduced.[3]

In this work, we focused on transport interventions, as they may have important benefits on various aspects related to health, including air quality and physical activity. Sustainable transportation can improve population health through individual transportation choices, such as by using active travel[4]. Promoting activity patterns leads to enhancing social participation and neighbourhood walkability, as well as increased exposure to green spaces. In the UK, a number of recent initiatives by local authorities have focussed on mitigating children's air pollution exposure at school and on promoting active travel, as described in the following sections.

Osborne and others (54) identified some transport and other interventions around schools and discussed evaluation of them in their comprehensive literature review on air pollution levels and exposure in outdoor school environments. However, the study concluded that there is a need for a greater number of studies that report on evaluation of local interventions aiming to mitigate children's exposure to air pollution (54). Mitsakou and others (48) reviewed the evidence on the exposure to air pollution in different transport microenvironments and considered factors affecting exposure, such as choice of route and cycle paths (48). Based on the conclusions of the review, the authors also made recommendations for transport interventions following the hierarchy of interventions model proposed by Public Health England (PHE) (56).

The current work has been conducted within the frame of the National Institute for Health and Care Research (NIHR) Health Protection Research Unit (HPRU) in Environmental Change and Health to deliver on air quality improvements and benefits of climate change action. We build upon the previous reviews on the exposure to air pollution at schools and in transport microenvironments and we focus on the efficacy of implemented or suggested transport interventions that aim to improve children's health, while also considering the co-benefits. We summarise information gathered from global and UK sources, and we conclude with the main findings and recommendations. This can be used in a number of applications, including informing decision making for implementing interventions that aim to improve air quality and public health around schools.

[2] Brain Development and Air Pollution Ultrafine Particles in School Children (BREATHE) Project. The objectives of the project are to develop methods for measuring children's personal exposure to ultrafine particles and also neuroimaging methods for assessing correlations between neurobehavior, neurostructural alterations and particle deposition with the aim to investigate how traffic pollution affects children's exposure to key contaminants and brain development.

[3] School run is the time when children are taken to or from school.

[4] Active Travel refers to journeys made by modes of transport that are fully or partially people-powered, irrespective of the purpose of the journey, including walking, people using wheelchairs, cycling. 'Walking and wheeling' is for moving as a pedestrian, whether or not someone is walking or wheeling unaided or using any kind of wheeled mobility aid, including wheelchairs, mobility scooters, walking frames, prams or buggies.

Aim and objectives

The main aim of this work is to identify sustainable actions that will have beneficial impacts on the health of school-age children and that once implemented, it will be easy for people to continue to follow them. Towards this aim, the objectives are to:

- collect information on road transport (or other outdoor) interventions that have been implemented around school areas
- summarise and categorise types of interventions
- discuss (expected) benefits and co-benefits on air quality, climate and health
- indicate which interventions are most likely to be beneficial

Outline of the document

In the Methodology: evidence summary section, we report the methodology that we followed in this work.

The Transport interventions at schools: impacts on air pollution section includes the findings of our evidence summary, while the Interventions aiming to increase physical activity and road safety describes those interventions that we identified in our collected information that do not aim primarily to improve air quality but may have beneficial to air quality indirect impacts.

The Tools for promoting active travel section includes a summary of tools that have been developed which aim to promote active travel and do not consider air quality impacts or benefits. In the Approaches and tools for assessing interventions section we report approaches and tools that we identify towards this aim. Finally, we conclude with the Discussion and Conclusions and recommendations.

Methodology: evidence summary

To collect the most updated information on the transport interventions around schools, we explored sources through publications in peer-reviewed and grey international literature, as well as through contacting and collecting relevant information from people in policy, academia and other sectors.

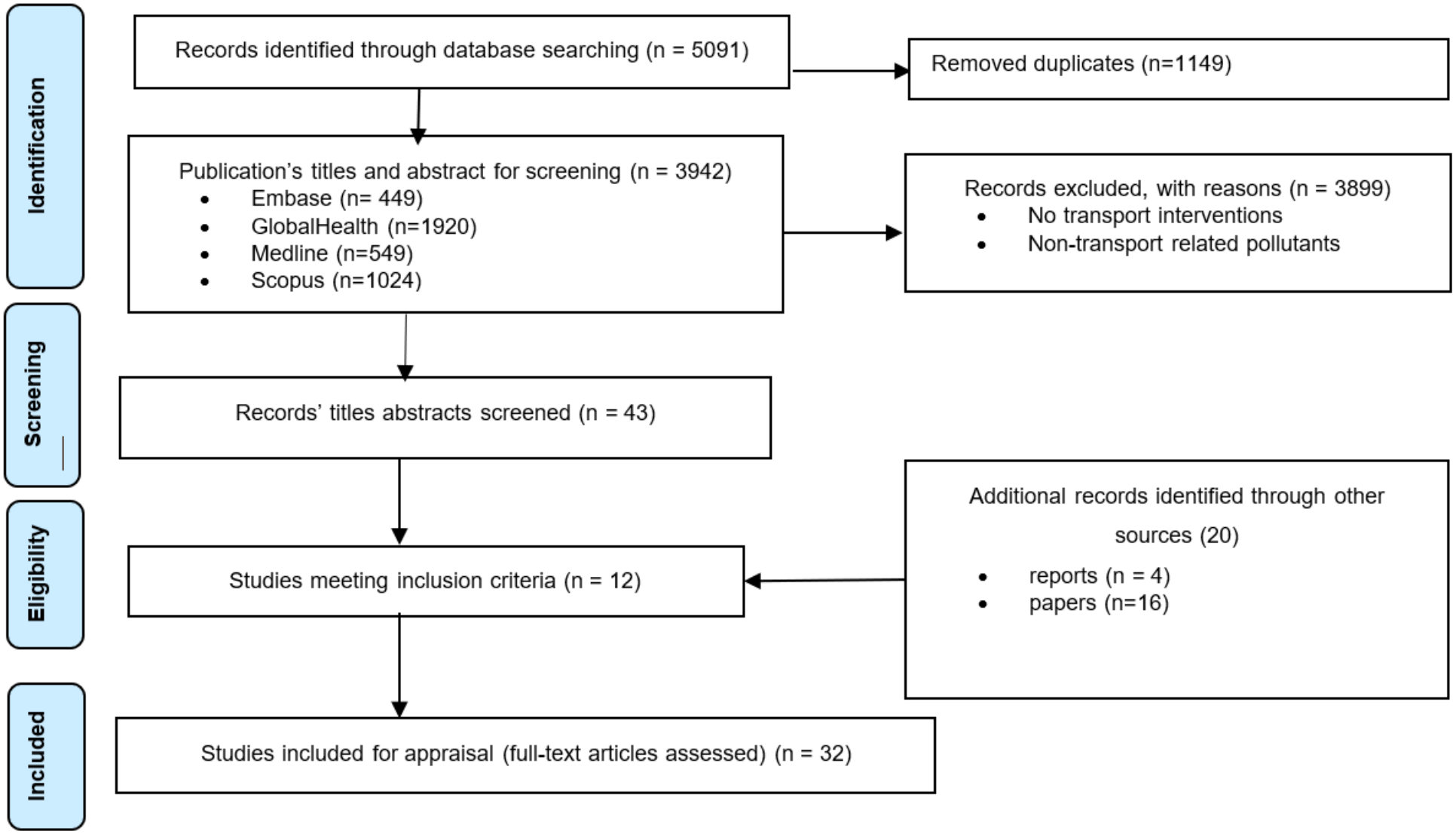
International studies

Information from different sources was collected, as summarised below:

1. Information on road transport interventions from the review of interventions to improve outdoor air quality and public health (56). In 2019, PHE (former organisation of UKHSA) was commissioned by the Department for Health and Social Care (DHSC) to review the evidence for practical interventions to reduce adverse health effects from outdoor air pollution. The focus of the review was on 5 areas for actions – vehicles and fuels, spatial planning, industry, agriculture, behavioural change – that could be available to local authorities. In the current work, we focused on the actions relevant to the outside of school environment.
2. Update the review of interventions around schools since July to August 2019 (54). This work reviewed the air quality around schools and identified some interventions that have been implemented around schools aiming to improve the air quality.

