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Review

Interventions for improving indoor and outdoor air quality in and around schools

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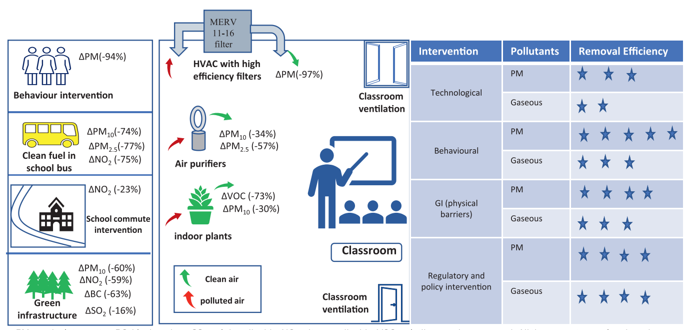
HIGHLIGHTS

- Air purifiers can effectively remove PM_{10} and $PM_{2.5}$ by up to 34 % and 57 % in classrooms.
- HVAC system with MERV 11-16 filter can remove PM_{10} up to 34 % and BC up to 97 %.
- Clean fuel policy intervention can reduce $PM_{2.5}$ concentration up to 62 % inside school buses and 94 % in tailpipe emission.
- Green barriers can reduce PM_{10}, $PM_{2.5}$ and NO_2 up to 60 %, 44 % and 59 % respectively.
- Combination of interventions may work effectively against PM and gaseous pollutants.

GRAPHICAL ABSTRACT



PM, particulate matter; BC, black carbon; SO_2, sulphur dioxide; NO_2, nitrogen dioxide; VOC, volatile organic compound; All the percentage values have been extracted from the respective articles discussed in the article. ★sign shows the comparative reduction in PM and gaseous pollutants.

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ABSTRACT

Students spend nearly one third of their typical day in the school environment, where they may be exposed to harmful air pollutants. A consolidated knowledge base of interventions to reduce this exposure is required for making informed decisions on their implementation and wider uptake. We attempt to fill this knowledge gap by synthesising the existing scientific literature on different school-based air pollution exposure interventions, their efficiency, suitability, and limitations. We assessed technological (air purifiers, HVAC - Heating Ventilation and Air Conditioning etc.), behavioural, physical barriers, structural, school-commute and policy and regulatory interventions. Studies suggest that the removal efficiency of air purifiers for $PM_{2.5}$, PM_{10}, PM_1 and BC can be up to 57 %, 34 %, 70 % and 58 %, respectively, depending on the air purification technology compared with control levels in classroom. The HVAC system combined with high efficiency filters has BC, PM_{10} and $PM_{2.5}$ removal efficiency up to 97 %, 34 % and 30 %, respectively. Citizen science campaigns are effective in reducing the indoor air pollutants' exposure up to 94 %. The concentration of PM_{10}, NO_2, O_3, BC and PNC can be reduced by up to 60 %, 59 %, 16 %, 63 % and 77 %, respectively as compared to control conditions, by installing green infrastructure (GI) as a physical barrier. School commute interventions can reduce NO_2

Abbreviations: ACH, air change per hour; ASHRAE, American Society of Heating, Refrigerating and Air-Conditioning Engineers; BC, black carbon; bVOCs, biogenic volatile organic compounds; CADR, clean air delivery rate; CCF, crankcase filter; CCV, crankcase ventilation; CDC, Centre For Disease Control; CIBSE, Chartered Institution Of Building Services Engineers; CNG, compressed natural gas; CO, carbon mono-oxide; CO_2, carbon dioxide; DOC, diesel oxidation catalyst; ECDC, European Centre for Disease Prevention and Control; EEP, Environment Education Programme; EPA, Environment Protection Agency; ESP, electro-static precipitator; GI, green infrastructure; HECA, high efficiency cabin air; HEPA, high efficiency particulate filter; HVAC, heating ventilation and air conditioning; I/O, input to output ratio; IAQ, indoor air quality; LNG, liquefied natural gas; LPG, liquid petroleum gas; MERV, minimum efficiency reporting value; NO_2, nitrogen dioxide; NOx, nitrogen oxides; PHE, Public Health England; PM, particulate matter; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RPG, regional priority goals; SAGE, Scientific Advisory Group on Emergencies; TRAPs, traffic related air pollutants; UFPs, ultra-fine particles; ULEZ, ultra-low emission zone; ULSD, ultra-low sulphur diesel; VOCs, volatile organic compounds; WHO, World Health Organization.

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concentration by up to 23 %. The in-cabin concentration reduction of up to 77 % for $PM_{2.5}$, 43 % for PNC, 89 % for BC, 74 % for PM_{10} and 75 % for NO_2, along with 94 % reduction in tailpipe emission of total particles, can be achieved using clean fuels and retrofits. No stand-alone method is found as the absolute solution for controlling pollutants exposure, their combined application can be effective in most of the scenarios. More research is needed on assessing combined interventions, and their operational synchronisation for getting the optimum results.

Contents

1. Introduction

Exposure to air pollutants is of particular concern for the vulnerable people such as elderly, pregnant women and young children (Makri and Stilianakis, 2008; Sharma and Kumar, 2022) and those suffering from existing health conditions such as the lower respiratory diseases (Peled, 2011). Children are particularly vulnerable to environmental exposures since they breath higher volumes of air as compared to adults, their body weight is low and immune system is still developing (Rovelli et al., 2014). Exposure of primary school children to traffic generated air pollutants can affect their cognitive development and may result in impaired learning skills. For example, Sunyer et al. (2015) reported that children from highly polluted schools had a smaller growth in cognitive development compared with the children of schools with lower level of air pollutants. UNICEF (2019) have found that children experienced 15 % of their daily black carbon (BC) exposure while travelling to school, and 44 % during their time in school. Therefore, ensuring a better air quality in such micro-environment, becomes more important for the benefit of the children and public health (Rivas et al., 2018).

During COVID-19 pandemic, closure of schools was one of the main strategies opted by many nations to prevent the spread; this interruption in children's learning deprived them of necessary development opportunities (Buonsenso et al., 2021). The air quality in classrooms needs to be investigated thoroughly since some studies suggest that respiratory infection's transmission depends on classroom $PM_{2.5}$ concentration (Jiang et al., 2020; Li et al., 2020; Yao et al., 2021; Zhu et al., 2020). Poor air quality may lead to the development of respiratory diseases among school students and rapid spread of infection during a future pandemic scenario. Greater London Authority's report on 'Indoor Air Quality in London's Schools' has found that the classroom air quality is generally worse than that of the outdoor, and level of PM_{10} and $PM_{2.5}$ were higher than the WHO limits (IAQ Report, 2018). This conclusion has a significant importance because of appreciable time spend by children in the classrooms where particulate matter (PM) concentrations may vary substantially due to building insulation, indoor sources, and resuspension (Amato et al., 2014) as well as ingress from outdoor sources (Che et al., 2021).

In England, around 7800 schools are in areas where annual mean $PM_{2.5}$ in 2017 exceeded the WHO recommended guideline (10 μgm^{-3}) (Osborne et al., 2021a). According to a report of Greater London Authority 802 primary and secondary schools in London, were located where the average annual mean nitrogen dioxide (NO_2) levels for 2013 exceeded 40 μgm^{-3} (GLA Report, 2017), similarly Dowler and Howard (2017) found that in England and Wales, 2092 education or childcare providers were located within 150 m of a road breaching the annual mean NO_2 standard level (40 μgm^{-3}). In addition, there are many idling cars and buses for pick-up and drop-off, that may increase $PM_{2.5}$ concentration by 3-times (Kumar et al., 2020b). Owing to the long-term impacts of air pollution on school children's health and rising level of air pollutants, there is a constant urge to prepare a strategy to combat these impacts in the form of various interventions. The "Parma Declaration on Environment and Health" adopted in the Fifth Ministerial Conference on Environment and Health (PDEH, 2017), declares timebound commitments to protect health and prevent diseases by improving the environment in children's facilities, including schools and kindergartens as one of the Regional Priority Goals (RPGs). Therefore, the study of indoor and outdoor interventions to reduce air pollutants concentration is of prime foci in the field of air pollution research and there is a vital need to consolidate the existing knowledge about various available and practised interventions to mitigate the rising air pollution in and around schools. The severity of the pandemic in terms of mortality and rate of spread has forced the governments, policy makers and researchers to think beyond the traditional mitigation strategies to more effective and target-oriented approach. The efforts of policy makers to combat rising air pollution have resulted into several citizen science campaigns to educate students, teachers, and parents about air pollution control strategies, increase in funding support for the technical innovations and scientific research, new legally binding regulations and policy initiatives.

Various studies have evaluated the performance of a particular type of intervention, but the gap remains for a review focused around indoor and outdoor interventions in school settings. As summarized in Table 1, previous review articles on this topic have discussed air quality in different school microenvironment, the exposure reduction strategies, effects of different air pollutants on children's health etc. Public Health England (PHE), an executive agency of Department of Health and Social Care, UK,

Table 1
Summary of review articles discussing various aspect of air pollution including types of air pollutants found in and schools, their sources and related health impacts on school children, and measures to reduce the exposure.

Author	Focus area	Research findings
Sadrizadeh et al. (2022)	Reviewed the research studies based on school IAQ and related social and health impacts on students and school staff and how different factors affect classroom air quality and comfort in schools, and also students' health.	The pollutants' concentration is higher in schools than in residential and commercial buildings. Poor air quality in classrooms cause a reduction in cognitive performance of students. Adequate temperature also affects classroom comfort. Comfortable temperature range depends on climatic context of the students and their prior exposure to air conditioning.
Sá et al. (2022)	Reviewed the studies based on low-cost sensor technologies to assess different low-cost sensors to monitor indoor air quality and compared them against other instruments.	Study concluded that low-cost sensors are reliable for qualitative air quality analysis in indoor sampling areas. A regular on-field calibration should be carried out between low-cost sensors and reference instruments.
Ding et al. (2022)	Reviewed past studies to assess the existing ventilation strategies of school classrooms and their adequacy of minimizing the spread of infectious aerosols.	Most of the school classrooms are naturally ventilated or having mixed mechanical ventilation. Both long-range and short-range airborne transmissions cannot be prevented by natural or mixed ventilation. The available ventilation in many schools fail to meet adequate ventilation standards, leading to poor classroom air quality (IAQ).
Gartland et al. (2022)	Reviewed the relation between traffic-related air pollution levels in and around schools and academic achievement of primary-school-aged children.	Air pollution from traffic sources has a negative effect on both the executive function and academic achievement of primary-school-aged children and on development of their working memory.
Osborne et al. (2021b)	Reviewed studies regarding air quality in outdoor school environments including playgrounds, drop-off zones, school commute across high income countries.	The study concluded that measures such as clean air zones in schools, greening of school area, promoting active travel, proper selection of school site etc. can be effective as air pollution control measures.
Stenson et al. (2021)	Assessed the relationship between Traffic Related Air Pollutants (TRAPs) and academic performance of school students.	School students, exposed to higher levels of traffic generated pollutants show poorer academic performance than those exposed to lower levels of these pollutants.
Kumar et al. (2021)	Summarized the best practices regarding air pollution exposure mitigation in and around schools and recommended mitigation measures, focusing on drop-off/pick-up points and traffic congestion around schools.	Fine particles' concentration is higher in classrooms facing road, and at traffic hot-spots. The concentration during pick-up hours are up to three times lower than at drop-off hours. The idling of cars during drop-off hours can increase the fine particle concentration up to 300 % in school premises.
An et al. (2021)	Reviewed the effects of TRAPs around schools on student health and mitigation measures.	TRAPs such as NO_2, elemental carbon, and particulate matter (PM) have a significant impact on the cognition and developmental nervous systems, respiratory system of students.
Cheek et al. (2021)	Reviewed the studies about portable air purifiers' impacts on $PM_{2.5}$ concentration and human health in different indoor environment, including schools	The use of portable air purifiers (PAPs) can result in reduction in $PM_{2.5}$ concentration up to 49 % in schools and is beneficial for human health.
Ma et al. (2020)	Reviewed studies on assessing schoolchildren's exposure to various air pollutants during the daily commute.	Concluded that commuter microenvironment plays a vital role in school children's total daily exposure and route choices have a determining impact on school children's exposure.
Salonen et al. (2019)	Synthesised the findings of the studies about local and global exposure to NO_2 in schools and offices	Indoor exposure to NO_2 from the infiltration of outside air can be significant in urban areas, and in the case of high traffic volume. Suggested to locate new schools away from roads with heavy traffic, reducing the use of NO_2-releasing heaters and classrooms facing green spaces rather than busy roads.
Chithra and Shiva Nagendra (2018)	Reviewed and summarized studies on IAQ of schools and related health effects in children.	The air pollutant concentration depends on site characteristics, climatic conditions, outdoor pollution levels, occupant activities, ventilation type and building practices. Among the indoor air pollutants, particulate matter was found to be a major pollutant and their concentration was found to be very high in many schools.
Salonen et al. (2018)	Reviewed the literature on magnitude of and the trends in global and local exposure to NO_2 in schools and offices, and the factors that control the exposure of occupants.	Indoor exposure to NO_2 from the infiltration of ambient air can be significant in schools in urban areas, and proximity of school to high traffic volume road. Apart from reducing transportation emission, other means to reduce indoor NO_2 concentrations are a better ventilation strategy with suitable filters; location planning of new schools, classrooms, and ventilating windows or intakes; traffic planning (location and density) and reducing the use of NO_2-releasing indoor sources.
Salthammer et al. (2016)	Reviewed the studies related to the effects of climatic parameters and air pollution on children's well-being and health, resilience to withstand the effects of climate change on urban school environment.	Thermal comfort and adequate ventilation to remove classroom-generated pollutants are essential to maintain the good indoor air quality in classrooms.
Choo and Jalaludin (2015)	Reviewed evidence of the association between indoor air quality (IAQ) and its implications on respiratory health among Malaysian school-aged children	Study found that most of the Malaysian school-aged children are exposed to the harmful pollutants in classrooms, deteriorating their respiratory health.
de Gennaro et al. (2014)	The study explored the methodological approaches used for the assessment of air quality in schools.	The study concluded that certain conditions such as the location, age and airtightness of school buildings, classroom design, ventilation rate, building and furnishing materials, occupant's activities

Table 1 (*continued*)

Author	Focus area	Research findings
		and outdoor pollution play an important role on the indoor pollutants' concentrations.
Annesi-Maesano et al. (2013)	Reviewed literature on adverse respiratory health effects of air pollutants related to IAQ and building characteristics of schools.	Schools have IAQ problems due to poor building construction and maintenance, poor cleaning, and poor ventilation
Mejía et al. (2011)	Reviewed the methodologies for assessing the exposure of children to air pollutants, especially traffic emissions, at school, and the effects of these methodologies on the assessment of the impact of this exposure on the children's health.	The study found that the school environment is the major contributor to children's exposure to air pollutants, traffic is another important source of indoor and outdoor air pollution in schools. Children from lower income families are exposed to higher levels of air pollution at school than those from more privileged families.
Ashmore and Dimitroulopoulou (2009)	Reviewed the personal exposure of school aged children to specific pollutants in western Europe and North America.	Concluded that sulphur dioxide (SO_2) exposure is expected to be lower than outdoor level, NO_2 exposure in indoors may exceed the outdoor one in case of presence of sources such as gas stoves.
Daisey et al. (2003)	Summarized the available literature on ventilation, carbon dioxide (CO_2) concentrations and other indoor air pollutants such as volatile organic compounds (VOCs) and biological contaminants and their associated health effects for school students.	Most of the classrooms are not adequately ventilated as per ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) ventilation standards. The pollutants found in schools were TVOC (Total Volatile Organic Compound), Formaldehyde and microbiological contaminants in the form of allergens. Exposures to these pollutants can cause asthma, and other respiratory symptoms. These pollutants are found in classroom floor dust and carpets.

has published a review of interventions to improve outdoor air quality and public health focusing on general outdoor settings (PHE, 2019).

