Phase 1 trial of covid-19 airborne transmission prevention technologies: Classroom Air Cleaning Technology (Class-ACT) Study

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Abstract

This protocol describes an early phase trial of two air cleaning technologies with a focus on feasibility and practical implementation. The air cleaning technologies have the potential to mitigate the aerosol transmission of viral particles - including the SARS-CoV-2 virus - within schools. This study seeks to explore the practicalities and possible benefits of fitting schools with these technologies. The study will be conducted within 30 primary schools in Bradford, UK. The study will have three arms: a control arm and two intervention arms; one with installation of portable high efficiency particulate air (HEPA) filter units, and the other with installation of germicidal ultraviolet (GUV) devices.

The trial has the twin aims of: 1) evaluating the feasibility and practical implementation of these technologies in a primary school context; and 2) assessing the effect of air cleaning technologies applied as a widespread intervention on transmission of the SARS-CoV-2 virus and other infections (including infection-mediated respiratory illnesses) in school settings.

The trial has been designed to evaluate the feasibility of utilising air cleaning; identify the optimum way to implement (utilise) air cleaning technologies to reduce the transmission of the SARS-CoV-2 virus; rapidly acquire robust epidemiological evidence regarding the use of the technologies.

It is anticipated that the study will yield valuable information that will shape future policy regarding the deployment of air cleaning technologies in school settings.

Keywords

COVID-19, SARS-CoV-2, outbreak, transmission, environment, education, infection, epidemiology, air cleaning, HEPA filtration, schools

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1 Introduction

This document presents the rationale for a feasibility study and multi-centre intervention trial of two air cleaning technologies (germicidal ultraviolet (GUV); and portable high efficiency particulate air (HEPA) filters) in primary schools in Bradford, UK. These technologies have been selected because there is high confidence, based on previous experimental and computer modelling work and published literature[12], that they have the potential to mitigate the aerosol transmission of the SARS-CoV-2 virus and other infectious pathogens in the air within schools and other buildings.

The proposed study has the twin aims of: (1) assessing the ability of the air cleaning technologies to mitigate the aerosol transmission of the SARS-CoV-2 virus and other respiratory viruses; and (2) evaluating the feasibility and practical implementation of these technologies in a primary school context. Accordingly, the study has been designed to: (i) evaluate the feasibility of utilising air cleaning in primary schools; (ii) identify the optimum way to implement and utilise air cleaning technologies in primary schools to reduce the transmission of infectious diseases (including SARS-CoV-2 virus); (iii) acquire robust epidemiological evidence to assess the use of the technologies as a widespread intervention in schools. The study will evaluate the application of the air cleaning devices applied alongside existing ventilation, irrespective of the efficacy of that ventilation and regardless of existing guidance on ventilation and infection control in schools. As such, it is anticipated that the study will yield valuable information that will shape future policy regarding the potential benefits from wide scale deployment of air cleaning technologies.

2 Rationale for the proposed study

It is widely recognised that transmission of COVID-19 can occur indoors due to the inhalation of small respiratory aerosols that remain suspended in the air and which can be widely dispersed in a room[1,2]. There is a particular association between airborne transmission of SARS-CoV-2 and poorly ventilated room spaces where infectious aerosol concentrations can build up to higher levels, especially over longer periods of time[3,4]. While adequate room ventilation is likely to inhibit aerosol transmission of the SARS-CoV-2 virus when room occupants are sedentary and talking sparingly[5,6], there may be greater risks when noise levels rise and people talk loudly (or sing)[3,7,8], or when occupants are active [9]. Under such conditions additional measures (e.g. increased ventilation, masks, regular breaks to flush away aerosols, etc.) may be required[4,5.] Some of these can be disruptive to normal social and economic activity or, in the case of improved ventilation, be costly to implement. Furthermore, in order to achieve sufficient ventilation rates in many UK schools that are naturally ventilated it is often necessary to retain open windows for longer periods than normal, which can lead to considerable discomfort during cold weather, bring challenges associated with noise and security, and increase energy consumption associated with heating[10]. Consequently, there is need for environmental interventions that can be readily deployed to enhance ventilation and to inhibit the aerosol transmission of COVID-19 in spaces with high sustained occupancy (e.g. schools, pubs, bars, restaurants, hospital waiting areas, places of worship, etc.). While the COVID-19 pandemic has exposed the need for environmental interventions to mitigate the spread of infection inside buildings, it has also highlighted: (i) the importance of schools remaining open in order to ensure that children can be educated; and (ii) the role that high occupancy density spaces play in facilitating spread of the disease to the wider community[11]. As such, reduction in transmission through improved ventilation and air cleaning has the potential to not only protect susceptible individuals, but also limit high occupancy spaces, such as schools, from becoming hubs for the transmission of infection to the wider community.