We carried out a literature search looking at peer-reviewed journal papers, but also the grey literature and the details are shown in Annexe A. The results of the screening study selection process are shown in Figure 1.

Figure 1. PRISMA flowchart of study selection process from the literature search



Text version of Figure 1

A PRISMA diagram showing the flow of studies through this review, ultimately including 32 studies for appraisal. From identification of studies via databases and registers, n=5,091 records identified through database searching and after removing duplicates (n=1,149), the records identified for screening were n=3,942:

- Embase (n=449)
- GlobalHealth (n=1,920)
- Medline (n=549)
- Scopus (n=1024)

From these, records excluded before screening were n=3,899:

- No transport interventions
- Non-transport related pollutants

The records' titles abstracts screened were n=43, of which studies meeting inclusion criteria were n=12. There were 20 additional records identified through other sources:

- n=4 reports
- n=16 papers

Finally, studies included for appraisal (full-text articles assessed) were n=32 for this review.

Studies in England

Interventions implemented by local authorities

In addition, we explored interventions adopted by local authorities in the UK aimed at managing air quality issues in their geographical area of interest, focusing on those most relevant to transport around schools. Actions taken are published on individual local authority webpages and submitted to the Department for Environment, Food and Rural Affairs (Defra) showing all declared Air Quality Management Areas (AQMAs) and providing further details on interventions to address air quality issues within their specific area; for example, the Civic Centre Southampton: LAQM Annual Status Report (ASR) 2019. ASRs are required from every local authority each year regardless of whether they have declared an AQMA. The Greater London Authority (GLA) has undertaken several relevant activities related to implementing school streets actions in London (more details in Annexe B).

We also explored information provided by academic institutions (for example, guidance from University of Surrey, University of Birmingham) and websites of key organisations, such as Transport for London (TfL). In addition to searching in websites, we approached and interviewed stakeholders, colleagues from collaborative organisations and government departments, such as Defra. Finally, we considered the publications and activities of the relevant Clean Air networks (Annexe C).

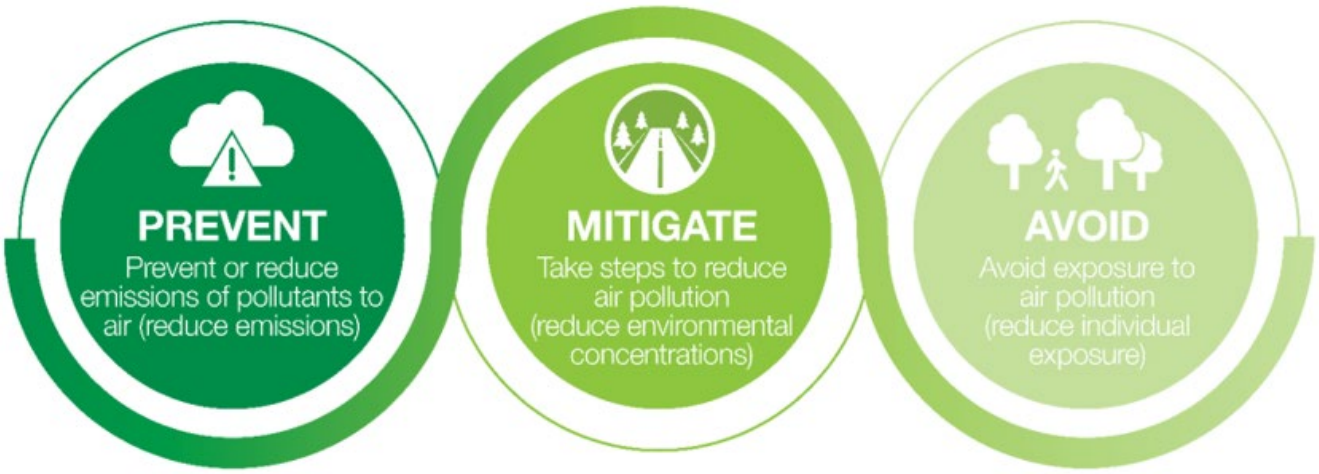
Transport interventions at schools: impacts on air pollution

In this section, we discuss the identified transport interventions around schools that have been reported to be associated with changes in air pollution. In the next section ('Hierarchy of interventions') we explain briefly the hierarchy of interventions developed by PHE (2019). The next section ('List of interventions') provides the definitions of some key interventions and in the 'Impacts and benefits' section, we report the findings of our evidence summary.

Hierarchy of interventions

A general principle of a hierarchy of air pollution interventions was established in PHE's 'Review of interventions to improve outdoor air quality and public health' (56) (Figure 2). This prioritises prevention of emissions as the most effective type of intervention, followed by mitigation of pollutant concentrations, with both of these being preferable to requiring individuals to avoid exposure by adapting their behaviour.

Figure 2. Hierarchy of air pollution interventions (PHE, 2019)



In the context of transport interventions, our previous studies (48, 49) recommended actions following this hierarchy and categories (Table 1).

Table 1. Applying the hierarchy to general transport interventions (Mitsakou and others 48, 49)

Prevention or reduction of emissions	Mitigation of pollutant concentrations	Avoidance of individual exposure
Promote active travel and public transport	Reduce traffic flows	Choose walking or cycling routes a distance from motorised transport

Prevention or reduction of emissions	Mitigation of pollutant concentrations	Avoidance of individual exposure
Flexi working to reduce motorised transport trips	In vehicle use of mechanical ventilation	Commuters with health problems avoid traveling in rush hour periods
Use of less polluting (and more frequent) public transport		When crossing air pollution hotspots, keep children distanced from traffic

The main pollutants to tackle through the implementation of interventions are particulate matter (PM) and nitrogen dioxide or oxides (NO_2/NO_x) as major components of traffic-derived air pollution.

List of interventions

The list of commonly implemented and/or considered interventions is summarised below, along with the definitions or explanation:

School streets

School streets restrict vehicle access during drop-off and pick-up times, and consequentially reduce levels of traffic and pollution in the immediate vicinity of schools during these times. Resources can be found at the School streets website.

Play street

Play street is a timed closure on the streets outside the school during a certain period of the day (for example, on Friday after the school day ends). A play street can be run periodically, say once a term. Games and activities are organised for children and parents on the reclaimed street space. Signing and enforcing the closure is a joint exercise between the borough and the school (‘borough’ refers to the local authority).

Filtered permeability

Filtered permeability involves closure of a road to motorised vehicles, whilst retaining routes through for pedestrians and cyclists. The scope to introduce road closures and filtered permeability measures depends on the wider road network, routing options and the impact of displaced traffic, as well as any requirements for preserving emergency access. Where implemented they can be paired with footway extensions, planting and public realm improvements.

Clean air zones around schools

Clean air zones around schools intervention includes the creation of school clean air zones (for example, through anti-idling campaigns, and the relocation of drop-off and pick-up points).