The novelty of this review lies in its design and scope that focuses on critically synthesising the available knowledge on a broad range of interventions – technological, physical/structural, behavioural, policy and regulatory – covering both indoor and outdoor school environments. This review also discusses the effectiveness, limitations, and efficiency of school-based interventions to limit air pollutants' concentration and the grey areas for future research. The overall goal of this paper is to evaluate current-state-of-the art on various interventions to reduce school children's exposure to air pollutants and to inform the research and policy responses to improve classroom air quality. The objectives of this review are to: (i) carry out a detailed review of available studies on interventions for reducing school children's exposure to air pollutants; (ii) provide a comprehensive summary of interventions for school environments; (iii) evaluate their effectiveness in terms of the potential advantages and disadvantages; and (iv) highlight the gaps for future research.

2. Scope and outline

The scope of this review is limited to interventions that are related mainly to schools (primary and secondary). We considered most of the air pollutants (PM, CO_2, BC, NO_2) that have been part of intervention studies and effectiveness of interventions on these pollutants' removal. Irrespective of any geographical area, all the relevant studies have been considered in our literature search. A systematic literature review of articles was performed from scientific database such as Google Scholar, Scopus, ScienceDirect, and Web of Science using a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach (Liberati et al., 2009). The following keywords and phrases were used for the search: 'interventions', 'schools', 'air pollution', 'classroom interventions', 'outdoor interventions', 'green walls', 'green screens', 'air purifiers in schools', 'childhood asthma', 'pollutant matter exposure to student', 'ventilation in schools', 'air pollution campaign in schools', 'behaviour changes and environmental education'. The keywords were selected based on certain criteria, such as the title of the paper, types of interventions, objectives of the study, advantages, and limitation of different interventions etc. While searching on web, the "People Also Ask" and "People Also Searched" sections were also used to find other relevant keywords and queries for the study. Our search was limited to publications written in English and published in the last 20 years. Fig. 1 shows the screening procedure followed, the number of papers included and excluded at each stage, and reasons for exclusion. Out of 2996 articles (after removing duplicates) obtained from the search, 1992 studies were excluded by manually screening abstracts. Further screening of full-text articles eliminated 671 papers. The procedure isolated 126 highly relevant papers for this review. Rather than dividing these papers based on types of pollutants, the interventions have been classified based on their working principle. Of this finalised body of literature, the distribution per topics covered showed the following composition: 31 % of the papers dealt with different technological interventions; 17 % addressed physical barriers (hedges, trees, boundary walls); 13 % involved studies of different behavioural interventions, 11 % addressed structural interventions, 9 % commute interventions and 5 % about policy and regulatory interventions; and remaining 14 % covered other topics including indoor air quality, children's exposure to air pollutants, health impacts of indoor pollutants etc.

This review is comprised of four sections. Section 1 provides the basic understanding of the subject, following by the scope and outline of the paper (Section 2). Section 3 discusses the various types of interventions in details, followed by conclusions, recommendations, and the grey areas for future research around the topic areas covered (Section 4).

3. Types of interventions

Interventions are the actions that are available to use by public, researchers, scientists, and regulatory authorities towards the solution of a problem. Numerous types of interventions exist, with targets to reduce the exposure of school children from air pollutants (as shown in Fig. 2). Technological interventions are based upon a scientific technology such as air purifiers, HVAC system with enhanced filters. Behavioural interventions aim at encouraging positive behaviour among students, teachers and parents through citizen science campaigns to limit students' exposure to air pollutants. School commute interventions encourage choosing less polluted alternate route and less polluted travel choice for commuting to schools. Structural interventions cover the infrastructural improvement of already existing school buildings, such as maintaining proper ventilation, renovating old school buildings and replacing aging furniture, structural changes to indoor environments such as doors and window openings to prevent leakage etc. National and international level policy and regulatory provisions in form of guidelines and laws are also successful in keeping the air pollutants under legal limits. Deploying GI can act as a physical barrier to incoming air pollutants from traffic sources and can reduce the exposure. These interventions have been discussed in detail in subsequent subsections and a summary of results is presented in Fig. 2. However, some interventions may fall into more than one category, for example clean fuel in buses works on a scientific principle but their implementation is a policy issue, therefore it can be considered both as technological and policy intervention. For this study, clean fuel in school buses is discussed under policy and regulatory intervention.

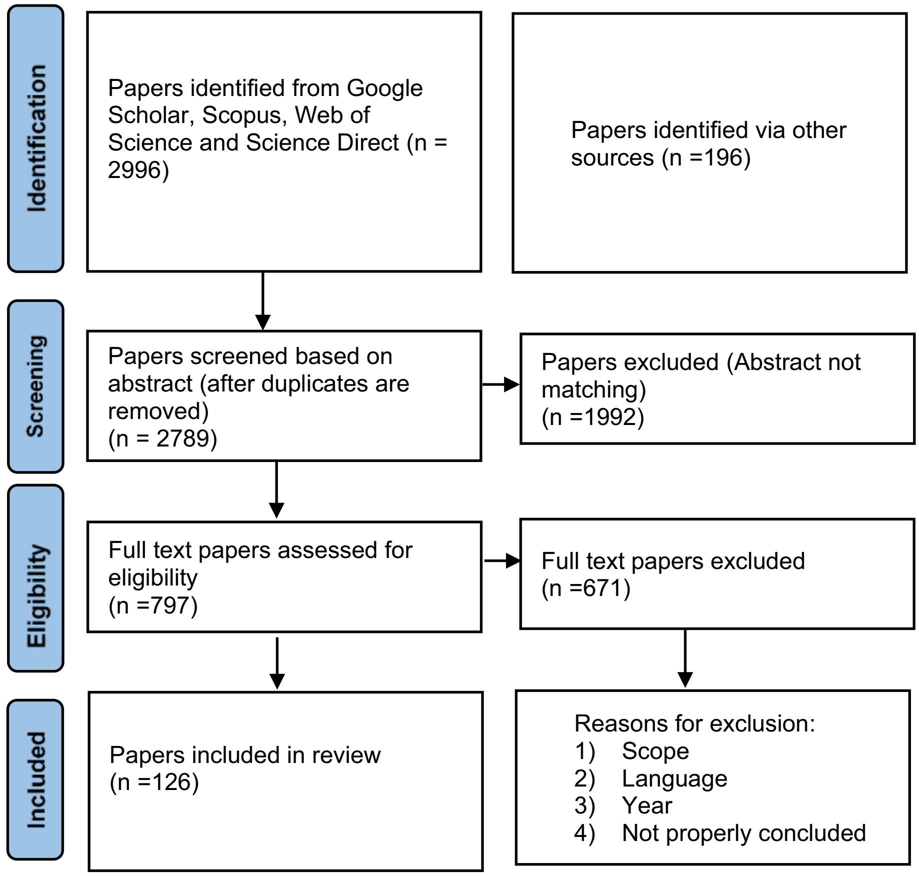

Fig. 1. Schematic representation of literature identified in the steps of systematic review.

3.1. Technological interventions

Technological interventions are those relying on a certain type of mechanically driven technology such as enhanced HVAC system (that include in-duct filtration system with high rating filters) and use of air purifiers. Table 2 summaries the research surrounding different types of technological interventions, places where these interventions are used and the associated research findings. Following sections discuss about different technological interventions: a) HVAC with high efficiency filters (Section 3.1.1), b) Air Purifiers (Section 3.1.2) in detail.

3.1.1. HVAC system with high efficiency filters

Natural ventilation has been shown effective on the improvement of IAQ. Opening the windows allows to maintain optimal ventilation, it is also possible to reduce the concentration of classroom air pollutants and improve the air quality (Heracleous and Michael, 2019), but for the schools located near traffic-bearing highways, windows opening may result in higher indoor concentration of traffic generated air pollutants. In a naturally ventilated school, where the external ventilation only provided by the manual airing of classrooms, a proper manual airing strategy is more crucial. Manual airing positively affects the concentration of indoor-generated pollutants (VOCs, radon, etc.) but at the same time indoor ultrafine particles (UFPs) concentration increases by longer window opening time and accelerated infiltration from outside sources (Stabile et al., 2017). Window opening may also affect energy losses related to air leakage and air-exchange rate (Ficco et al., 2015). Therefore, HVAC system is becoming popular as an intervention to control classroom air quality and energy losses.

The conventional use of HVAC systems is to control the environmental conditions inside a building. It can also prevent ingress of outdoor pollutants by generating negative pressure inside the building, if designed and maintained properly (EPA, 2015). To reduce indoor PM concentration, use of high-efficiency HVAC filters is recommended as an alternative to supplying additional ventilation because such filters can lower particle concentration with lesser energy consumption and are effective even when outdoor concentrations of particles are high (Zaatari et al., 2014). In schools with central HVAC systems, medium-efficiency filters (MERV 6–7) tend to reduce BC concentrations by approximately 31–66 %, while higher performance filters (MERV 11–16) can reduce BC concentrations from 74 to 97 % (McCarthy et al., 2013). van der Zee et al. (2017) reported that using fine filter F8 (MERV-14) in HVAC system in a school classroom reduced BC, PM_{10} and $PM_{2.5}$ concentration by 36 %, 34 % and 30 %, respectively. MERV is a performance indicator for filters, which reports a filter's ability to capture particles between 0.3 and 10 μm. For better IAQ a minimum MERV-13 filter should be used (ASHRAE Epidemic Task Force, 2021). Polidori et al. (2013) compared three types of air filtration units; air conditioning based high-performance panel filter (HP-PF), register-based air purifier (RS) and a stand-alone air cleaning system inside different classrooms and found that the combination of RS and HP-PF was the most effective solution for lowering the indoor concentrations of BC, UFPs, and $PM_{2.5}$, with average reductions between 87 and 96 %. Martenies and Batterman (2018) suggested that using enhanced filters in conventional HVAC system can reduce input to output ratio (I/O) of $PM_{2.5}$ and BC. They reported that as the filter efficiency increases, the I/O for $PM_{2.5}$ and BC reduces and upgrading the filters from MERV 7 to MERV 15 reduces the cases of mortality, chronic bronchitis and stroke risk by 33 %. Increasing the ventilation rates in HVAC system is also found to significantly improve children's performance in classroom in many tasks, including how fast they response in class (Bakó-Biró et al., 2012; Wargocki and Wyon, 2011). Some studies have been performed to find out the optimum intervention settings in times of COVID-19 and to

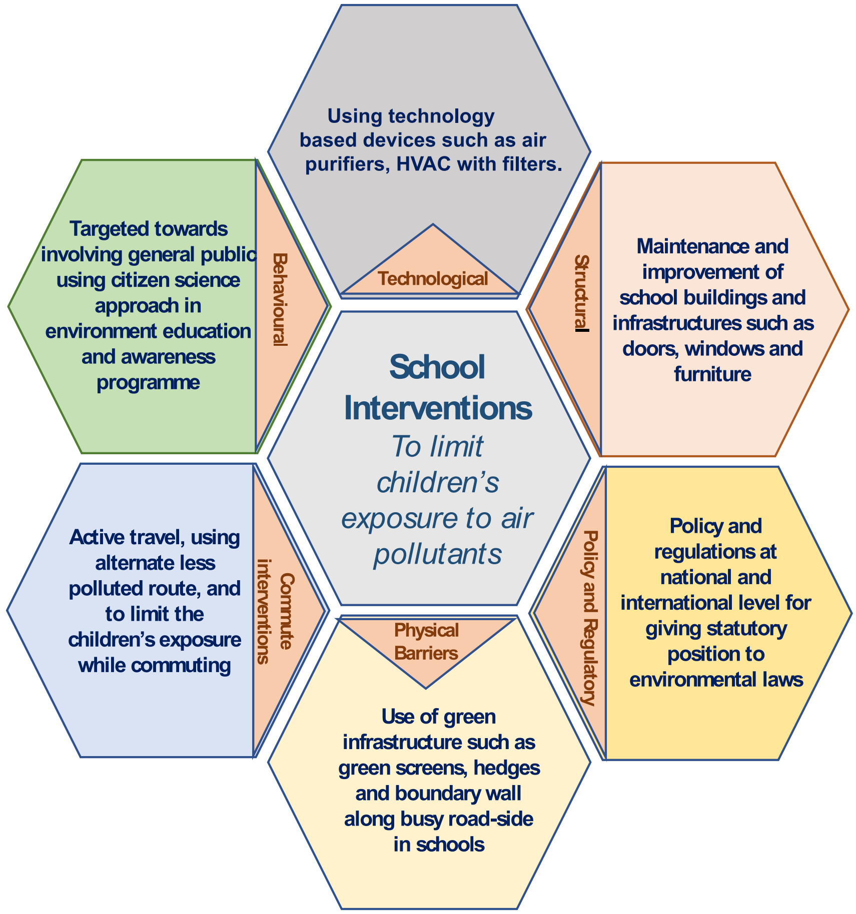

Fig. 2. Classification of different types of school interventions used in and around schools to limit student's exposure to air pollutants and their methodologies.

prevent the pandemic spread. Some modifications have been suggested by these studies in the existing practices of indoor pollutants removal. The air outlets of HVAC system should be located such that the clean air can be reached above the sitting areas and the air suction should take the air from the floor by means of a suspended floor or via ducts distributed near the floor level of the sitting areas (Lipinski et al., 2020). As the older schools have pre-built HVAC system, and it is not feasible to alter the existing ventilation and filtration system, it has been recommended by Centre for Disease Control and Prevention (CDC), USA to use portable air purifier (PAP) units in such situations (Asanati et al., 2021).