Ultra-low emission vehicle (ULEV)

Ultra-low emission vehicle (ULEV**)** only restriction, utilising a recently approved exemption for ULEVs paired with access restrictions such as a Pedestrian Zone, No Motor Vehicles or a Bus Lane to promote ULEV uptake and significantly reduce traffic emissions. Like School Streets, ULEV-only streets can have exemptions for permits holders such as residents, businesses, and blue badge holders (held by those with disabilities).

Walking school bus

A walking school bus is a group of children walking to school with one or more adults and can be as informal as 2 families taking turns walking their children to school as a structured route with meeting points, a timetable and a regularly rotated schedule of trained volunteers. A bicycle train is a further variant on this, with adults supervising children riding their bikes to school. These can be planned in conjunction with cleaner walking routes to school initiatives to avoid the most polluted streets where possible. This would count as a STARS ‘Other Walking Activity’ (see UK TfL road safety programmes).

Green infrastructure

Green infrastructure interventions consider greening at school areas for pollutant filtering.

Impacts and benefits

We categorised the interventions around schools in 4 broad categories corresponding to different types of settings and policies:

1. Vehicle technology and driving
2. Traffic management
3. Active travel and behavioural change
4. Urban planning or school location

These interventions, along with their estimated or discussed impacts and benefits on air quality, health and various other aspects (for example, traffic flow, noise) are reported per study in the 4 tables in Table 2.

Table 2a. Traffic interventions around schools: Vehicle technology and driving behaviour

Study area or reference	Intervention or setting	Assessment or method	Reported (or discussed) impacts on: air quality	Reported (or discussed) impacts on: health	Reported (or discussed) impacts on other aspects (for example, traffic flow, noise)
Seattle and Tahoma, Washington USA. Adar and others, 2015 (2)	Engine, tailpipe retrofit, clean fuels on school bus	(1) Exposure and (2) pulmonary health characterisation before, during and after the adoption of clean fuel technology (between 2005 and 2009). (1) In-bus measurements for $PM_{2,5}$ and UFP (188 school buses/597 trips greater than 10 minutes). (2) Monthly pulmonary measurements: (a) lung function testing; (b) biomarkers of inflammation (exhaled nitric oxide); and (c) absenteeism in a total of 275 bus riders - 3,223 observations.	$PM_{2,5}$ and UFP concentrations were 10 to 50% lower on buses using ultralow-sulphur diesel, diesel oxidation catalysts, and/or closed crankcase ventilation systems.	The adoption of ultralow-sulfuric diesel reduced exhaled nitric oxide (marker for inflammation) in children's lungs by 16 percent for all children. 8% reduction was on absenteeism, with stronger associations among children with asthma. Diesel oxidation catalysts, and to a lesser extent closed crankcase ventilation systems, also were associated with improved exhaled NO, spirometric value - forced vital capacity (FVC) growth, and absenteeism for children with asthma. No health benefits were noted for biodiesel.	
Dublin, Ireland. Tang and others, 2019 (63)	Vehicle fleet composition; Different speed limits	Modelling approach was used to assess the impact of different speed limits and fleet composition. A traffic model along with an emission and dispersion model were used to evaluate traffic and air quality changes near a primary school in Dublin city centre in 2013.	Outside the school, shifts from diesel to petrol vehicles could reduce NO_2 and PM_{10} by 4% and 3% but would increase CO and benzene by 63% and 35%.		
Los Angeles, USA. Zhang and Zhu, 2011 (68)	Engine, tailpipe retrofit, clean fuels on school bus	Tailpipe emissions and in-cabin ultra-fine and other air pollutant levels were measured before and after retrofitting when the buses were idling and during actual pick-up or drop off routes.	Retrofit systems for diesel-powered school buses significantly reduced tailpipe emissions with a reduction of 20 to 94% of total particles with both diesel oxidation catalyst and crankcase filtration system installed.	Although current retrofit systems reduce children's exposure while waiting to board at a bus station, retrofitting by itself does not protect children satisfactorily from in-cabin particle exposures.	
Seattle, USA. Ireson and others, 2011 (39)	Engine, tailpipe retrofit, clean fuels or school bus	$PM_{2.5}$ sampling campaign to evaluate penetration of bus emissions into the cabin	In-bus concentrations of its tailpipe and crankcase vent emissions showed self-pollution to be higher with windows closed, and despite their lower emission rate, crankcase PM concentrations were substantially higher than those of tailpipe exhaust PM.		

Study area or reference	Intervention or setting	Assessment or method	Reported (or discussed) impacts on: air quality	Reported (or discussed) impacts on: health	Reported (or discussed) impacts on other aspects (for example, traffic flow, noise)
Los Angeles, USA. Zhang and Zhu, 2011 (68)	In-cabin air filtration, window position on school bus	Tailpipe emissions and in-cabin air pollutant levels were measured before and after retrofitting when the buses were idling and during actual pick-up or drop-off routes.	The AC or fan unit and the surrounding air pollutant concentrations played more important roles for determining the in-cabin air quality of school buses than did retrofit technologies.	The use of an air purifier was found to remove in-cabin particles by up to 50% which might be an alternative short-to-medium term strategy to protect children's health.	
Modelling study. Li and others, 2017 (44)	In-cabin air filtration, window position on school bus	Measured BC and UFPs concentration inside with different window openings in school buses Simulate the infiltration airflow through window gaps using Computational Fluid Dynamics (CFD) modelling to determine the effects of window openings on the self-pollution.	Opening the driver's window could allow the infiltration of exhaust through window or door gaps in the back of school bus; whereas, opening windows in the middle of the school bus could mitigate this phenomenon.		
Modelling study. Li and others, 2017 (44)	Driving speed or school bus	Measured BC and UFPs concentration inside with different window openings in school buses Simulate the infiltration airflow through window gaps using Computational Fluid Dynamics (CFD) modelling to determine the effects of window openings on the self-pollution at different speeds	Increased driving speed (from 20mph to 60mph) could result in a higher ventilation rate (up to 3.4 times) and lower mean age of air (down to 0.29 time) inside the bus.		
Texas and California, USA. Zhu and Zhang, 2014 (69)	Driving speed, driving route, or school bus	$PM_{2.5}$ and BC were measured simultaneously in and around school buses in 4 sets of tests: (1) on-road; (2) during idling; (3) before and after retrofitting with a diesel oxidation catalyst, a crankcase filter system, or both; and (4) before and after operating a high efficiency particulate air (HEPA) filter air purifier inside the cabin. Measurements were made in small sets of buses (model years 1990 to 2006) in Texas and California.	The larger air exchange rate at higher driving speed helped to dilute the in-cabin air pollutants with the cleaner ambient air; that applies only to school buses with the windows open that are driving in rural areas.		
Dublin, Ireland. Tang and others, 2019 (63)	Vehicle speed limits changes	Modelling approach was used to assess the impact of different speed limits and fleet composition. A traffic model along with an emission and dispersion model were used to evaluate traffic and air quality changes near a primary school in Dublin city centre in 2013.	Outside the school, speed limit changes from 30km/h to 50km/h could reduce NO_2 and PM_{10} concentration by 3% and 2%.		