Olsiewski et al. (2021) suggested that to reduce respiratory infection risk in schools, classroom ventilation should be improved by bringing in as much outdoor air as the HVAC system will safely allow and also by upgrading filtration to the highest efficiency filters possibly MERV 13. They also suggested to switch fans from 'auto' to 'on' so that they operate continuously ('auto' mode only providing ventilation when HVAC was running in heating or cooling mode). The ventilation rate in HVAC systems is an important air quality control measure, as several studies suggest that there is a direct link between ventilation rate and student performance, their respiratory health effects, and student absence (Fisk, 2017; Gaihre et al., 2014; Mendell et al., 2013). Therefore, for proper ventilation rate in classrooms, the HVAC system must be configured to continuously provide outdoor air when the classroom is occupied regardless of heating or cooling needs and should have a routine filter maintenance and correct fan control settings (Chan et al., 2020). EPA guidance document suggests that the central HVAC system is more effective in indoor air quality improvement than the single portable air purification system as it is easier to maintain HVAC system because of the reduced number of individual units and are compatible with higher efficiency filtration. HVAC system can achieve higher air exchange rates and therefore better indoor air quality with effective air distribution (EPA, 2015). Some schools are able to incorporate high efficiency filters in their existing HVAC system, but in older school buildings, HVAC systems are not compatible with high efficiency filters. Replacing existing HVAC system with an inbuilt enhanced filter poses a challenge of cost constraint in terms of repair cost as the older HVAC systems that exist in older schools were not designed with air filtration in mind (Polidori et al., 2013), resulting into shift of focus of research towards PAP's application in schools. Apart from air quality improvement and ventilation, the noise generated by HVAC system is also an important criterion that demands careful attention to the design and selection of HVAC system in classrooms. Since classrooms should be quiet places for better concentration of students, the background noise levels should be in accordance with noise standards. For example, the upper limit for the indoor ambient noise level in schools in the UK should be in the 30-45 dB range, depending on the type of the room. The noise limits are lower for rooms used for music recording purpose or for teaching spaces intended to be used by students with specific hearing needs whereas the places like libraries and science laboratory have higher standard for noise (Daniels and Bodkin, 2015). Therefore, for new schools, proper consultation among designers, building construction engineers, and acoustic experts should take place in early building design process.

Central HVAC system in schools are energy efficient as a single unit can serve for multiple rooms, and apart from providing proper ventilation, they also can serve for air filtration if provided with high efficiency filters. Routine cleaning of filters and proper maintenance can prevent pressure drop, facilitate smooth functioning of HVAC system and maintain filter performance. In older school buildings, the cost of replacing existing ventilation system with enhanced HVAC system is high but the cost savings due to higher energy efficiency of HVAC system makes it a viable option to be considered in school development and upgradation plan.

Table 2
Different types of technological interventions used in schools, based upon underlying technology of pollutant removal, location and key findings. The studies included are based on the application of technological interventions' in schools to minimise students' exposure to air pollutants.

Intervention in focus	Country	Key findings	References
Air purifier with pre-filter, activated charcoal, HEPA-filter.	Germany	Opening the window and the use of portable air purifiers are effective in reducing the number of viruses in the room. The positioning of the source and sampling points affected the removal efficiency of air purifier in the test room. The change in air purifier's location did not show any variance in the results.	Uhde et al. (2022)
Water-based air purifier	Thailand	The tested air purifier was found suitable for gradual PM reduction, ranging from 0.5 to 10 μm and was most effective after 15 min of machine operation. Since the air purifier was water-based, it can emit humidity which has no effect on overall RH of the closed room and has minor effect on CO_2 levels.	Jumlongkul (2022)
HEPA-filter based air purifier	USA	The particle removal efficiency of air purifier was found higher for coarse particles. For particle size between 5 and 10 μm, the removal efficiency was 99.4 %. Air purifier was efficient in removing UFPs with removal efficiency of 82.8 %.	Aldekheel et al. (2022)
Air purifiers with high efficiency filters	South Korea	Air purifier efficiencies in the elementary, middle, and high schools were approximately 29 %, 23 %, and 31 % for PM_{10} and 31 %, 25 %, and 33 % for $PM_{2.5}$, respectively.	Choe et al. (2022b)
HEPA filter (H-14) based air purifier	Germany	Air purifier can reduce PM_1 concentrations in a combined loading and decay scenario by 58 %-70 % without outlet obstructed and with outlet obstructed condition, respectively.	Tobisch et al. (2021)
HEPA filter (H-14) based air purifier	Germany	Depending upon the location of the source, the reduction in the aerosol concentration in a classroom varies between 70 %-90 %, when air purifier is used, compared to control conditions.	Burgmann and Janoske (2021)
Box fan air purifiers	USA	The box fan air cleaners can reduce the aerosol concentration up to 12 % as compared to the no air purifier condition. The efficiency of the air purifier increases with smaller size rooms and when air outlet is in bottom rather than on top part of air purifier.	Elson et al. (2021)
Water-bath filtration system-based air purifier	Italy	A commercial air purifier device was used that was based on a water-bath filtration system through which the air was forced without the use of any other type of filter. Dust particles and allergens were trapped directly into the water. The study was performed to evaluate the capacity of the air purifier to reduce both PM and TVOCs concentrations and it was found that the water-bath filtration air purifier resulted in reduction of 90 % in PM_{10} and about 80 % for $PM_{2.5}$, and about 40 % reduction in VOCs.	(Fermo et al., 2021)
Air purifier with pre-filter, photocatalytic filter, active carbon and HEPA filter.	China	The air purifier can reduce the particle ($PM_{2.5}$) concentration to a great extent but it can cause higher level of CO_2 concentration, if used on recirculation mode. Air purifiers should be used on fresh air mode so that CO_2 concentration and $PM_{2.5}$ would be in limit.	Tong et al. (2020)
Ionization based air purifier	China	The removal efficiency of ionization air purifier for BC, $PM_{2.5}$ and PM_{10} was 50 %, 44 % and 34 % respectively, as compared to control conditions.	Dong et al. (2019)
Fresh air ventilation systems (FAVS) with high efficiency particulate air filter (HEPA)	China	Application of FAVS with HEPA filter was effective in reducing 66 % school indoor air $PM_{2.5}$ in the filtered classroom indoor air.	Gao et al. (2019)
Enhance filters (MERV (Minimum Efficiency Reporting Value) rating 12)	US	I/O ratios for $PM_{2.5}$ and BC fall as filter efficiency increases, more efficient filters in classrooms reduce the asthma-related health burden, Upgrading from MERV 7 to MERV 15 filters reduce the cases of mortality, chronic bronchitis, and stroke risks by 33 %	Martenies and Batterman (2018)
HVAC system with fine F8 Filters (MERV rating 14)	Amsterdam	The mean concentration of BC decreased for both the elementary schools under the study	van der Zee et al. (2017)
Commercial air cleaners with HEPA filters	United States	$PM_{2.5}$ and BC levels were significantly reduced compared to the control classrooms that received a sham air filter. The air cleaner intervention reduced $PM_{2.5}$ and BC levels by up to 49 % and 58 %, respectively.	Jhun et al. (2017)
Air purifiers with electrostatically charged filter	China	Air purification use resulted in the reduction of 57 % in $PM_{2.5}$ concentration in college classrooms and demonstrated cardiopulmonary benefits among students.	Chen et al. (2015)
Improving the filtration system in already existing HVAC system	United States	Mean concentrations of BC inside the classrooms decreased from 0.75 to 0.29 μg/m^3 at one school and from 0.27 to 0.040 μg/m^3 in another. Personal exposures for children are thus expected to be lower at the near-roadway schools as a result of the enhanced filtration systems.	McCarthy et al. (2013)
Tailor made mechanical ventilation device	Netherlands	Classrooms CO_2 levels can be significantly reduced by installing a CO_2 controlled mechanical ventilation system, increased ventilation with unfiltered air decreased the levels of indoor-generated pollutants, but outdoor-generated pollutants' concentration remained unchanged.	Rosbach et al. (2013)
Increasing the ventilation rate	UK	Classroom CO_2 concentration reduced and resulted into higher level of focused attention at higher ventilation rates compared to low rates with natural ventilation. In poorly ventilated classrooms, students are likely to be less attentive and to concentrate less well on instructions given by teachers.	Bakó-Biró et al. (2012)
Combining the dust reducing carpet with air filtration	Netherland	The study shows a reduction of 27–43 % in particulate air pollution during teaching hours, and a 51–87 % effect during weekends. For gaseous air pollution components, no conclusive effect was found	Scheepers et al. (2012)

(continued on next page)

Table 2 (*continued*)

Intervention in focus	Country	Key findings	References
HEPA filter-based air cleaner in combination with increased outdoor air exchange.	United States	A fully integrated energy recovery ventilator, air purifier and air conditioning unit, the HEPAiRx, was designed to study the impacts of the improving IAQ on reducing the asthma symptoms and found to be effective in reducing particle and gas concentrations with notable reduction of 72 % in PM_{10} concentration and reductions of 59 % in VOC, 19 % in CO_2, and a 30 % in CO concentrations.	Xu et al. (2010)
The electrostatic air cleaners	Sweden	The electro-static air purifiers were found successful in reducing the particle concentration of all sizes and their operation also reduced settled dust on horizontal surfaces.	Wargocki et al. (2008)
Changing the outdoor air supply rate by increasing the fan speed and changing the filter conditions	Denmark	A significant effect of ventilation rate was observed in 70 % of all the statistical tests for an effect on work rate, but there were no significant effects on errors, reduction in the average CO_2 concentration from 1300 to 900 ppm.	Wargocki and Wyon (2007)
1) A controlled mechanical incoming and exhaust air system, with mechanical coarse filter. 2) A controlled mechanical incoming and exhaust air system, with a mechanical and a chemical filter (consisted of carbon (C) and aluminium oxide (Al_2O_3) saturated with potassium permanganate ($KMnO_4$) 3) A simple ventilation system with only the exhaust fan running while other fans were off. The coarse mechanical filter was also used in the duct.	Finland	With a ventilation system that included chemical filtration of incoming air the indoor nitrogen oxide levels could be reduced to about 35 % of outdoor levels at times when outdoor levels were high, the other two mechanical systems reduced indoor PM to about 30 % of outdoor level when outdoor level was high. The best results were obtained when mechanical filter is combined with the chemical one.	Partti-Pellinen et al. (2000)

3.1.2. Air purifiers

The efficiency of HVAC system for air quality improvement in sudden pollution episodes is comparatively less. Therefore, the application of HVAC system for localised effects are not popular, standalone air purifiers are preferred in such situations. Owing to the higher installation cost of HVAC system, many schools in developing countries do not have HVAC system. For such schools, natural ventilation is the only means of providing external ventilation in classroom. To improve the classroom air quality and prevent the incoming pollutants from outside sources, air purifiers can be used along with manual opening of windows. Also, in older schools and those with pre-installed HVAC system, without high efficiency filters, portable air purifiers are preferred as an alternate for classroom air quality improvement. The main air purifying technologies include mechanical filtration, ozone generators, plasma, UV radiation, catalytic oxidation, and absorbent materials (Cheek et al., 2021), as described in Fig. 3.