Study area or reference	Intervention or setting	Assessment or method	Reported (or discussed) impacts on: air quality	Reported (or discussed) impacts on: health	Reported (or discussed) impacts on other aspects (for example, traffic flow, noise)
Seattle, USA. Ireson and others, 2011 (39)	Driving route or school bus	$PM_{2.5}$ sampling campaign to evaluate penetration of bus emissions into the cabin.	Internal $PM_{2.5}$ levels were lower for buses driving along quiet residential streets.		
USA Choma and others, 2024) (18)	Electric school bus	Estimation of health benefits of replacing diesel school buses with electric school buses in each of the 3,108 counties in the contiguous United States, covering diesel school bus emissions of primary $PM_{2.5}$, NO_x, NH_3, SO_2, and VOCs, and power plant emissions of SO_2 and NO_x.		When electric buses replace old diesel vehicles in large cities, health benefits associated with reduced mortality and childhood asthma total $207,200/bus.	Climate benefits amount to $40,400 per bus. These benefits likely exceed replacement costs. Replacement of old buses can improve social welfare.
Review of different school-based air pollution exposure interventions. Rawat and Kumar, 2023 (57)	Clean fuel in school buses	Review of studies (in the last 20 years) on interventions for reducing school children's exposure to air pollutants.	Clean fuel policy intervention can reduce $PM_{2.5}$ concentration up to 62% inside school buses and 94% in tailpipe emission.		

Table 2b. Traffic interventions around schools: Traffic management

Study area or reference	Intervention or setting	Assessment or method	Reported (or discussed) impacts on: air quality	Reported (or discussed) impacts on: health	Reported (or discussed) impacts on other aspects (for example, traffic flow, noise)
London Boroughs (Brent, Enfield, Lambeth), UK. Air Quality Consultants, 2021 (5) London, UK. Breathe London, 2021 (14)	School streets (Streetspace for London programme)	30 air quality monitors were installed near schools in 3 boroughs in London to investigate air quality benefits due to COVID-related travel restrictions.	Closing roads around schools to traffic can reduce nitric oxide (NO) concentrations of up to 34% and NO_2 levels during the school drop-off by up to 23%.		Reduce car travel to school, increase in walking or cycling to school.

Study area or reference	Intervention or setting	Assessment or method	Reported (or discussed) impacts on: air quality	Reported (or discussed) impacts on: health	Reported (or discussed) impacts on other aspects (for example, traffic flow, noise)
London, UK. GLA, 2018 (33)	Play streets	Toolkit of measures and recommendations to improve air quality at schools.	Low potential air quality improvement.		Expected benefits in road safety and sustainable travel. Also raises awareness of air quality and sustainable travel. Socialising.
London, UK. GLA, 2018 (33)	ULEV only streets	Toolkit of measures and recommendations to improve air quality at schools	Medium potential air quality improvement.		Expected benefits in promoting sustainable travel.
London, UK. Mudway and others, 2019 (51)	London's Low emissions zone	Sequential annual cross-sectional study of 2164 children attending primary schools between 2009 to 2010 and 2013 to 2014 in central London, UK, following the introduction of London's LEZ in February 2008. Four boroughs in London were selected with schools located close to monitoring stations. The association of modelled NO_2 $PM_{2.5}$ and PM_{10} with lung function and respiratory or allergic symptoms was investigated.		Within London's LEZ, a smaller lung volume in children was associated with higher annual air pollutant exposures. Interventions that deliver larger reductions in emissions might yield improvements in children's health.	
Cincinnati, USA. Ryan and others, 2013 (61)	Anti-idling campaign	Pre- and post-anti-idling campaign air monitoring for outdoor air pollution measurements at 4 urban schools with varying traffic (5 school day measurements).	Reduce $PM_{2.5}$, EC and PNC at schools with significant amounts of buses and passenger cars.		
Guildford, UK. Omidvarborna and others, 2020 (53)	Commuting style for dropping-off and picking-up of pupils – school driven initiative	A primary school co-designed a study with local community and researchers to understand air pollution levels and possible mitigation measures. Five different sampling sites were identified at primary school to assess the hotspots of vehicle fumes during peak hours and collect air pollution data.	Cars queuing during drop-off hours intensify the concentration of $PM_{2.5}$ by approximately 3 times. $PM_{2.5}$ levels at the playground was comparable to the main road during morning hours. About 2 times higher $PM_{2.5}$ concentration was noted during drop-off hours in a nearby classroom.		Citizen science exercises (interested communities in collaboration with researchers and local authorities) can collect air pollution data to support behavioural change.

Study area or reference	Intervention or setting	Assessment or method	Reported (or discussed) impacts on: air quality	Reported (or discussed) impacts on: health	Reported (or discussed) impacts on other aspects (for example, traffic flow, noise)
London, UK. GLA, 2018 (33)	Filtered permeability (see List of interventions)	No assessment of air quality mentioned.	Medium potential air quality improvement.		Expected benefits in road safety and sustainable travel
London, UK. Laverty and others, 2021 (42)	Low traffic neighbourhoods	No assessment of air quality mentioned.		They can make residential streets safer for play, socialising, and exercise.	18% reduction in street crime after 3 years, and a 75% reduction in the risk of being injured in a road traffic collision.
London and Luton, UK. Xiao and others, 2024 (67)	Ultra-Low Emission Zone (ULEZ)	Prospective parallel cohort study of 3,414 multi-ethnic children aged 6 to 9 years attending 84 primary schools in Central London (intervention) and Luton (control with similar baseline air quality).			ULEZ was associated with a shift in children's travel to school towards more sustainable and active travel modes. Children in London were more likely to have switched from inactive to active modes (OR 3.64, 95% CI 1.21 to 10.92) and children in the intervention group were also less likely to switch from active to inactive modes (OR 0.11, 0.05 to 0.24).
London, UK. Abhijith and others, 2022 (1)	'Car-free' hours (also known as 'school-street') initiative during school pick-up time	The car-free' hours intervention was implemented in the street in front of a selected school during school pick-up time when the street was closed off to road traffic. Pre- and post-intervention monitoring for two weeks	'Car-free' hours intervention showed that a 30% reduction in the traffic volume around the selected school, resulted in reductions in PM_{10}, $PM_{2.5}$, PM_1 concentrations of 36%, 31% and 30%, respectively		Car-free hours intervention showed a 30% reduction in the traffic volume around the selected school.

Table 2c. Traffic interventions around schools: Active travel and behavioural change

Study area or reference	Intervention or setting	Assessment or method	Reported (or discussed) impacts on: air quality	Reported (or discussed) impacts on: health	Reported (or discussed) impacts on other aspects (for example, traffic flow, noise)
England. Living Streets, 2022 (43)	Walk to school	No assessment of air quality mentioned.	It supports that it brings benefits to air quality.		30% reduction in car journeys to the school gate and a 23% increase in walking rates (CMO, 2022). Also, expected benefits in road safety.
Barcelona, Spain. Enlaira't Plataforma per la Qualitat del Aire in Rivas and others, 2018 (59)	Students in secondary schools think about air pollution and how to improve air quality in their city	No assessment of air quality mentioned.			
Bradford, UK. Dirks and others, 2016 (26)	Walking school buses	UFP measurement journeys to and from school for 3 participants: one traveling by car and 2 on foot for the same journey and on the opposite sides of the road – 5 replications.	Largest reductions in exposure for pedestrians by avoiding close proximity to traffic queuing up at intersections and walking on the side of the road opposite the traffic, especially during the morning commuting period.	Increase physical activity.	Reduce traffic congestion. Road safety consideration.
Auckland, New Zealand. Dirks and others, 2018 (25)	Walking school buses	UFP and CO measurement on journeys to and from school for 2 participants on the opposite sides of the road and aligned with one another.	Pedestrians travelling on the footpath next to the less congested side of the road in the morning avoid many short-term peaks in concentration and experience significantly lower mean exposures than those travelling on the footpath next to the more congested side.		
London, UK. GLA, 2018 (33)	Walking buses	Toolkit of measures and recommendations to improve air quality at schools.	Low potential air quality improvement.		Expected benefits in visual amenity, awareness raising and support STARS (a TfL community project) and Healthy Schools London (HSL) objectives.