Table 3 presents technical features of some commercially available air purifiers that can be used in classroom settings, based on their portability, size, flow and technology. Most of the commercially available air purifiers

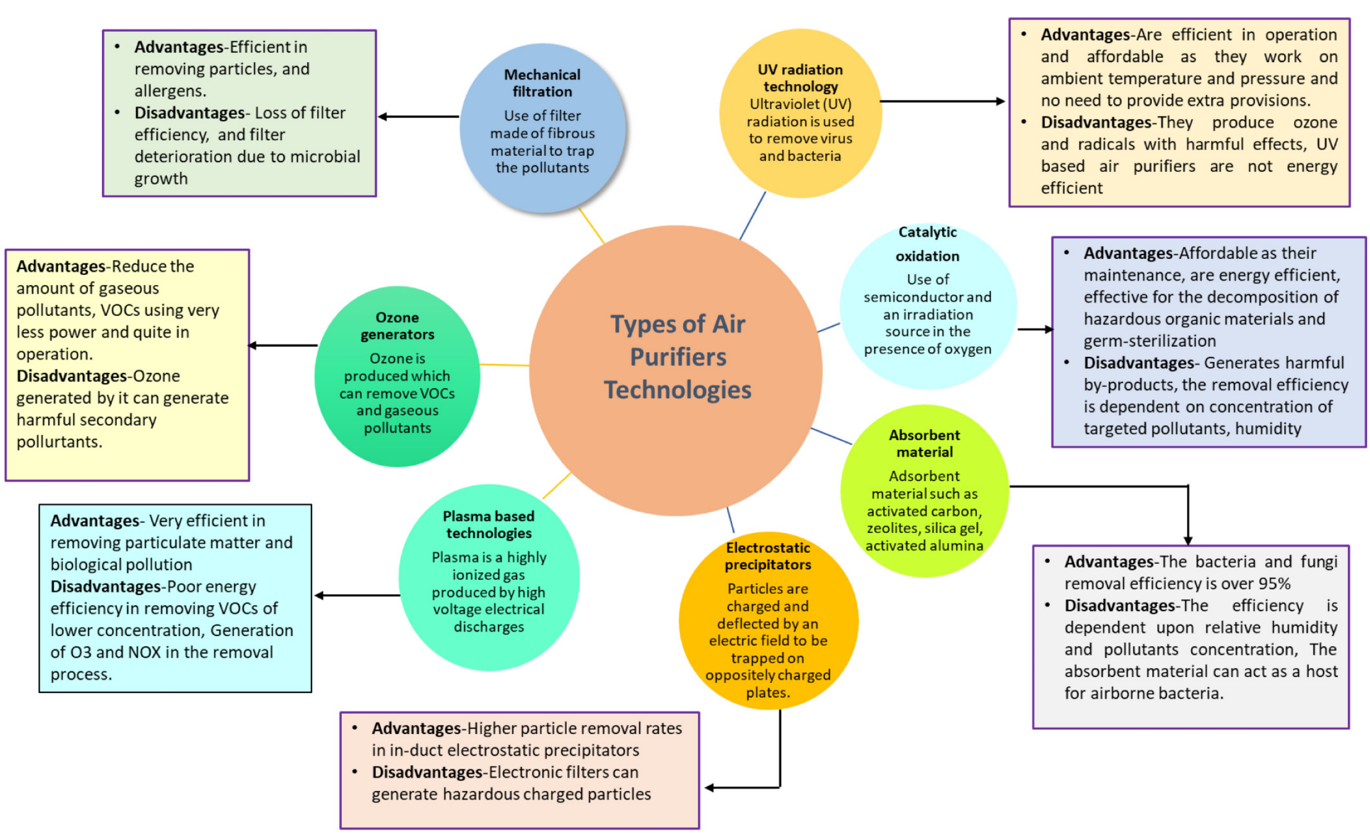

Fig. 3. Schematic representation of different types of air purifiers' technologies explaining their underlying mechanism, with their advantages and disadvantages of use.

Table 3
Technical features of selected commercially available air purifiers suitable for school settings. The list is not comprehensive, and the selection is based upon the results of the web search for commercially available air purifiers under a particular air purification technology. While the list below is not exhaustive, we selected air purifiers based on their suitability to classroom settings such as portability and weight via the web search results. This search was based on the air purifiers working the five types of technologies noted in table below. There is no preference order or priority ranking of the air purifiers listed in the table. The table is only for reference and authors are not recommending any of the devices mentioned in the table below. The information shown here has been taken from manufacturer's official website. The '-'sign is used when the relevant information was not available.

Commercial Air Purifier Name	Technology	Flow rate/CADR	Power Consumption	Room size coverage	Sound level	Pollutants removed
HEPA filter-based air purifiers						
AirHavn Pro (AirLabs) 	HEPA with activated carbon	CADR (Clean Air Delivery Rate) of 278-576 m^3/h (particles) (Depending upon Speed)	78w	Up to 1000 sq. ft.	29 dB	$PM_{2.5}$, PM_{10}, NO_2, ozone (O_3) ammonia (NH_3) and VOCs.
MINUSA2 ultra quiet air purifier (SPA-780A, SPA-780 N 	HEPA with activated carbon	CADR of 328m^3/h (dust)	7-61w	Up to 815 sq. ft.	25.6-51.3 dB	Large particles, dust mites, pet hair, pollen
Alen BreatheSmart Classic air purifier 	HEPA with activated carbon	CADR of 510m^3/h, Flow rate 255-493 m^3/h	1.6-105w	Up to 1100 sq. ft.	42-56 dB	–
IQAir HealthPro Plus air purifier 	HEPA with activated carbon	CADR of 70-510 m^3/h, depending upon the speed	–	Up to 1125 sq. ft.		Allergens, asthma triggers, chemicals and odours
Dyson Pure Cool (TP04) 	HEPA with activated carbon	CADR- 119 m^3/h (smoke)	56 w	Up to 1000 sq. ft.	45-63 dB (depending upon the flow rate)	Microscopic allergens and particles (size up to 0.1 μm)
Levoit 	HEPA with activated carbon	Flow Rate-200.6 m^3/h	37w	Up to 183 sq. ft.	24–48 dB (depending upon the speed)	Dust, hair, pollen, smoke, odour
Philips AC0820 	HEPA with activated carbon	CADR of 520 m^3/h	55 watts	Up to 1119 sq. ft.	15-34 dB	Air borne UFPs, allergens, gases, bacteria and viruses
Medify MA-40 	HEPA with activated carbon	CADR of 950 m^3/h	95w	–	70 dB (Max.)	Pollen, dust, mold, bacteria, smoke, fine particles up to 0.1 μm
AEG AX91-404GY AX9 air purifier 	HEPA with activated carbon	CADR of 442 m^3/h	4-28w	–	46 dB (Max.)	–

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Table 3 (*continued*)

Commercial Air Purifier Name	Technology	Flow rate/CADR	Power Consumption	Room size coverage	Sound level	Pollutants removed
Beurer LR210UK 	Pre filter, HEPA filter and activated carbon	–	60w	Up to 280 sq. ft.	–	Dust, bacteria, viruses, harmful gasses, pollen and pet dander, odours
Boneco P710 	HEPA with activated carbon	CADR of 442 m^3/h	–	Up to 775 sq. ft.	37 dB	allergens, pollen, viruses, dust, pet dander, dust mites, smoke and odours
Ruhens WHA-320 	HEPA with UV sterilization	CADR of 302.4 m^3/h	33 w	Up to 753 sq. ft.	19.2-48.8 dB (depending upon the speed)	PM_1, $PM_{2.5}$, bacteria, virus
Leitz TruSens Z-3000 	HEPA with UV sterilization	CADR of 460 m^3/h (dust)	68w	Up to 753 sq. ft.	32-66 dB	Allergens, pollen, bacteria, viruses and odours, VOCs, fine particles up to 0.3 μm and ultrafine particles up to 0.033 μm.
HoMedics TotalClean 	HEPA with UV sterilization, carbon odour filter and ionizer	–	75w	Up to 1176 sq. ft.	41-57 dB	Germs, bacteria, virus, allergens, large particles, odours, VOCs
Blue Air Blue Pure 221 	HEPA filtration and electrostatic precipitation	CADR of 593 m^3/h	30-61w	Up to 538 sq. ft.	31-56 dB	Particles, pollen, pet dander, odours
Winix Zero Pro 	Pre filter combined with HEPA and activated carbon, with ion generation	CADR of 470 m^3/h	5-90w	Up to 1292 sq. ft.	28-55 dB	Particles up to size 0.3 μm, dust mites, mold spores, and pet dander
Proscenic A9 	HDOF Purifying Technology (including a primary filter, HEPA filter with activated carbon and nano silver ions	CADR of 460 m^3/h	55w	Up to 968 sq. ft.	25-55 dB	Dust, pet dander, smoke, mold, and pollen and fine particles up to 0.3 μm size
Ion generator air purifiers						
AIRVIA Pro 	Ion generation and UV sterilization	CADR of 90-550 m^3/h (particle), 36.9-226 m^3/h	9.8w-54.5w (depending upon the speed)	Up to 1600 sq. ft.	30-68 dB (depending upon the speed)	PM_1, $PM_{2.5}$, VOCs
Homelabs 4 in 1 air purifier 	Ion generation with HEPA filter	–	–	40 sq. ft	–	Smoke, large particles, odour
Clenzair air	Needlepoint bipolar	Flow rate 690m^3/h	–	Up to 132 sq. m	0-21 dB	Virus, bacteria, VOCs, particles,

Table 3 (*continued*)

Commercial Air Purifier Name	Technology	Flow rate/CADR	Power Consumption	Room size coverage	Sound level	Pollutants removed
purifier 	ionization system					odours
Plasma technology-based air purifiers						
Air Oasis 	Cold plasma technology	Flow rate 51 m^3/h	15 w	Up to 250 sq. ft.	30 dB	Virus, bacteria, smoke, VOCs, mold, allergens, odours
Photocatalytic oxidation technology air purifiers						
Molekule 	Photocatalytic Oxidation technology	–	26-123w	Up to 1000 sq. ft.	41 dB	PM_1, $PM_{2.5}$, PM_{10}, VOCs, bacteria, viruses
Zandair 100C air purifier 	Photocatalytic Oxidation with activated carbon, HEPA filter and UV light	Flow rate 450 m^3/h	110w	–	–	Automobile exhaust fumes, organic hydrocarbons, formaldehyde, VOCs, chemically active compounds (CACs), pollen, mold, fungus, virus, bacteria
ESP based air purifiers						
Evergen 	ESP	Flow Rate 1400-3400 m^3/h- Monolite 330 Flow Rate 2100-5100 m^3/h-Monolite 510	190w-Monolite 330 255w-Monolite 510	Up to 1000 sq. ft.	43-56 dB	PM_{10}, virus, bacteria, gases
Trion Electrostatic Series 120 air purifier 	ESP	Flow rate 680 - 1360 m^3/h	260w	Up to 54 sqm	41-65 dB	Tobacco smoke, dust, pollen, lint, bacteria and mold spores

use HEPA filters as they are capable of capturing 99.97 % of PM, smog and bacteria having size >0.3 μm, from the air passing through them (Chuaybamroong et al., 2010). Curtius et al. (2021) found that effective combination of venting along with HEPA filter-based air purifier in classroom settings is effective to reduce the inhaled dose of aerosols up to 83 %. They also suggested that these air purifiers are capable to reduce the COVID-19 transmission risk to students up to six times. HEPA filter-based air purifiers are very efficient in removing the fine particles, for $PM_{0.1}$ (particle diameters ≤0.1 μm), removal efficiency is almost 100 % (Duill et al., 2021). Burgmann and Janoske (2021) concluded that air purifiers with HEPA filters are able in transient reduction of aerosols in the range of 70-90 %. Another study by Smythe (2018) conducted two trials to test the efficiency of HEPA based air purifier in elementary school settings and concluded that the air purifier was effective in removing $PM_{2.5}$ (total mass removal efficiency was 45.8 % in Trial 1 and 53.8 % in Trial 2) and elemental constituents of $PM_{2.5}$ such as S (particulate sulphur) and K (potassium) were also reduced. There are some limitations associated with use of HEPA-based air purifiers in school classrooms. The filter may get clogged, after a certain period of operation and the particle loading on the filters will begin to significantly influence the particle removal efficiency and pressure drop (Xia and Chen, 2020). The efficiency of the filter material keeps on decreasing with time when it is clogged because of continuous particle retention. Though the filter can be replaced but the clogged filter could become a source of contamination from micro-organisms harmful to human health (Yu et al., 2009). Another major concern of using these air purifiers is the noise generated by them. The maximum flow rate noise levels exceed the acoustic performance standards for UK schools (35 dBA- 45 dBA) for most lecture rooms in both new and retrofitted schools (Peck et al., 2016). Wargocki et al. (2008) studied the effects of ESP based air purifiers on indoor air quality and students' performance and concluded that they are effective in reducing airborne particles, but there is no significant improvement in air quality perception and academic performance of students. Some studies suggest that the air purifiers based on ESPs generate ozone due to high voltage use (Afshari et al., 2020; Boelter and Davidson, 2007), the trace amount of which can have chronic impacts on human health (Salonen et al., 2018). Day et al. (2018) studied combined use of HEPA filters and ESP in an air handling unit in office settings and concluded that use of ESP generated ozone and it may increase the blood pressure and the risk to cardiovascular health of occupants. Dong et al. (2019) studied the effects of ionization-based air purifiers on the concentration of PM, BC, in classrooms and found that the concentration reduction for $PM_{2.5}$, PM_{10}, BC was 44 %, 34 % and 50 %, respectively. Waring and Siegel (2011) in their study found that use of ionization air purifier can though reduce the particle concentration slightly, but it is associated with increased concentrations of UFPs, ozone, and VOCs that are harmful to human health. Therefore, ASHRAE recommends that the air purifiers that generates ozone as secondary pollutant should not be used in occupied spaces because of negative health effects that arise from exposure to ozone and its reaction products (Wargocki et al., 2015). Shaughnessy et al. (1994) in their study on different air purification technologies (HEPA filter based, ionizers, ESPs) on pollutants removal, concluded that none of the technologies was effective in CO removal.

The selection of a particular type of air purification technology in the classrooms, is affected not only by the type and amount of secondary pollutants generated, but sufficient CADR must also be ensured for improving the indoor air quality. CADR of an air purifier represents the filtration efficiency and the removal rate of particles by filtration. It is the product of decay rate of particles by using air purifier, and volume of the room (Küpper et al., 2019). CADR score is specific to particle sizes and is reported for 3 categories of particle sizes: pollen (2.5–80 μm), dust (1–30 μm), and tobacco smoke (0.1–1 μm) (Sahu et al., 2013). For example, an air purifier having high CADR should be selected for the removal of smaller size particles from tobacco smoke (EPA Guide, 2018). To clean the air as efficiently as possible from particles or virus-containing aerosols, the CADR of air purifier should be as high as possible (Curtius et al., 2021). CADR of an air purifier is measured while air purifier is running at full speed. Higher fan speeds and longer run times will increase the amount of air filtered which may generate higher noise (EPA Guide, 2021). Therefore, higher the CADR, more will be the noise generated by the purifier which may also result into higher level of noise (Liu et al., 2017). Therefore, the air purification units to be used in schools should be selected carefully, keeping in mind all the pros and cons of the air purification technology. UK Government's Scientific Advisory Group on Emergencies (SAGE), has published the guidelines regarding use of air purifiers, suggesting that the air purifiers where the primary principal of operation is either filtration based or UV light-based technology, should be used (SAGE, 2020).

Some studies suggest that though air purifiers are efficient in removing PM, as shown in Table 2, they are not effective in controlling the CO_2 concentration. Choe et al. (2022b) found that CO_2 concentration significantly affects the IAQ satisfaction of students in the classroom; measures such as maintaining proper external ventilation should be adopted. Naturally ventilated schools use opening of windows as a source of external ventilation, but this may cause ingress of traffic generated pollutants for the schools located near heavy traffic roads. Some studies (Pacitto et al., 2020; Stabile et al., 2017) have suggested that a proper ventilation strategy should be selected for maintaining sufficient ventilation in naturally ventilated schools to keep classroom CO_2 level under the safe limit. Use of air purifiers in naturally ventilated classrooms is receiving increased attention, to reduce the indoor particles concentration that is contributed by outdoor sources. The performance of a particular air purifier depends upon the ventilation settings in the room, it's flow rate or air exchange rate provided by it. The minimum value of air exchange rate depends further on room size and number of persons sitting in the room. Pacitto et al. (2020) used four air purifiers (HEPA filter and activated carbon) and installed them in the four corners of the school gyms. They found that with flow rate of 660 m^3/h and air change per hour (ACH) of 1.5, the air purifiers were effective in removing particles and black carbon, but no effects were observed on CO_2 concentration. ACH is the number of times an air purifier can clean the same amount of air as the volume of the room, in an hour. The bare minimum value for ACH of an air cleaning device in schools is suggested as 3 and ideally 6 (Allen et al., 2020). Tong et al. (2020) used two wall mounted air filtration units in two primary school classrooms with flow rate of 70–150 m^3/h and concluded that the CO_2 reduction was mainly contributed by fresh air supply. They concluded that for reducing the CO_2 concentration there should be a break time in schools with no students inside the class and windows should be kept open. In another experiment by Curtius et al. (2021), four air purifiers were at different locations of classroom and they found that air purifiers are efficient in reducing the aerosol load in a classroom. If windows and doors are closed for a longer period, then using air purifier can reduce the inhaled dose of PM containing virus RNA and thus the chances of aerosol infection can be lowered. Park et al. (2020) suggested to use surface cleaners along with air purifiers in the classroom as the fine particulate matter are removed by air purifiers and the settled coarse particles can be removed by surface cleaning. Scheepers et al. (2012) used dust reducing carpets in combination with two compact air filtration units in their study and found that this combined intervention had high benefit to cost ratio, and high particulate matter removal efficiency during teaching hours. No conclusive evidence for gaseous pollutants were found. They also mentioned to use this method temporarily; in case of a structural improvement of an existing building or when a school is moving to a new building with a state-of-the-art HVAC system. Some primary schools in London have installed "Pollution Tower" in the school playground to tackle the rising outdoor and indoor particulate concentration in the schools by trapping UFPs and filtering pollutant gases such as NO_2. Pollution Tower is a 9 ft. tall filter-less system that collects particulate matter from the air in a tray (Pollution Tower, 2019). The working principle of pollution tower is same as that for smog towers. Smog towers are used in public places and are generally 30-40 ft. high. Smog tower sucks the air inside and treat the air by ionization technology and works as an outdoor air purifier (Guttikunda and Jawahar, 2020).

Although several studies have concluded that air purifiers are effective in removing PM, CO_2 concentration in classroom is not affected by air purifiers. In a classroom setting where occupants are children, their academic performance and attention in classroom are also affected by CO_2 levels (Wargocki et al., 2020). As the air purifiers alone are not effective against CO_2 removal, they should be used in combination with centralized HVAC system (Duill et al., 2021) or with properly timed window opening (Wargocki et al., 2020) to have lower CO_2 concentration in classroom. Another important aspect of air purifier's effectiveness in removing PM is its location in the classroom. Some studies have been carried out on location effects of air purifiers (Curtius et al., 2021; Duill et al., 2021), most of them are conducted in hospital, office and restaurant. However, there are hardly any studies that have focused on the best possible location of air purifier in classrooms. Classrooms are a complex micro-environment with unique characteristics such as large area, densely occupied spaces, presence of several furniture objects that act as obstruction for free air flow, and frequent activities of students that lead to indoor generation of particles and other pollutants. Filtration in classrooms presents some unique challenges as they often have high ventilation rates with doors and windows that are frequently open to outside air (Polidori et al., 2013).

The challenges ahead of air purification technology include: 1) Reducing the airborne transmission of infection and improving IAQ while having adequate CO_2 in classrooms. Minimum ACH (Air Change Per Hour) of an air purifier should be between 5 and 6 to maintain sufficient ventilation in an occupied classroom. To achieve this, an air purifier must be able to maintain the CADR >400 cfm (cubic feet per minute), depending upon the classroom volume (Allen et al., 2020). This high CADR is difficult to maintain in resource limited indoor places (He et al., 2021). 2) Having sufficient research data related to health impacts of secondary pollutants generated by different air purification technology to facilitate national and international level policy formulation related to air purifiers' application in classrooms. There is no consensus among various national and international guidelines and recommendations concerning the use of air purifiers. The Chartered Institution of Building Services Engineers (CIBSE), UK has recommended that HEPA filters or UV radiation technology-based air purifiers can improve the air quality in highly occupied and poorly ventilated indoor spaces that are located near heavy traffic (CIBSE, 2021), whereas according to European Centre for Disease Prevention and Control (ECDC) guidelines, air purifiers should be considered as a supplementary solution only, because there is a limited research and data on their efficiency and about the health impacts due to generation of ozone as a secondary pollutant (ECDC, 2020).

The use of air purifiers had significant importance during the COVID-19 pandemic. Elson et al. (2021) concluded that air purifiers can not only reduce the overall concentration of aerosols in the space but are also capable to limit the spread of infection. Several studies have advocated the use of air purifiers to reduce COVID-19 virus transmission (Burgmann and Janoske, 2021; Curtius et al., 2021; Lindsley et al., 2021). Proper ventilation is necessary not only for preventing airborne transmission of infection but also for students' better performance in the classrooms. There is also very limited evidence on air purifiers' efficiency in removing bioaerosols and VOCs (Zhang et al., 2021), therefore, the future research should focus on the combining air purifier technology with proper ventilation strategy in schools and guidelines should be developed for the use of air purifiers for well-ventilated areas. Scientific research should also focus on air purifiers' effectiveness in VOC removal and secondary pollutants generated by them, so that proper risk analysis can be performed before their application in the classrooms. The ongoing research in this field has evolved new air purification technology that generate lesser amount of ozone and is more effective in improving air quality, such as shorter-wavelength UV-C lamps (222-nm lamps) (Claus, 2021).

3.2. Behavioural interventions

Behavioural interventions are mainly focused on individual behaviour that can be changed without much difficulty to gain better outcomes. The behaviour changes towards any activity have long term effects. A properly planned and well-motivated Environmental Education Programme (EEP) can bring a positive behavioural change towards climate change in parents and children. A formal educational program amalgamated with ecological activities in an EEP, could potentially be more effective in bringing about desired changes in children's ecological attitudes and behaviours (Legault and Pelletier, 2000). Several studies have suggested that these education programmes run in the form of campaigns have been successful in achieving the intended achievement of educating teachers, parents and children about climate change. Barnes (2014) reviewed the behaviour change, indoor air pollution exposure and children's respiratory health and concluded that behavioural interventions can reduce indoor air pollution exposure by 20 %–98 % in laboratory settings and 31 %–94 % in field settings, depending on the type of behavioural intervention and the targeted air pollutant. In laboratory-based studies the studied interventions were tested in controlled laboratory conditions and using technical instruments. The field studies were performed in actual indoor environment, and the results showed that behavioural change can reduce indoor air pollution exposure, with or without using high-end technology. Ballantyne et al. (2010) has suggested that EEPs are successful to influence students' environmental behaviour by combining research activities, environmental experiences and class discussion, making the programme inclusive of community and industrial engagement, making the programme outcomes public by means of newspaper and local magazines. When students learn that they can influence their local environment, it provides them positive experiences and affects their perspective positively towards climate change. The emergence of low-cost sensor technologies encouraged the participation of lay citizens and children in scientific research and citizen-science initiatives. One such initiative was development of a toolbox by Castell et al. (2021) to raise the awareness of primary school students about air quality and how to increase their participation in air quality improvement activities. The toolbox included study material for teachers and activities to be performed by the students, an interactive website was developed for the students so that they could see the results of the activities performed by uploading the data. During recent COVID-19 pandemic the public awareness campaigns on actionable measures for the public to reduce pollution and limit exposure have become more prominent and public response towards surrounding air quality has sharpened, specifically around schools and classrooms. Recent studies also suggest a direct link between a person's exposure to surrounding air pollution and the severity of the symptoms of COVID-19 infection (ERG, 2020). Therefore, there have been many campaigns and programmes that have been started during this period and some are still running. Table 4 shows summary of the behavioural interventions in the form of citizen science campaigns, information toolkits and environment education programmes.

Environment education programmes and campaigns involving citizen science approach are effective in generating awareness among citizens about the effects of human activities on surrounding environment. These programmes also increase the knowledge of mitigation measures against environmental problems and motivate the citizens to participate actively (Parra et al., 2020). The campaigns should focus upon skill development and changing the citizens' attitude towards air pollution. The citizen science campaigns should be designed collaboratively with joint participation of researchers, academicians, community and policy makers. Prioritising citizens' say in policy making and programme designing will motivate them to participate actively. New technologies and skills such as mobile applications and gaming should be incorporated in designing the behavioural intervention programmes, to attract and engage large number of students.

3.3. Physical barriers

GI can offer range of benefits to human society such as well-being of ecosystem and human health, numerous social and psychological services (Pataki et al., 2011). GI can reduce human exposure of particulate matters in both microscale as well as macroscale environment (Tiwari et al., 2019). Therefore, they are used as physical barriers for roadside traffic-generated air pollutants, especially important for schools located near heavy-traffic roads. Apart from improving the air quality, Pataki et al. (2011) found that green spaces improved alertness in children with attention deficit disorder. GI can be provided in schools in various forms and shapes, depending upon the targeted aspect of air pollution. The "Toolkit of Measures to improve Air Quality at Schools" by the Mayor of London, UK, has suggested several measures to plan GI in schools, situated in the most polluted areas of London, such as providing green screens, trees/shrubs/planters, green gateways and pocket parks in and around the schools (Toolkit, 2018).

Numerous studies have been performed to find the effects of GI, in various forms, over air quality and concentration of air pollutants. The summary of these studies has been shown in Table 5. Greenness within and surrounding school boundaries can result into lower indoor and outdoor levels of TRAPs such as NO_2, UFPs, BC, $PM_{2.5}$ (Dadvand et al., 2015). GI is a potential mean to mitigate pollution impacts and can refer to street trees, hedges, bushes, green walls, green roofs, green screens and green spaces (Kumar et al., 2019a, 2019b). Trees are effective in reducing gaseous pollutants such as O_3, NO_2, SO_2 and also CO_2 by uptake through the leaf stomata and can also reduce particles through interception by leaf surface (Escobedo and Nowak, 2009). Green screens (Hedera Ivy screens) are found effective in capturing PM and protecting students from traffic emissions from nearby roads and are beneficial in many ways such as providing healthier environment, providing privacy and they are also easy to install and are fast growing (Living Green Screens and Ivy Screens - Biotecture, 2020). Green screens are also provided in the form of "Green Barriers", that are basically different species of plants and vegetation that are placed in vertical as well as horizontal spatial arrangements. Green walls and green roofs are also popularizing as a viable option for air pollution mitigation in schools. The pollutants removal potential of green walls depends upon wind speed, humidity and LAI (Leaf Area Index) (Joshi and Ghosh, 2014). Green roofs are efficient in air pollution mitigation, reducing urban heat island effect, noise pollution and also in reducing energy consumption (Abhijith et al., 2017). Some schools around the world have green roofs, such as in China, Netherland, France, U.K., U.S. etc. In USA, a proposed legislation allocates fund for installing green roofs on public schools as a part of the post-covid recovery plan for New York City. The green roofs will be beneficial in reducing air pollutants' concentration by capturing PM and will also reduce urban heat island impacts (Green Rooftop, 2020). Phytoremediation (using plants to remove air pollutants) is also popularizing as an IAQ intervention (Liu et al., 2007). Pegas et al. (2012) reported the effects of house plants on classroom air quality and found that indoor plants can reduce PM_{10} concentration up to 30 % and VOCs concentration up to 73 %. GI can also be provided in form of solid wood fence or shrubs. Kumar et al. (2020a, 2020b) concluded that higher PM_{10} concentration in playgrounds is due to dust resuspension whereas the $PM_{2.5}$ concentration in playground is comparable to ambient $PM_{2.5}$ concentration during morning drop-off hours in schools. They suggested that solid wood fence panel, trees and semi-partial low-height shrubs between the school and the road can lower to exposure to $PM_{2.5}$ in the school playgrounds.

While planning and implementing GI along schools, proper care must be taken, such as type of GI (trees or hedges) depending upon the location

Table 4
A summary of behavioural intervention programmes based on citizen science campaigns.