Study area or reference	Intervention or setting	Assessment or method	Reported (or discussed) impacts on: air quality	Reported (or discussed) impacts on: health	Reported (or discussed) impacts on other aspects (for example, traffic flow, noise)
Antwerp, Belgium. Ahmed and others, 2020 (4)	Behavioural intervention: current and suggested walking or cycling route to school.	Children's school route information recorded using Route2School online platform and street maps to adjust the route or compute alternative routes. Fixed-site NO_2 measured data and high resolution modelled NO_2 Criteria to identify alternative routes Customised information feedback.	60% participants (N=104) could benefit themselves by adopting the suggested routes regarding NO_2 exposure; 77 % switched their routes.	Less exposure to Air Pollution. Intervention was effective and can bring higher benefits when implemented on a wider scale.	
Greater Manchester area, UK. Mölter and others, 2015 (50)	Choice of school route	Network analysis (walking network, ArcGIS, Population data, LUR): simulation of 100,000 walking routes to primary schools (500 schools)	For most routes relative reductions in exposure exceeded the increase in duration.	Identifying less polluted school routes could provide health benefits for children.	
Lancaster, UK. Davies and others, 2014 (23)	Choice of school route	Comparison of exposure between multiple origins and destinations to assess least-polluted routes. Physiology and activity level incorporated MasterMap, transport network, ArcGIS and Modelled $PM_{2.5}$ to identify pedestrian routes between multiple origins and destinations.	For 49% of route combinations, the lowest $PM_{2.5}$ exposure routes are from their corresponding shortest routes.		
Europe. Villa-González and others, 2017 (70) in Adnan and Passani, 2017 (3)	School-based intervention on active commuting	Activity-based information delivery mechanism was introduced in the school such as: illustration on environment in the neighbourhood, story and performing scenes related to active commuting, illustrations on road safety.		Health-related effects are monitored. Intervention was able to increase the bicycle use, however not able to increase walking among school children.	
England. Brown and others, 2021 (15)	Behaviour change: reduced essential travel during COVID period in England	NO_2 data from all fixed-site monitoring sites within 500m of nurseries, primary schools, secondary schools and colleges in England. Data was collected between the lockdown period (23rd of March to 23rd of April 2020) and the same time period for the 5 previous years (23rd of March to 23rd of April, each year from 2015 to 2019), and to adjust the data for meteorological influence.	NO_2 significantly reduced at background (−35.13%) and traffic (−40.82%) sites. The possible reductions of NO_2 at schools in England and potential reductions of child exposure that are achievable when public behaviours shift towards active travel, work from home policies and generally lower use of polluting vehicles and reduction of non-essential traveling.		

Study area or reference	Intervention or setting	Assessment or method	Reported (or discussed) impacts on: air quality	Reported (or discussed) impacts on: health	Reported (or discussed) impacts on other aspects (for example, traffic flow, noise)
Toronto, Canada. Elford and Adams, 2019 (27)	Choice of school route	(modelling: low-dosage routing optimization): The shortest-distance route versus the lowest UFP dosage route.	The shortest route is likely the lowest-dosage route for most children in Toronto.	Ultra-fine low-dosage routing.	
Copenhagen, Denmark. Blond and others, 2019 (11)	Bicycling to work	School intervention and health (randomised controlled trial).		Bicycling to work or school intervention improved cardiometabolic health.	
Edinburgh, UK. Luengo-Oroz and others, 2019 (45)	Route bike choice	Traffic and bike infrastructure factors – promotion of cycling. Bike commuters' exposure to UFP along 3 alternative routes from central University campus.	Bicycle boxes (spaces at intersections that allow cyclists to position themselves ahead of vehicle traffic) are effective for reducing UFP exposure and that using shared bus-bike lanes should be avoided where possible.		Heavy duty vehicles (buses and trucks) and construction sites were identified as the main sources of peaks in UFP exposure.
Review of different school-based air pollution exposure interventions. Rawat and Kumar, 2023 (57)	Behaviour changes, school-commute interventions	Review of studies (in the last 20 years) on interventions for reducing school children's exposure to air pollutants.	School commute interventions can reduce NO_2 by up to 23%.		
Perth, Western Australia Rumchev and others, 2021 (60)	Anti-idling intervention	Based on two focus group discussions with parents, a low-intensity 4-week anti-idling intervention was conducted. Exposure to selected air pollutants was assessed during pick-up and drop-off times pre- and postintervention at 12 randomly selected independent schools (10 intervention and 2 control) across the Perth metropolitan area	Reduced number of idling vehicles were observed in 8 of the 10 intervention schools; decreased overall particulate matter concentration after the anti-idling intervention.		The study results showed that a low-intensity behavioural intervention can be an effective strategy to affect parents' attitude towards vehicle idling.

Table 2d. Traffic interventions around schools: Urban planning and school location

Study area or reference	Intervention or setting	Assessment or method	Reported (or discussed) impacts on: air quality	Reported (or discussed) impacts on: health	Reported (or discussed) impacts on other aspects (for example, traffic flow, noise)
Melbourne, Australia. Birch and others, 2020 (10)	Urban planning childcare centre site selection			Co-location of childcare with car parks may have long term impact of children health Significant impact on children's exposure to AP.	

The interventions related to vehicle technology, in particular the tailpipe retrofit, clean fuels or changes in vehicle fleet composition reported in studies (2, 39, 44, 63, 68), had positive results for air quality with reductions in exhaust emissions and concentrations of fine and ultrafine particles and health benefits for people in the surrounding affected areas, such as bus stops. However, retrofitting by itself did not protect children satisfactorily from in-cabin particle concentrations and the air filtration through window opening played an important role in improving or deteriorating in-cabin air quality. A study in USA (68) reported that the use of an air purifier could remove in-cabin particles by up to 50% which might be an alternative short-to-medium term strategy to protect children's health. The bus speed also determined the air quality inside the vehicle, in particular higher driving speed led to larger air exchange rate and thus greater dilution of the in-cabin air pollutants, that applied to school buses with the windows open that are driving in quiet areas (39, 44, 63, 69).

With regard to traffic management around schools, cars queuing during drop-off hours intensify particle concentrations substantially, and pollution levels at the playground were comparable to the main road during morning hours (53). Actions to address this issue by closing temporarily streets around schools have been taken in some areas in the UK and other countries and include interventions such as 'school streets' and 'play streets'. These actions can lead to reductions in traffic-pollutant concentrations during certain hours of the day, such as school drop-off times, but they offer low to medium air quality improvements in the wider area (5, 14, 33). However, they are expected to offer health co-benefits, including increase active travel for school runs, improve road safety and sustainable travel, as well as raise awareness of air pollution and socialising. Anti-idling campaigns may lead to reduction in pollutant emissions at schools with significant amounts of buses and passenger cars (61). In regard to London's low emission zone, it was reported that interventions aiming to achieve larger reductions in emissions might yield improvements in children's health (51). In relation to the 'low traffic neighbourhoods' intervention, a co-benefit reported was that they can make residential streets safer for play, socialising, and exercise (42). However, it should be noted that these interventions – low emission zone and low traffic neighbourhoods – are not designed specifically for schools, therefore not all the related information has been considered in the current work.