Name of the intervention	Objective	Methodology	Country (year)
Idle-Free Schools Toolkit	To reduce the amount of toxins emitted to environment because of vehicle-idling with the help of the toolkit materials in the form of information, and recommended schedule, and an idling reduction campaign run by schools.	This toolkit includes information needed to run an effective idling reduction campaign which aims at reduction in students' exposure to harmful vehicle exhaust.	USA (2021)[a]
Global Action Plan's Clean Air Projects	To reduce the rising concentration of air pollutants and make the air more breathable. The project includes several sub-projects that aim to get a better air quality including that around schools and nurseries.	There are a series of projects that are running to make the desired changes in the air quality, visible. These projects include: 1)Build Back Cleaner Air 2) The Clean Air Hub 3) Air Pollution Calculator 4) Business for Clean Air 5) Business Clean Air Taskforce 6) Clean Van Commitment and 7) The Clean Air for Schools Framework.	UK (2020 – 2021)[b]
Clean Air Week	Combating air pollution caused by cars left running when dropping off and collecting children at school gates.	School students are encouraged to measure air quality outside their schools, using diffusion monitors or by accessing local air quality monitoring data. During this one-week period, schools encourage no-idling zones near schools' vicinity	Ireland (2020)[c]
School and Nursery Air Quality Audits Programme	This audit was targeted towards addressing the rising air pollution level in London.	This audits report recommended certain measures to reduce emissions and exposure of school students that included moving school entrances and play areas away from busy roads, 'no engine idling' schemes to reduce emissions from the school run, reducing emissions from boilers, kitchens and other sources, local road changes including better road layouts, restricting the most polluting vehicles around schools and pedestrianisation by school entrances, adding green infrastructure. Schools and nurseries in London were provided financial support to implement these recommendations.	U.K. (2020)[d]
Guidelines for schools to mitigate air pollution	To recommend action points to enable schools, children and communities to make informed decisions, to reduce the exposure of school children to air pollution.	The guidelines are in the form of a document that summarises the best practice regarding air pollution exposure mitigation in and around schools. These recommendations are based upon contemporary scientific evidence. These guidelines are available in more than 20 languages.	U.K. (2021)[e]
London schools pollution helpdesk	This platform is targeted towards the schools which were situated in the worst polluted areas of London to help them clean up toxic air at schools.	This is a free to use service for all London schools that can use the expert advice, resources to support teaching air quality in the curriculum, support in reducing traffic outside the school gate etc. for tackling rising air pollution around the schools.	U.K. (2020)[f]
STOP project (Schools Tackling Oxford's Pollution)	To raise awareness of the main sources and health effects of air pollution emissions among the school community.	The air quality toolkit prepared for this project provides science teachers at a school with a series of interesting air quality scientific activities to present to students, to promote understanding of the causes and impacts of air pollution and help to reduce children's exposure to air pollutants, within the school and through their travel to the school.	U.K. (2020)[g]
The Clean Air for Schools Framework	To help schools to prepare clean air action plan to tackle air pollution in and around the school.	This is a free online tool to educate schools to tailor the clean air programme according to the school specific requirements and recommend appropriate actions with the help of expert advice on the subject.	UK (2020)[h]
Cleaner Air Sooner	To help schools, parents and local authorities to improve air quality in and around schools.	Based upon six cleaner air programmes designed to quickly improve the air quality by enabling schools to create a Clean Air Route map for students commuting to schools with the help of mapping toolkit available on the website, and to educate students, teachers and parents about the air quality through webinars and video lectures.	UK (2020)[i]
School Streets	1)Restrict through traffic and drop-off activity in school peak periods. 2)Reduces emissions and improves road safety	Traffic access restrictions at school opening and closing times to help create a safer, more pleasant environment for children travelling to school, by removing air quality and road safety problems associated with through traffic and drop-off activity on the street/s outside the school, in following steps: 1)Introducing separate Pedestrian Zones or Pedestrian & Cycle Zones 2)Use of access signs and ANPR cameras. 3)Penalty charge notices for contraventions.	U.K. (2020)[j]
Play Street	Restrict through traffic and drop-off activity and raise awareness of air quality & sustainable travel.	A 'play street' is a timed closure on the street/s outside the school during a certain period of the day (e.g., 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.	U.K (2020)[k]
Green School Project	Educate the school students about climate change and empower them to tackle it with sufficient knowledge base.	This project has several sub-projects to achieve the overall aim, these include: 1) Zero Carbon Schools: To make school children and teachers aware of climate change and carbon emission. 2)Climate Action Programme: It is a series of teachers' training sessions for teachers to help their school develop a plan to tackle the climate crisis, by including climate change education and into the curriculum and help students develop a greater understanding about the subject. 3)Eco-Team Support Programme: There would be an eco-team of the students in the school, to be supported by a university students	U.K. (2019)[l]

Table 4 (*continued*)

Name of the intervention	Objective	Methodology	Country (year)
		volunteer and also by an expert's visit to the school providing guidance.	
Anti-idling education campaign	The campaign was successful in reducing vehicle idling by lowering the number of vehicles that idled, the percentage of vehicles that idled and idling duration.	To educate people about the harmful impacts of vehicles idling.	U.K. (2020)[k]
Green School Programme	It is an environmental education programme that aims at educating school students and teachers about better natural resources management, including air, water, energy, food etc.	Helps schools understand how their transport policies affect air quality and to find ways of reducing their emissions to limit the students' exposure to harmful pollutants.	India (2017)[m]
Active and Safe Routes to School (ASRTS) Programs	To promote sustainable and healthy school travel among children by reducing their exposure to pollutants	There were three ASRTS programs across Canada that worked to promote daily exercise, cleaner air due to reduced vehicle congestion, taking help from the principle of 6 Es, i.e., Evaluation, Engineering, Events, Enforcement, Equity, and Encouragement.	Canada, 2017 (Diaz-Insense et al., 2017)
Safe Routes to School and Traffic Pollution guidelines	To reduce the potential risks of exposure of school students to traffic pollution	The guidelines are about the low-cost infrastructure improvements, such as sidewalks, crosswalks, school zone signage and traffic calming, made through Safe Routes to School	U.S. (2012)[n]
Use of classroom air quality monitors	To improve the ventilation and classroom CO_2 concentration to combat the spread of COVID.	CO_2 monitors to be installed in U.K. school classrooms to alert staff and students if CO2 levels rise above critical level so that appropriate measures can be taken by them	U.K. (2020)[o]
Walking School Bus	Promoting walking to and from school among students and parents to reduce pollutants' concentration in and around pick-up and drop-off locations in schools and provide health benefits of walking.	Group of children walking to and from school with one or more adult volunteers. Routes are selected through trial walk by volunteers and based upon health and safety of students.	U.S.A. (2020)[p]

[a] https://www.epa.gov/schools/idle-free-schools-toolkit-healthy-school-environment.
[b] https://www.globalactionplan.org.uk/.
[c] https://www.irishtimes.com/news/education/dozens-of-schools-to-introduce-no-idling-zones-under-campaign-to-tackle-air-pollution-1.4416178.
[d] https://www.london.gov.uk/what-we-do/environment/pollution-and-air-quality/mayors-school-air-quality-audit-programme.
[e] https://www.surrey.ac.uk/global-centre-clean-air-research/resources/guidance-for-schools.
[f] https://www.pollutionhelpdesk.co.uk/.
[g] https://www.oxford.gov.uk/info/20299/air_quality_projects/1254/schools_tackling_oxfords_air_pollution_stop.
[h] https://www.transform-our-world.org/clean-air-for-schools.
[i] https://www.cleanerairsooner.org/.
[j] https://www.london.gov.uk/sites/default/files/school_aq_audits_-_toolkit_of_measures_dr_v3.3.pdf.
[k] https://www.london.gov.uk/sites/default/files/school_aq_audits_-_toolkit_of_measures_dr_v3.3.pdf.
[l] https://www.greenschoolsproject.org.uk/.
[m] https://www.greenschoolsprogramme.org/.
[n] https://www.saferoutespartnership.org/sites/default/files/pdf/Air_Source_Guide_web.pdf.
[o] https://www.theguardian.com/education/2021/aug/21/classrooms-england-monitor-air-quality-effort-combat-covid-better-ventilation.
[p] https://guide.saferoutesinfo.org/walking_school_bus/.

(Abhijith et al., 2017), and type of species (Kumar et al., 2019a, 2019b). Fantozzi et al. (2015) in their study, concluded that the pollutant removal capacity of GI depends upon the species of plants and climatic conditions. They found that some species of trees (*Quercus ilex*) can form secondary organic aerosols and O_3. Trees also release biogenic volatile organic compounds (bVOCs) and during the events of heat wave, drought and air pollution, increase these emissions (Barwise and Kumar, 2020; Holopainen and Gershenzon, 2010). This bVOC can make ozone as a secondary compound when reacts with air oxidants and can thus deteriorate air quality (Churkina et al., 2017). Although several studies suggest that GI can lower NO_2 concentration (as shown in Table 5) but Yli-Pelkonen et al. (2017) in their study in Finland, found elevated levels of NO_2 inside greenbelts (elongated forest belt). They have suggested that pedestrians and cycling routes parallel to a busy road and in front of a dense canopy or green belt may cause higher exposure to NO_2. While implementing GI in areas near vulnerable population such as schools, old-age home and day-care centres, proper care must be taken. Local differences in vegetation, surrounding traffic conditions, climate, micro-climatic conditions, characteristics of plant species should be considered before selecting a particular GI intervention.

Boundary walls or barrier walls (BW) are solid walls that are effective to lower incoming pollutants' concentration by altering the air flow pattern. For schools located near highway, noise barriers also act as a barrier to traffic generated pollutants. Noise barriers are commonly placed on major high-speed highways to reduce noise pollution for populated areas, but these barriers can also influence localised dispersion and thus can improve downwind air quality. The air pollutants removal by noise barrier found to be affected by local meteorological conditions (wind speed and direction) (Gallagher et al., 2015). The height of the BW, its location and whether spaces exist in the barrier was found to influence air flow. Gallagher et al. (2015), concluded that higher walls can restrain the spread of the traffic-spewed particles towards the roadside. They also studied the impact of low boundary walls (LBW) (1–2 m height). The study concluded that the effectiveness of LBWs depends upon barrier configuration, wind conditions and vehicular turbulence. McNabola et al. (2008) reported the reductions of between 35 % and 57 % in personal pollutant exposure for pedestrians while walking through a boardwalk with BW as compared to walking on adjacent footpath. In another study by McNabola et al. (2009) reductions in personal pollutant exposure of up to 40 % and 75 % in perpendicular and parallel wind conditions, respectively were found. They studied two scenarios, one with BW in the middle of the street and another one on the footpath and concluded that the location of the BW impacted the reduction in pollutants' concentration. They also concluded that height to width ratio of the wall (H/W) may impact the reduction in particles' concentration by BW.

Despite of several socio-economic and environmental benefits, the wider uptake of GI as a passive air pollution mitigation measure in schools is limited, presumably due to lack of awareness on the performance of GI. GI should not be perceived simply as an intervention to improve school's contribution towards better environment, but also as a pedagogic resource in teaching sustainability and other competencies (Onori et al., 2019).

3.4. Structural interventions

Structural measures are basically school premises related measures that may affect the indoor/outdoor air quality in school. The older school

Table 5
Summary of the results of numerous research studies based on the effects of different GI on air pollutants reduction.

Source	Objectives and methodology	Findings
Redondo-Bermúdez et al. (2021)	Scanning Electron Microscopy (SEM) and 3D optical profilometry were used to study and compare the pollution-filtering mechanism of three plants species that are parts of a green barrier in a school playground in UK.	All the three plants species were found to be capable of capturing particles. The fraction of PM_1 trapped on leaves surface was higher in percentage of total trapped particles, followed by $PM_{2.5}$ and PM_{10}.
Abhijith and Kumar (2020)	SEM and leaves image analysis of leaves from a hedge at different heights, were performed to find out total PM deposition, variation in deposition within the hedge. Analysis of elemental composition of particles on filter paper to study the sources of particles removed by leaves.	The deposition of PM was higher on leaves at the back of the hedge than at the traffic-facing side. The reduction of PM_1 was highest (9 %), followed by PM_{10} (7 %) and $PM_{2.5}$ (2 %), when compared between before hedge and after hedge.
Ottosen and Kumar (2020)	To find change in air pollution reduction as a function of phases of the vegetation cycle (greening up phase and maturity phase) of deciduous vegetation.	During maturity phase of vegetation, the reduction in PM_1 concentration was 52 %, for $PM_{2.5}$ and PM_{10} the reduction was 44 % and 35 % respectively. The effect of wind direction was minor on pollutants' concentration.
Abhijith and Kumar (2019)	Concentration reduction potential of different air pollutants categories for different GI types were studied in near road environment.	The tree-hedge combination reduced BC concentration up to 63 %, PM_{10} up to 24 %, whereas hedge alone scenarios reduced PNC up to 30 % and $PM_{2.5}$ up to 14 % and PM_1 up to 25 % behind the GI compared to in-front monitored concentration.
Tremper and Green (2018)	NO_2 concentration was measured at either side of a green screen, installed at a primary school in London to study the efficacy of the green screen.	Up to 23 % reduction in NO_2 concentration was achieved by a matured green screen of height 2.4 m.
Jayasooriya et al. (2017)	Air quality improvement by different GI scenarios (trees, green roofs and green walls) were analysed using i-Tree Eco software.	Green infrastructure can remove PM_{10} up to 47.92 %, $PM_{2.5}$ up to 1.54 % and NO_2 up to 21.42 % from the annual total air pollutant uptake when all industrial and commercial buildings of the study area have green roofs and boundary walls covered with 2 m high hedges.
Lin et al. (2016)	To study the effects of vegetation barrier (trees) on the concentration of UFP and CO in near road environment through both mobile and stationary measurements.	Reduction of up to 63.6 % in UFP concentration and 56.1 % in CO concentration were achieved behind the vegetation barrier.
Fantozzi et al. (2015)	Long term monitoring of NO_2 and O_3 was performed at increasing distances from a busy road and in an open area to study the impacts of urban trees on pollutants concentration.	The NO_2 removal rate of tree canopy was found to be 14-59 % depending upon the season. The concentration of O_3 was higher when measured under the tree canopy.
Brantley et al. (2014)	To find out the effects of a mixed-species tree stand on near road air quality on a location very near to highway under various meteorological and traffic conditions.	The reduction in BC was in the range of 7.8-22 % behind the tree, depending upon the wind direction and time of the day but no significant reduction in $PM_{2.5}$ was found.
Al-Dabbous and Kumar (2014)	To study the effect of vegetation barrier on nanoparticles generated from traffic. The monitoring was performed front, middle and back of the barrier and at open-field without the barrier.	The reduction in PNC was found in the range of 37-77 % depending upon sampling location and direction of wind, as compared with vegetation free location.
Nowak et al. (2006)	A modelling study was performed using hourly meteorological and air pollutants' concentration data to find out the magnitude of air pollution removal capacity of urban tree cover in 55 US cities.	The short-term air quality improvement in urban area is 16 % for O_3, 9 % for NO_2, 8 % for PM_{10}, 16 % for SO_2 and 0.03 % for carbon monoxide (CO).

buildings are not energy efficient therefore, to make them compatible with the modern air purification technology, they must be renovated. Adequate ventilation must be ensured for providing safer and healthier classroom environment for students, because during classroom hours, the occupation density is high (close to 1.8 m^2/pupil) and students inhale more indoor air (Theodosiou and Ordoumpozanis, 2008). Although CO_2 is not an air pollutant, but still can be considered as a proxy for classroom air quality (Chatzidiakou et al., 2015), maintaining proper ventilation to maintain better air quality in classroom. Majd et al. (2019) found that physical defects in the school building, such as cracks and holes in the walls, broken windows and peeling wallpaper or paint, were associated with higher indoor NO_2 concentrations. They also found that building characteristics also affect CO concentration in the classroom with an 8.2 % increase in the daily mean CO concentration for each additional open window. Mold growth in school buildings can cause health and performance related problems in students. The mold contamination in the buildings also contribute to the sick building syndrome (Straus, 2011). EPA listed certain building characteristics that can trigger excessive mold growth such as wet or damp construction cavities, moisture-laden outdoor air entering the building due to leakage in windows and walls, use of deeply wetted building materials. It suggests several measures related to school buildings to control mold growth such as sloped roofs, ground slope, use of vapor barriers etc. (Toolkit, 2021).