There are a number of interventions related to active travel and behaviour change implemented at schools (4, 11, 15, 23, 25, 26, 27, 33, 43, 45, 50, 59, 70), but they appear to be more effective when combined with other factors affecting the exposure to air pollution. The 'walking school buses' intervention was found more effective in reducing the children's exposure to air pollution when travelling on the footpath next to the less congested side of the road and avoiding close proximity to traffic queuing up at intersections, especially during the morning commuting period. However, these interventions offer great co-benefits including increase in physical activity and road safety consideration, reduction in traffic congestion. In relation to the air quality, they are expected to bring measurable benefits when implemented on a wider scale.

With regard to school location, a study on childcare centre site selection in Australia (10) found that co-location of childcare centres with car parks may have long term impact on children's health; consideration of such factors should be given in urban planning activities.

Interventions aiming to increase physical activity and road safety

A number of transport or travel-related interventions at schools aiming to increase physical activity and/or road safety awareness have been implemented or considered for implementation. Those reported in this section have not assessed or reported impacts on air quality or exposure.

Bicycle train

Bicycle train is an adult-guided group of children who are cycling, and this intervention aims to promote active travel. It has been piloted in Seattle, USA and the assessment showed that children who participated in the bicycle rides to and from school increased their physical activity by 21 minutes per day and daily cycling commutes by 45% (see Bike trains shown to increase physical activity among children).

Beat the street

This intervention is designed as a game, where someone earns points, wins prizes and learn more about the area by walking, running and cycling (Beat the street). It aims to improve physical activity (36) and reduce traffic congestion, as shown in a study from Norwich, UK (20).

Bikeability

Bikeability is a national cycle training program for children and adults, launched by the UK Department for Transport in 2007, offering cycle training designed for children in the final years of primary school. As reported in the study by Goodman and others (35), children whose school had offered this scheme were more likely to have completed cycle training than the control group (68% versus 28%), but there was no evidence that Bikeability was associated with cycling more often (49.0% cycling at least once per week in the intervention group versus 49.6% in the control group) (35).

Safe and secure cycling to school

This intervention that aims to increase cycling behaviours through a multicomponent cycling promotion program was implemented in Denmark (55). The study reported that the cardiorespiratory fitness was increased in the intervention group compared to a control group and there were no changes in recreational cycling, overall physical activity, body mass index (BMI) and obesity.

Safe Route to School (SRTS)

The 2005 US Transportation Bill funded each state to offer Safe Routes to School (SRTS) initiatives in order to increase active commuting to school. This intervention was reported in a study in Texas (38) and showed that it increased students' engagement in physical activity.

Ride2School program

This is an intervention for promoting active transport – walking and 'wheeling' (cycling, scooter or skate) – to school that included offering of mapping of safe routes to school and infrastructure improvements such as bicycle storage, as reported in a study in Victoria, Australia (21).

UK TfL road safety programmes

In London, TfL have introduced several programmes that have as their primary aim, children's awareness regarding travel safety. These include:

- road safety club – a free educational programme that teaches young Londoners safe behaviour around roads
- use the STARS Safer Journey Planner – helps students and parents or carers plan their journeys and provide useful advice on walking, cycling and scooting to school safely
- cycle skills course – a course providing easy to follow tips and advice to get children cycling
- youth travel ambassadors programme guide – an older programme that linked to curriculum subject in a variety of ways, for example, collecting, analysing and presenting school travel survey data in maths and science, using GIS and maps to interpret current and desired travel behaviours of the school community in geography

More details can be found in at TfL's Schools and young people webpage.

Tools for promoting active travel

In the UK, there are some developed techniques that aim to promote active travel for the general population or specific population subgroups and which can be adapted or learn from and apply around schools – some of these consider diversity and inclusion. Examples are:

GET IT (Gender Equality Toolkit In Transport) Future Transport Visions Group (FTVG)

The vision of this toolkit is to inform transport professionals how the work that they do and the decisions that they make impact women's mobility and to provide a resource to encourage them to be gender responsive, to ultimately create gender inclusive transport systems.

The toolkit aims to:

- inform: explain and demonstrate why gender needs to be a key consideration during transport work
- support: provide a practical introduction to gender inequality with clear steps that can be taken to support gender mainstreaming and encourage gender-responsive actions and mobilise and unite action (join people together from across the transport industry to create a movement and platform for connected thinking

The Gender Equality Toolkit in Transport (GET IT) is available online.

Active Travel: getting people back to work safely

This toolkit was published in June 2021 by the Prince's Responsible Business Network. It outlines some of the challenges and opportunities in promoting active travel in light of the COVID-19 pandemic and the pressure to respond to the climate emergency. The toolkit includes:

1. The business case for active travel.
2. What national funding is available.
3. What are the barriers or opportunities.
4. Examples of how leading businesses, such as Fujitsu and Heathrow, are embracing travel initiatives.

The Active Travel toolkit is available online.

Active Travel Tool (beta)

In June 2022, the Road Safety Foundation launched an Active Travel Tool with funding from the Road Safety Trust. The tool aims to help UK road authorities evaluate active travel facilities for both safety according to Safe System principles, and age and ability. The tool allows a spot evaluation of the different available facilities for a given road, rather than a network or route-based evaluation that can be achieved using the full iRAP methodology or CycleRAP. The tool uses safety Star Ratings, together with a set of criteria for age and ability, to compare bicycle and pedestrian facilities, such as paths, crossings and low traffic neighbourhoods (LTN). It is envisaged that the tool will be used to support practitioners in their decision making and help communication of safety and LTS considerations to road safety stakeholders and the public.

The Action Travel toolkit is available online.

Impact Community carbon calculator

This is a digital visualisation tool published by the Centre for Sustainable Energy in June 2022. The tool helps the users understand their community's carbon footprint. It works for parishes, wards and local authority areas. It helps identify the areas where taking action to tackle climate change can make the biggest difference. The Impact community carbon calculator can be accessed online.

Place-Based Carbon Calculator

The Place-Based Carbon Calculator is a free tool that maps the carbon footprint of every neighbourhood in England, produced by the Centre for Research into Energy Demand Solutions in June 2021 with funding from UK Research and Innovation. The purpose of the tool is to provide a resource for local government and community organisations to help them plan and enact the changes that are needed to meet net-zero goals and their own climate emergency declarations. The tool estimates the average carbon footprint per person for each LSOA in England and it takes a consumption-based approach to carbon footprints, this means that the emissions are counted by the consumer of a good or service not the producer.

The Place-Based Carbon Calculator is available online.

Approaches and tools for assessing interventions

The implemented interventions (or interventions considered for implementation) have been assessed following different approaches. The assessment of interventions can be challenging for several reasons, as discussed in the report by the Air Quality Expert Group on 'Assessing the effectiveness of interventions on air quality' (6). In general, in order to assess the impacts on health, the process should include:

1. Exposure assessment.
2. Health impact assessment.
3. Economic valuation of impacts.

Below are some examples of approaches and/or tools that have been used in studies or suggested for assessing local transport interventions.

1. Exposure assessment

A variety of approaches has been used to assess potential impact of interventions around school settings. Methods used comprise a combination of different available data sets or platforms with modelling tools or measurements capable to assess exposure or dose reduction or health outcomes improvements. Different aspects need to be considered:

- children school routes information with options to record or adjust trips (web-application platforms, street maps and/or questionnaires)
- infrastructure network data to enable computing alternative active (walking or cycling) commuting routes around schools
- feasibility of walking or cycling (age, infrastructure)
- traffic mitigation policies (for example, fleet composition change, speed limits, parking restrictions)
- high resolution air quality data
    - geographic Information systems (GIS) packages to compute 'low-exposure' route in buffers around schools
    - land use regression (LUR) modelling and atmospheric dispersion modelling to compute pollutant concentrations (that accounts for traffic flow and emissions data)
- population data
- traffic model for scenario calculator
- sampling sites measurement (for example idling interventions, green space)
- questionnaire survey and personalised feedback to study participants that estimate effectiveness pre-to post-intervention
- exposure categorisation

2. Health impact assessment

In order to assess the health impacts following the implementation of an intervention, different modelling tools can be used that consider various factors:

Air pollution only

- WHO AirQ+
- USEPA BenMAP-CE

Integrated assessments

Air pollution, carbon emissions, physical activity, traffic crashes:

- WHO HEAT (Health Economic Assessment Tool)

Integrated assessments

Air pollution, noise, heat, physical activity, green space:

- UTOPHIA (Urban and TranspOrt Planning Health Impact Assessment tool) (52)

3. Economic valuation of impacts

The methods currently used by the UK Government to estimate the effects of air pollution within economic appraisals are described by the Guidance on Air Quality Appraisal: Impact pathways approach. These appraisals provide Defra with cost-benefit analysis to inform the development of policies on air pollution. Following discussions in the COMEAP, an ad hoc group on economic valuation of morbidity related to air pollution was formed in 2022, which aims to propose ways for improving the currently used approaches.

Discussion

Following on from the review of air pollution outside schools (54), recommendations were made for action to mitigate the children's exposure to air pollution. In particular, the authors discussed interventions including:

- the creation of school clean air zones (for example, through anti-idling campaigns, and the relocation of drop-off and pick-up points), where the evidence supports the wider application of this approach
- green infrastructure with greening of school grounds and surrounding areas as a mechanism for mitigating children's exposure
- active travel to and from school, as walking and cycling on the school commute is known to provide health benefits and reduces the amount of traffic and pollution around the school overall
- avoiding major roads on the school commute by maximising the distance between heavy traffic and those travelling to school
- school site selection that involves air quality-conscious selection of new sites for schools

The above study highlighted the importance of a holistic approach, where measures aiming to reduce emissions, and those designed to mitigate exposure to pollutants already emitted, are tackled simultaneously by introducing the implementation of multiple interventions and strategies.

The review on exposure to air pollution in different transport microenvironments (48) has been provided a series of recommendations for preventing emissions of traffic pollutants, mitigating pollutant concentrations, and avoiding exposure to air pollution during transport. The review pointed out that the exposure to air pollution is only one aspect of many important considerations when communicating about public health, including physical activity, as well as personal safety and environmental equity. Holistic transport planning and communication strategies through collaborative working amongst public health, air quality, decarbonisation, transport, planning and sustainability professionals and groups to inform were proposed.

A number of studies and guidance have been developed that aim to promote cleaner air at indoor and outdoor school environments. The guidance on mitigating exposure to traffic pollution in and around schools, provided by the University of Surrey, aims to offer action points that will enable schools, children and communities to make decisions for reducing the exposure of school children to air pollution. The Global Action Plan (GAP) have developed the Clean Air for Schools framework that is an online tool aiming to help schools create a clean air action plan to tackle air pollution in and around the school. ARUP developed an interventions toolkit that is designed to work alongside with the GAP framework and identifies the actions that will have the greatest impact on local air quality; it recognises that around schools the largest source of emissions will typically be from road vehicles, therefore reducing traffic will have the most effective impact and proposes ways to monitor the efficiency of the interventions. However, it

should be noted that there is no strong evidence yet presented for the efficiency of the proposed actions.

The recent review on interventions for improving indoor and outdoor air quality in and around schools (57) identified effective interventions for the indoor school environment, but they also examined transport and other interventions for the outdoor environment. The review concluded that heating, ventilation and air conditioning combined with filters can lead to substantial pollutant removal indoors, as well as citizen science campaigns, such as development of a toolbox to raise the awareness of primary school students about air quality and how to increase their participation in air quality improvement activities. In the outdoor environment, installing green infrastructure as a physical barrier and school commute interventions, such as selecting alternate route and alternate mode of travel that are safer regarding the exposure to pollutants are effective at reducing pollutant concentrations. The review also indicated the need for future research in analysing interventions, their application and benefits. Fernandes and others in their review on school-based interventions to support healthy indoor and outdoor environments for children examined different types of interventions including those that aim to increase active travel to school (29). Their review concluded that the interventions can increase walking and cycling after 3 years.

In the outdoor school environment, the greening of school grounds and surrounding areas has been shown to have positive impacts in improving air quality (9) and thus proposed as a mechanism for mitigating children's exposure (34, 41, 59). As discussed in Osborne and others (2021) (54), the evidence shows the positive role that green infrastructure can play on ambient air quality, noise mitigation and improved mental health, but caution should be taken to avoid pollutant trapping on the source side of the barrier (56).

As regards transport or travel-related interventions, the UK government including the Department for Transport, Office for Zero Emission Vehicles, Active Travel England and HM Treasury, have been publishing information on local transport funding that aims to support local authorities implement plans for sustainable and net zero transport. In one of the policy papers produced by the UKRI funded TRANSITION network, the use of e-cycling was investigated (13). It reported that as e-cycling is a less strenuous activity than conventional cycling, it has led individuals to ride e-bikes more frequently and for longer periods of time than conventional bicycles, leading to greater weekly energy expenditure (16, 62).Studies on interventions have shown that e-cycling may increase individual physical fitness by up to 10% in both inactive adults and those with chronic disease and a couple of studies have reported that e-cycles have been used by working mothers for transport including transporting their children, as well as for shopping (24, 65).

With regards to Low Emission Zones (LEZs), these present an opportunity for local authorities to improve air quality and public health, but they may have unintended consequences for local communities and businesses associated with restrictive management; for example, disadvantaged communities are more likely to own non-compliant cars and thus these communities may be disproportionately impacted by the introduction of charging schemes (66).

The Born in Bradford Breathes study investigates people's views and the impact of the Clean Air Zone in Bradford; Mebrahtu and others (47) reported improved pollution levels and cardiovascular and respiratory health in the first two years of implementation of the Bradford Clean Air Plan, however, the study highlights that caution is needed when interpreting these results due to impact of other factors during the study period, such as changes in traffic during the COVID-19 pandemic. A 2023 review suggests LEZs can reduce harmful air pollution-related health outcomes, with the most consistent effect on cardiovascular disease. The study also highlights the importance of the ongoing evaluation of interventions in order to understand longer-term health effects (17).

Conclusions and recommendations

In this work, we identified a range of transport and travel interventions that have been implemented or considered for implementation near schools and categorised them in those related to:

- vehicle technology and driving behaviour
- traffic management
- active travel and behavioural change
- urban planning and school location

The interventions related to vehicle technology were effective for the local environment, but they did not improve the in-cabin concentrations levels, which were affected by the air filtration and the vehicle speed. The traffic management interventions, such as those related to closing streets temporarily can lead to reductions in traffic-pollutant concentrations during certain hours of the day, but they offer low to medium air quality improvements in the wider area or any benefits related to climate. The interventions related to active travel and behaviour change were effective when combined with other factors affecting the exposure to air pollution, and they appear to have potential to offer great co-benefits including increase in physical activity and road safety consideration, and reduction in traffic congestion.

Recommendations

We identify some interventions that can have a positive impact on climate, air quality and children's health and we prioritise those following the hierarchy of interventions (56):

Prevention

1. The main aim is to reduce emissions of pollutants and greenhouse gases, so interventions such as school streets and anti-idling are expected to have a positive impact.
2. There is a need to improve pedestrian and cyclist environments, so that children can actively travel to school safely.
3. The selection of school location at a distance from heavy traffic areas would help at protecting children from being exposed to air pollution and other hazards.