Playground in schools act as a source for particulate matter in outdoor and for indoors also. Minguillón et al. (2015) found that the presence of sandy playgrounds acts as a source of high concentration of $PM_{2.5}$ and PM_{10}, especially at the time of children activity like entry and exit time for school, during games hours and other breaks. This higher concentration of PM_{10} can be as high as 57-times than the average concentration at night. The mineral major and trace elements concentration are found to be higher in schools with sandy playgrounds. School playgrounds expose children to particulate matter and other vehicular emissions due to their closer proximity to roads or their location along a major road (Famuyiwa et al., 2018)..

Some other structural measures include relocating the playgrounds and free flow spaces to the less polluted areas of the school premises, relocating pedestrian entrance, co-ordinating start and finish time with nearby schools, and providing additional space for scooter or cycle parking (Toolkit, 2018). Chatzidiakou et al. (2015) found in their study that providing hard-tiles flooring may lead to an average of 38 μg/m^3 and 29 μg/m^3 lower indoor PM_{10} and PM_1 respectively, as compared to the carpeted floor. They suggested that replacing the carpeted floor with hard-tiles, proper selection of cleaning products and fleecy cleaning cloth introduced in the classroom can limit the exposure to TVOCs.. School buildings play an important role in maintaining better IAQ and to prevent health problems in students, therefore, school infrastructure upgradation should be carried out by schools at regular interval. The upgraded school facilities will benefit to students' and teachers' health and reductions in infectious disease transmission; therefore, schools should be audited frequently to check the structural maintenance requirements and should be supported financially to carry out renovation and facilities improvement plan.

3.5. School commute interventions

Children's exposure to TRAPs during the school commute is influenced by mode of travel, selection of route to school, especially for schools located in urban and sub-urban area. Children can encounter pollution peaks on their way to schools and commuter microenvironment is a significant contributor to their total daily air pollution exposure. Selecting alternate route and alternate mode of travel that are safer in terms of exposure to pollutants can lower students' exposure to traffic generated air pollutants. Studies have suggested that active travel (walking and cycling) causes lower exposure to $PM_{2.5}$ as compared to travel by bus or car (Dirks et al., 2018;

Gilliland et al., 2019; Jeong and Park, 2017). Adar et al. (2015) in their study measured the in-cabin concentration of pollutants to be three times higher than that in ambient air. Though retrofit can lower the tailpipe emissions but there is no significant improvement found for in-cabin pollutants. Thus, the exposure of students is more when they are travelling in bus, as compared to their exposure while waiting to be picked-up (Zhang and Zhu, 2011). Therefore, active travel is recommended for lower exposure to air pollutants while commuting (Paunescu et al., 2017). Evidence suggests that choosing alternative routes away from busy roads can significantly mitigate exposure. It is suggested by some studies that walking on the alternate quieter route away from the busy road may lead to significantly lower exposure to TRAPs (Dirks et al., 2016, 2018). Cunha-Lopes et al. (2019) studied the BC exposure of children by their daily activity. They concluded that active travel resulted in 2.8 % of total BC dose while travel in car contributed up to 20 % of total BC dose. Thus, active travel reduced around 17 % of BC dose compared with travel by car. Mölter and Lindley (2015) have concluded that most of the school routes have an alternate route which is less polluted, may be longer in distance but the percentage decrease in exposure tends to be slightly larger than the percentage increase in route length. They found that for 50 % of routes, every 1 % increase in travel time was associated with 1.5 % decrease in concentrations of NO_2 and PM_{10} exposure. They also suggested that to identify alternative low pollution walking routes, a tool should be developed, taking into account future exposure estimates. There are mixed and conflicting findings on exposure levels in commuting to school by car. Dirks et al. (2016) concluded in their study that school children received lower UFPs exposure than those using active transport during commuting from home to school, whereas Both et al. (2013) concluded in their study that median UFP exposure was significantly higher for car commuters than that of the walking group. Car type, ventilation settings in the car and surrounding air quality also affect in car exposure (Tartakovsky et al., 2013; Weichenthal et al., 2015) therefore the car commute exposure needs to be studied further to have a better understanding of exposure while commuting.

Commuting by school bus is a popular choice but can cause higher level of pollutant exposure for students. Sabin et al. (2004) studied children's air pollutant exposure during school bus commute showed that children travelling to schools by buses and through congested urban area, are exposed to much higher concentrations of vehicle-generated pollutants inside the bus cabin, than that in background concentration. School Street is another school commute related intervention in which road outside a school is transformed and a temporary restriction on motorized traffic is applied at school drop-off and pick-up time, as the use of cars for drop-off and pick-up of pupils from schools may lead to pollution hotspots at school premises (School Street, 2021). School streets not only encourages active travel but also reduces emission of harmful traffic pollutants. In 'Breathe London' project a study was conducted on air quality of school streets and concluded that the school street may reduce NO_2 concentration during the school drop-off up to 23 % (Breathe London, 2021). For the schools that are located on arterial or heavy traffic roads, it is not feasible to make school street functional. For such schools, authorities should explore suitable solutions such as funding living green walls, preventing stop and start of the vehicles that is ten times more severe in terms of pollutants' emissions as compared to moving vehicles and idling outside school gates (School Street, 2021). Kumar et al. (2020a, 2020b) suggested that safe walking passages with a green barrier should be provided to link the school premises with main connecting roads, in order to reduce the exposure to $PM_{2.5}$.

Commuting to school by walking may reduce students' exposure to harmful TRAPs but selecting better alternate route and transport mode to school depends upon other factors such as distance of school, traffic intensity on the route and safety of school children. Alternate routes should be selected as per its suitability to students and parents and should be tested first by adult volunteers. If research evidence suggest that certain travel modes or environmental characteristics contribute to significantly higher levels of children's exposure to harmful pollutants, then behavioural or environmental interventions may be applied to reduce exposure to TRAPs.

3.6. Policy and regulatory interventions

Policy and regulatory interventions are believed to have wider impacts on achieving the desired objectives. Legislations setting out air quality standards, both national and international, are important to reduce the impacts of air pollution on the public and the environment. Legislation can enable citizens to hold government institutions responsible for air quality. It can also establish processes for monitoring, enforcement, and public participation in air quality control which could have significant impacts on improving air quality (UNEP, 2021). In 2013, the tailpipe emission from cars in USA was up to 98-99 % lower than that in 1970, when the Clean Air Act was implemented (EPA History, 2022). That shows that policy interventions' effects take time to be visible but are successful in terms of air quality improvement. Several publicly available documents and guidelines have also been published by national and international organisations and governments such as EPA guidance document (USA), different building bulletins related to school building standards and ventilation, air quality standards regulation (UK), health and air quality standards (European Union), WHO global air quality guidelines (WHO), and air quality standards document published by different countries. These guidelines and recommendations focus on existing policies on providing healthy environments in schools, measures to lower students' exposure to air pollutants environmental risk factors in schools, use of various modes of transportation to school (WHO Europe, 2015; US EPA, 2022; UBA Kreuscher, 2008). COVID-19 pandemic has prioritised the children's health in national and international level legislations. The Mayor of London has rolled out an ambitious plan to control the rising levels of air pollutants near schools by introducing world's first Ultra-Low Emission Zone (ULEZ) in Central London. This initiative declared that the 50 primary schools located in areas exceeding legal limits of NO_2 will be assessed to identify key interventions to reduce the exposure of the children while simultaneously, running a pollution awareness-raising education program at each of these schools (Mayor of London, 2017). The Energy White Paper for U.K. Government's Ten Point Plan for Green Industrial Revolution and the National Infrastructure Strategy has provided fund for promoting use of electric heating and heat pumps, reforming building regulations and upgrading the school buildings (EWP, 2020). At an international level, WHO publishes various scientific articles concerning air pollution around the countries, guidelines and regulations, with updated statistics, and recommendations for different sectors. These guidelines are updated every year (WHO, 2021).

The emission control policies of national and international level have many components, such as (1) using low-sulphur fuel standards, (2) tailpipe emission standards, and (3) CO_2 emission standards etc. (G20 Nations Report, 2015). Diesel powered buses are particularly more vulnerable in terms of PM and other air toxins generation. Therefore, policy interventions in form of using clean fuel in school buses are needed so that children commuting to schools through buses may experience lower exposures to air pollution, less pulmonary inflammation, more rapid lung growth over time, and reduced absenteeism (Adar et al., 2015). Many scientific studies advocate the clean fuel composition to reduce harmful emissions, for instance, Adar et al. (2015) discussed the impacts of Diesel Oxidation Catalyst (DOCs), Crankcase Ventilation Systems (CCVs), Ultra-Low Sulphur Diesel (ULSD) on the amount of tailpipe and engine emissions, respectively. They found that $PM_{2.5}$ concentrations were 25–40 % lower on buses with DOCs and CCVs, and UFP levels were 40–50 % lower on buses with DOCs and ULSD. They concluded that, in terms of health impacts, ULSD proved to be most beneficial with evidence of less pulmonary inflammation, faster lung growth, and lower risks of school absenteeism. Providing retrofit systems for diesel powered school buses, DOC muffler and a spiracle crankcase filtration system (CFS) reduced 20-94 % $PM_{2.5}$ from tailpipe emissions (with both DOC and CFS installed). No significant improvement was found for in-cabin pollutants.. The tailpipe emission from school buses increases the in-cabin concentration of pollutants, only when the bus's windows are open and the wind blows from tailpipe towards its hood (Zhang and Zhu, 2011). Rim et al. (2008) concluded that using spiracle CFS and DOC can decrease the in-cabin concentration of NO_x up to 37 %, up to

62 % in $PM_{2.5}$ and up to 43 % for UFPs concentration. Using High Efficiency Cabin Air (HECA) filters in school buses is an effective alternate of using air filtration devices and can reduce the concentration of UFPs, $PM_{2.5}$ and BC up to 94 %, 77 % and 89 % respectively, the percentage of reduction to be higher on freeway driving (Lee et al., 2015). Retrofit closed crankcase ventilation filters (CCFs) and DOC in diesel school buses can reduce the in-cabin concentration of $PM_{2.5}$ by 56 % and 33-41 % for UFPs (Trenbath et al., 2009). Muala et al. (2014) have suggested to use cabin air inlet filters to reduce the PM_{10} concentration inside diesel-powered vehicles by 74 %, NO_2 by 75 % and hydrocarbons by 50 % (when combined with active charcoal component). EPA in their report 'Best Practices for Reducing Near-Road Pollution Exposure at Schools' has suggested measures like upgrading bus fleets because pollutants emissions can be reduced by retrofitting older school buses with PM filters or oxidation catalysts, or by replacing older buses with newer models, by using certain alternative fuels, including biodiesel blends. It also suggests that engines certified to operate on alternative fuels such as liquid petroleum gas (LPG), compressed natural gas (CNG), and liquefied natural gas (LNG) can also reduce emissions (EPA, 2015).

Rising levels of air pollutants call for urgent statutory provisions such as upgrading fuel and vehicle technology, anti-idling laws, mandatory phase-out of old buses and use of electric buses etc. In particular, the increase in electric vehicles has shown a high impact on emission reduction of PM, SO_2, NO_x, VOCs and CO. The vehicle regulation standards based on Euro 6 have shown significant emission reductions of NO_x compared to previous Euro standards (PHE, 2019). Better air quality for school children cannot be achieved by researchers, academicians, or government agencies alone. Their collaborative efforts should be combined with strict observance of laws and the researchers should be actively engaged in the implementation of their research findings. The available interventions for air quality improvement in school depends upon several factors. Therefore, prioritising the order of these interventions is a challenging task. The preference or priority could vary depending on the scale and place of implementation (indoor, outdoor or during commute), associated costs (implementation and operation), available resources and comparability of benefits. Therefore, we do not prioritise them in a specific order but present them based on their ease in implementation and associated cost in Table 6.