Mitigation

1. For mitigating the concentrations of air pollutants and greenhouse gases, it is important to upgrade public transport vehicles and consider the technology of school buses
2. Mechanical or natural ventilation in public transport and school buses is a factor controlling the in-vehicle air quality and needs to be considered
3. Driving behaviour, such as adjusting the vehicle speed, impacts on the air pollutant concentrations inside and outside the vehicles.

Avoid

While a shift from motorised transport to more active travel options is recommended, there is a need to provide options for minimising children's exposure to air pollution and other hazards, including:

1. Provision of cycling training and other activities or tools that facilitate shifting to active travel.
2. Use of modelling or monitoring techniques to produce maps for identifying cleaner air routes for travellers, by exploring the collaboration of local authorities with exposure researchers and modellers.

However, the current state of evidence includes limited information on the assessments of interventions and thus it does not allow prioritising beneficial interventions based on the quantified benefits that can be offered. The evaluation of interventions can be challenging, and the benefits of local interventions are in general difficult to be captured and assessed properly. Therefore, in terms of evaluating interventions:

1. We highlight the need to develop and/or adapt approaches that would consistently measure the benefits on health in relation to air quality improvements. A number of tools including dispersion modelling of traffic pollution, land-use regression modelling, exposure models, source apportionment techniques should be coupled to form the evaluation process.
2. In addition to the air quality related improvements, the evaluation of interventions approach should consider co-benefits in relation to potential increase in physical activity and climate change benefits. That may require liaising with other science or policy groups that specialise on other than air pollution scientific areas. It is also important to consider the social inequalities and vulnerabilities as interventions are assessed; in their study on analysing the sociodemographic and built environment associates of travel to school by car in New Zealand adolescents, (46) concluded that school level deprivation is associated with higher likelihood of car travel to school compared with active transport, so it is suggested that interventions focus on both social and built environment factors for reducing car travel to school.
3. Citizen science programmes can help to evaluate the interventions and community engagement or communications and share information for public awareness. They also allow interested parties to develop their own projects and deliver tailored messaging for air pollution and new methods on how information should be fed back to the participants and the general public including general advice on reducing exposure. These might include the use of low-cost monitoring techniques for dynamic exposure assessment with potential for wider public participation.
4. Inform future research needs, systematic measurements of impacts on children's health considering various endpoints, such as cognitive development, in order to confirm the evidence related to contribution of school commuting to observed health effects (7, 31).

In terms of prioritising interventions, we highlight the hierarchy of interventions that prioritises prevention of emissions as the most effective type of intervention, followed by mitigation of

pollutant concentrations, with both of these being preferable to requiring individuals to avoid exposure by adapting their behaviour. Also, we support the implementation of interventions that may have limited direct benefits for the air quality and environment, such as active travel and behavioural change, but may have the potential to offer important health co-benefits and increase of public awareness.

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Authors

Christina Mitsakou – Air Quality and Public Health; Environmental Hazards and Emergencies department; Radiation, Chemicals, Climate and Environmental Hazards Directorate, UKHSA

Artemis Doutsi – Air Quality and Public Health; Environmental Hazards and Emergencies department; Radiation, Chemicals, Climate and Environmental Hazards Directorate, UKHSA

Karen Exley – Air Quality and Public Health; Environmental Hazards and Emergencies department; Radiation, Chemicals, Climate and Environmental Hazards Directorate, UKHSA

Alison Gowers – Air Quality and Public Health; Environmental Hazards and Emergencies department; Radiation, Chemicals, Climate and Environmental Hazards Directorate, UKHSA

John Thornes – Centre for Climate and Health Security; Radiation, Chemicals, Climate and Environmental Hazards Directorate, UKHSA

Annexe A. Literature search

Research question

What road transport interventions have been implemented for improving air quality or exposure to air pollution around school areas in high-income countries?

Time period covered

The search started from June 2019 until the submission of the search request (December 2021). An update of the literature search up until autumn 2024 was carried out.

Search databases

Embase, Global Health, Medline, Scopus.

Inclusion criteria:

- focus on areas around schools' settings
- exposure (measured or modelled) for current and/or alternative traveling route or mode to and from schools
- factors that affect implementation of interventions investigated
- intervention or evaluation of an intervention that has an impact on exposure or health
- high-income countries

Search String for EMBASE

1 exp air pollution/
2 exp air pollutant/
3 (air adj (pollut* or quality or ambient)).tw.
4 exp environmental exposure/
5 ((car or vehicle or diesel or exhaust or traffic or bus or buses or coach* or "public transport") adj (relate* or fume* or gas* or emission* or exhaust* or partic* or pollut* or congestion or queuing)).tw.
6 smog.tw.
7 exp particulate matter/
8 (particulat* or PM or PM0* or PM1* or PM2* or PM10*).tw.
9 ultrafine.tw.
10 UFP.tw.
11 concentrated ambient particle*.tw.
12 exp Ozone/

13 exp nitric oxide/
14 exp nitrogen oxide/
15 exp nitrogen dioxide/
16 exp sulfur dioxide/
17 exp carbon monoxide/
18 (urban adj (dust or air)).tw.
19 combustion derived nanoparticle*.tw.
20 CDNP.tw.
21 or/1-20
22 exp school/
23 exp day care/
24 (school* or nurser* or college* or sixth?form or "play?ground*" or "playing field*" or "play?area*" or drop-off or drop or "car share*" or drop-in or pick-up or "loading area" or parks or "recreation ground*" or "green space*").ti.
25 or/22-24
26 (policy or measure* or countermeasure* or interven* or guidelin* or regulation*).tw.
27 traffic.tw.
28 "public transport".tw.
29 exp motor vehicle/
30 exp car/
31 commut*.tw.
32 exp pedestrian/
33 (road or roads).tw.
34 or/26-33
35 21 and 25 and 34

Annexe B

The GLA has undertaken various activities related to implementing school streets actions in London. Those that cover findings on air quality, mode of transport or active travel changes include:

- Streets improve air quality (March 2021)
- Mayor hails success of Schools Streets programme (March 2022)

Other reports for London generally and specific schemes include:

- Schools Streets, Interventions sites versus control sites full report (TfL 2021)
- Getting to know school streets: an in-depth analysis of 5 school streets in London (TfL 2022)
- Making school streets healthier: learning from temporary and emergency closures (University of Westminster, Active Travel Academy and Cross-River Partnership March 2022)

Annexe C

The Clean Air Programme funded networks of researchers from across a wide range of specialisms, spanning the physical, social and life sciences to the atmospheric sciences, arts and humanities. By working together, these networks aim to better predict and understand exposure to air pollution and its effects on our health, including the impacts on vulnerable groups such as children and older people. Two of these funded networks carried out relevant research:

TAPAS (Tackling air pollution at school)

TAPAS is a network designed to bring together stakeholders across academia, education, public policy, civil society and business. The network works towards supporting the development of healthy schools by improving air quality. Their work is broken down into 4 in-depth content areas relating to schools and air quality:

1. Understanding the problem
2. Understanding the solutions
3. Prioritising the solutions
4. Dissemination and outreach

Each group meets regularly to discuss the research landscape and identify priority areas for further work.

More information about TAPAS is available online.

TRANSITION Clean Air Network

TRANSITION has the objective to co-define key areas with potential to improve, and reduce the risk of deterioration in transport related ambient and indoor air quality, and catalyse the delivery of innovative, evidence-based clean air solutions at the intersect of technological innovation, behaviour change and public policy.

More information about TRANSITION is available online.

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