4. Conclusions and recommendations

We summarized and evaluated the indoor and outdoor school-based interventions to counter the harmful impacts of air pollutants on students' health. Key conclusions are summarized as follows:

- Most intervention studies in and around schools have shown positive results to reduce the airborne concentrations of pollutants. As expected, their efficacy varies depending on factors such as classroom characteristics, occupancy, and ambient conditions. There were also advantages and disadvantages of each intervention, making it essential to understand the underlying mechanism of their working before their implementation in schools.
- The technological interventions such as air purifiers, HVAC system with high efficiency filters is effective in reducing classroom pollutants' concentration. Studies performed on air purifiers in classrooms suggested that all the available types of air purifiers are effective in reducing particulate matter (up to 54 %), and some are also effective for VOCs (up to 40 %), allergens, virus and bacteria. The deployment of a particular type of air purifier in schools depends upon several factors such as amount and type of secondary pollutants generated, removal efficiency in terms of CADR, size of the room, noise generated while in operation etc.
- Behavioural interventions in form of citizen science campaigns, environment education programmes, etc., have been successful in generating awareness among students, teachers and parents. They are relatively inexpensive and easy to replicate, but more methodologically rigorous studies in terms of planning, data collection, analysing and reporting, are needed to understand the impact of behaviour change on school students' indoor air pollution exposure and respiratory health.
- GI act as a physical barrier for traffic generated air pollutants to enter in the school, especially for those schools that are located near the heavy traffic roads. Green infrastructure offers a range of localised and distributed benefits for local amenity, students' well-being, and air pollutant concentration reduction. There is wider evidence around the positive role that green infrastructure can play on ambient air quality; therefore, GI should be adopted on a wider scale as an effective passive measure against air pollution.
- Structural interventions in terms of school building renovation and improvement are an important and crucial factor in air quality of schools. Most of the research reach to an agreed consensus that generally school buildings are poorly ventilated and have higher CO_2 concentration in classroom, which leads to the conclusion that there is a lack of holistic interest concerning energy efficiency and air quality problems in school buildings. The school buildings should be audited regularly, and their renovation and improvement plan should be given priority in every country's national development plan.
- School commute interventions promotes active travel to schools, rather than travel by buses and cars. Also, selecting alternate route to schools that may be longer in distance but causes lower exposure, may lead to significant reduction in children's exposure to TRAPs and promotes better health.
- The school bus retrofits and clean fuel in school buses is an effective intervention to reduce the exposure of school students to harmful vehicle exhaust in outdoor pick-up, drop-off or walking along roadsides and have been successful in reducing the exposure of children during commute and could be especially beneficial for the children having asthma or other respiratory problems. Policy and regulatory interventions are the key to implement the research findings at the grass root level. The national and international level regulation must be formed with giving the statutory positions to the environmental laws. The effect of regulatory provisions are the most visible ones in case of environment protection, because of having associated fine and penalty. The WHO guidelines reflect a high degree of scientific consensus, giving them global authority. Countries can use them as a reference benchmark to formulate their national plans and policies related to air pollution mitigation programmes.

The best strategy to reduce the exposure of school children is to have a better source control strategy for air pollutants. However, the change in this respect would be gradual. Below are the recommendations which are based on the above findings and therefore evidence based.

- Implementing a most effective set of interventions. Pre-installed HVAC system (with panel filters) and portable/fixed air purifiers should be seen as counterparts to each other. Air purifiers are though effective in removing particles and aerosols, but they do not supply fresh air to the room. The CO_2 concentration in the room is therefore not changed, if only stand-alone air purifier unit is used for air purification (without opening the windows). Therefore, air purifiers can be used in combination with pre-installed HVAC system, where appropriate, or with properly timed window opening, if the classrooms are naturally ventilated, for maintaining CO_2 concentration within limits. The pre-installed HVAC systems in older schools do not have high efficiency filters inside them, therefore these should be used in combination with air purifier units.
- Use of electric buses for school commute should be encouraged. Though school buses have become cleaner over the years, most still operate on diesel fuel, emitting air pollutants from their tailpipes that are particularly harmful to children therefore the future research is going towards the use of electric buses to put an end to the vehicle exhaust. The widespread adoption of electric buses could result in significantly less emission on NO_2.
- Behavioural interventions should be planned comprehensively and should have inclusive approach. Most of the behavioural interventions and campaigns are designed with homogeneity in the approach, but practically people from any two communities and groups are different from each other in terms of their understanding of the issue and approach to

Table 6
Prioritising of the interventions on the basis of ease and cost. The ease includes ease of availability, selection, installation and operation. The cost associated includes cost of installation, operation and maintenance. The priority has been given based on six qualitatitve criteria, varying from very high to very low. The ease and cost associated with different criteria: very high ease refers very easy selection, installation, and operation; without extra machinery or professional supervision whereas very low ease means operation and installation difficulties in terms of extra supervision and requirement of technical expertise. The cost criteria are arranged from very high to very low; by comparing the probable cost of installation, operation and maintenance of least expensive intervention with the higher cost interventions.

Intervention	Ease in interventions application in school				Cost for interventions application in school		
	Selection	availability	Installation	Operation	Installation	Operation	Maintenance
Air purifier	Very high Selection of an air purifier for classrooms, depends upon secondary pollutants and sound generated during their operation, size of the classroom, occupancy etc. Some air purifiers generate Ozone, therefore, should not be selected for classrooms	Very high Based on the underlying technology, there are many options available in the market that are compatible with classroom settings (Table 3)	High Portable air purifiers are easy to install and do not require specific arrangements. Wall mounted air purifiers' installation depends upon classroom characteristics such as ceiling height, type of walls etc.	Very high Both portable and wall mounted air purifiers are easy to operate and can be adjusted manually to the change classroom and environmental settings.	Moderately low The wall mounted air purifiers need to be installed properly and need specific consideration of building material characteristics whereas portable air purifiers are very easy to install.	High The cost of operation in terms of power consumption charges for air purifiers depend upon the room size and energy efficiency of air purifier. Generally, larger the area of the room, the more power consumption will take place to clean the indoor air.	High The filtration based air purifier' filter need to be changed on regular basis to run the air purifier at optimal performance. Electrostatic and Ionization based air purifiers do not need frequent maintenance, but they are not commonly used in schools because of ozone generation
HVAC system with high efficiency filters	High The selection of a particular type of HVAC system depends upon building characteristics and its requirements. The choice of HVAC system can also affect other high-performance goals, including water consumption and acoustics.	Moderately high Typical HVAC filters are categorised as Pre filters, Secondary filters and Final filters. Commercial options are available for all three category filters, depending upon the requirement of HVAC system.	Very low The installation process of HVAC system needs careful consideration about the where to install the outer components owing to the noise generated whilst in operation, thermostat to have a proper temperature reading, placing the duct system etc	Very high After installation, HVAC systems are easy to operate with manually operated control settings	High The installation of HVAC system with high efficiency filter in pre-existing school buildings is a tedious process and it depends upon its compatibility with school building. The installation is an expensive process that needs proper building survey and fixing the associated accessories in given buildin	Moderately high Using centralized HVAC system is more energy efficient as compared to portable air purifier units as they cover larger area. The energy consumption by HVAC system depends upon equipment efficiency, building design, orientation and location, type of HVAC system.	Moderately high Owing to the fact that HVAC system require regular maintenance and cleaning of filters, the maintenance cost of an HVAC system is usually high.
Physical barriers/Green infrastructure	Low There are many options available in market to opt as a green infrastructure barrier in schools, but the selection of a particular type depends upon the properties of the plant species. Some species of the plants may alleviate allergy and asthma symptoms in school children; therefore GI barrier should be selected carefully	Moderately high There are many different options available commercially to use as GI barriers in schools, depending upon the plant species selected. The GI barrier can be designed as per the school's requirements which needs some design inputs.	Low The installation of GI barrier is sometimes restricted due to limited availability of space and sometimes permissions need to be sought for installing GI on the land outside the school ownership area. If the size of the barrier is large, then more space would be needed for their installation. Automated irrigation system may be required to install	High Once installed, GI barriers do not require any specific expertise to operate it. It is the plants' intrinsic property to act as a barrier for the traffic pollutants which get deposited on their leaves.	Low Trees and hedges are not costly but they take time to reach maturity. The fully grown green walls are expensive and require an automated irrigation system. Planters are more expensive than planting the GI barriers directly into the soil.	Low The automated irrigation system may consume electricity, the consumption depends upon the size of the barrier.	Moderately high The maintenance of GI barrier is not expensive and needs only visual inspection. Most of the routine maintenance activities can be performed manually without much input of cost, such as removing the leaves, cleaning the irrigation drainage system etc.
Structural interventions	Moderately high School building infrastructural deficiencies can be identified in the form of windows and doors leakage, old heating system, faulty or inadequate ventilation system etc	Moderately high The infrastructural deficiency of school buildings can be improved with school building audit and maintenance or improvement plans	Very low Once identified, the building infrastructure can be improved by commercially available construction service providers. The limitations remain in the form of scope of refurbishment and improvement in existing school buildings,	very high The building improvements are fixed interventions, and they operate well if constructed and maintained properly.	Very high The cost of infrastructural improvement activities depends upon the extent of repair required. The cost may vary from low for some minor improvement such as repair of doors and windows, to very high for new constructions.	Low Once built or repaired, there is no major operational cost incur for building repairs and modifications.	Very high The cost incurred for maintenance includes cost for regular audit, replacing the older heating system, doors, windows and other accessories with the new one. If the repair plan includes building a new infrastructure, then, the cost may be very high.

(continued on next page)

Table 6 (*continued*)

Intervention	Ease in interventions application in school				Cost for interventions application in school		
	Selection	availability	Installation	Operation	Installation	Operation	Maintenance
			availability of land for new construction plans and availability of funds.				
Behavioural interventions	Very low Selecting a particular type of behavioural intervention programme depends upon the objective. The selection is a complex process as it involves many participants and some programmes may have some ethical constraints.	Low After careful consideration of all the factors and targeted group, a suitable behavioural intervention programmes is designed that should be ethically appropriate, capable of engaging many participants and capable to achieve the objective.	Low Operationalization of behavioural intervention may face difficulties in the initial phase such as changing the route of the traffic, creating low emission zones, no idling rules etc. But it may become easier to follow after it comes into practise	High Once in practice, the behavioural intervention plans are easy to follow and can be operated for certain duration without difficulty.	High By implementing behavioural interventions may cause financial burden in other sectors, such as changing traffic habits and creating emission sones may affect transport section financially	Moderately high Implementation and execution of behavioural intervention require man power and resources. For wider outreach the participants should be encouraged on different media platforms, sometimes financial incentives may also increase participation.	Moderately high Similar to execution, if a behavioural intervention is modifies and new aspect is included then, it require further resources to implement the changes and to make people aware of the modification
Regulatory and policy interventions	Very low Selecting a suitable policy that not only serves the purpose of school air quality improvement but is also cost effective and suitable for every section of society, is a very tedious process. There are many constraints in devising a suitable policy for controlling school air pollution exposure	Very low The availability of an optimum air pollution exposure reduction policy and regulations is limited by other constraints such as its applicability and effects on other sectors such as transport, industries, its cost effectiveness and the intended benefits.	Very low The policy implementation is a crucial and difficult process. Modifying or replacing old technology which was in practice with the new one require skills and resources, detail evaluation of future outcomes.	High Once implemented the operationalization of a new regulations and policy actions become mandatory to follow for everyone, therefore the execution of policy interventions are easier as compared to its implementation	Very high New regulations and policies related to school air quality, may have high cost inputs because the area and population of influence of that policy may be larger and it may affect some sectors adversely in financial terms	Very high After implementation the cost occurred for new policies depends upon the type of initiative in the policy. Upgrading the vehicle exhaust emission standards and fuel constituents may be expensive in initial years of implementation.	Very high Minor amendments in older policies such as declaring low emissions zones near schools, anti-idling laws, creating safe routes near schools may have lower cost constraints but the change in laws related to fuel constituents and vehicle emission standards may incur higher cost inputs.

tackle them, therefore this remains a challenge for researchers to have an inclusive approach towards students, parents and teachers of different groups and communities. New technologies and skills should be incorporated in designing the behavioural intervention study. Environment education programme combined with display of real-time classroom air pollutants' level, can generate awareness among students and teachers about air quality.

- GI should be adopted as an effective measure on wider scale: Despite offering many socio-environmental advantages, GI such as hedges or green screens is not yet employed as normal practice in urban planning. Many impediments are blocking the way for their wide scale uptake in schools such as people’s perceptions of technological capability and performance of GI, building construction practices, and building planning process of schools. Promoting GI as a means of acquiring new skills and as a resource that naturally enhances student welfare and academic achievement, will help the school community adopt it more widely. Therefore, the key concern should be extending the awareness of advantages and usefulness of GI to the students and teachers beyond sustainability curriculum and operations.
- Regular audit and repair of school buildings. There should be frequent audit programme of school building by professionals and their suggestions should be implemented on priority basis, there should be a continuous measuring of school IAQ by a third party and the data should be accessible to the school administration so that they can take appropriate actions.
- Alternate routes to school tool should be developed. A publicly available tool to identify alternative low pollution walking routes, with exposure estimate for each route, should be developed that could help deliver health benefits for children and adults.
- Environmental policies and regulation should be given statutory status. The national and international level environmental laws should be provided with punitive provisions. Though WHO guidelines are made on international level, but they are not binding upon countries. Not having an international regime on air quality standards, which is binding upon nations, has resulted into several different national laws and acting as a barrier in adopting contemporary approaches.

This review investigated currently available school classroom air quality improvement interventions. There is a significant gap in knowledge regarding the use of combined interventions in classroom settings. The future research should focus on critically analysing available interventions regarding their application with respect to different types of classroom layouts, occupational density, geographical location of the school etc., and should emphasise on amalgamating the benefits of different interventions by devising a strategy for their combined application in a classroom, focusing on operational synchronisation for optimum results.

CRediT authorship contribution statement

Nidhi Rawat: Conceptualization, Methodology, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Prashant Kumar:** Conceptualization, Funding acquisition, Methodology, Formal analysis, Project administration, Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing.

Data availability

No data was used for the research described in the article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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