Air cleaning technologies, such as local GUV and HEPA filter based devices, have the potential to mitigate aerosol spread of COVID-19[12,13]. Such devices can be portable free-standing units, or devices fixed to a wall or ceiling that circulate air through the UV light or filter. Portable free-standing filter units work by drawing air from the room through a device which contains a high efficiency filter known as a HEPA filter. These filters can remove at least 99.5% of particles in air that pass through the device[14], including microorganisms, and hence their capability at cleaning the air is determined by the flow rate of air through the device and their ability to mix air in the room[15]. Devices are commonly tested against a range of particle sizes and the performance is expressed as a Clean Air Delivery Rate (CADR) which indicates the effective amount of clean air that a device provides in m^3/min or cfm[15,16]. Devices typically have a minimum efficiency (99.5%) for particles around 0.3µm diameter, with greater removal rates for both smaller and larger particles. A number of studies have shown that HEPA filter devices are effective at removing particles, pathogens and allergens from room air[17-20] including in schools[21,22] and a recent study has shown a reduction in the SARS-CoV-2 viral RNA in air[23] suggesting that this technology could have the ability to inhibit COVID-19 transmission. The hazards associated with using HEPA filter devices are likely to be minimal, with very small risks associated with changing filters[24] mitigated by good hygiene practices and safe waste disposal.

GUV utilises light in the UV-C wavelength range to inactivate microorganisms as they are carried in air through a UV field. Most devices use lamps that produce UV-C light with a wavelength at 254nm, which is well recognised to be germicidal and when using good quality lamps does not produce ozone[25]. UV-C technology can be applied in a range of different ways including within portable air cleaning units, within “active-air” units that are installed on the wall or ceiling of a room (similar to an air conditioning unit), or as an upper-room device which utilises an open UV-C field, above the heads of room occupants. It has been shown that UV-C light readily inactivates SARS-CoV-2[26] as well as multiple other pathogens[25]. There have been a number of previous epidemiological studies of upper-room GUV including on the spread of measles and other respiratory infections in schools in the 1940s and 1950s[26-29] and tuberculosis (TB) on hospital wards[30,31]. GUV must be applied with care. Direct human exposure to UV-C light is hazardous and can cause skin and eye irritation[32,33], hence all devices for use in occupied rooms have to be designed and installed in such a way to prevent direct exposure to the UV-C light. Portable and active-air units have no exposure to UV light as the lamps are fully enclosed and are classified as Risk Group 0 under The Control of Artificial Optical Radiation at Work Regulations 2010[34]. NIOSH recommend upper-room devices should be designed so that an 8 hour exposure based on the maximum irradiance at eye level does not exceed 60 J/m2.

Evidence to date suggests that there is a high degree of confidence that, if deployed appropriately, both HEPA and GUV based technologies have the potential to reduce viral transmission by the aerosol route, thus helping to make buildings ‘COVID-safe’ and allowing the return of normal social and economic activity. However, it is unclear how much benefit may be seen from such devices, particularly when applied alongside existing ventilation rather than as a direct intervention to manage a poorly ventilated space.

Although there is considerable evidence supporting the use of air cleaning technologies, much of it is laboratory-based or relies on proxy measures (such as reduction in particles), with limited data available that directly relates the use of air cleaning devices with a reduction in infection rates. Air cleaning devices have already been recommended as a feasible solution where ventilation in a shared space is insufficient and cannot be improved[12] but there is a lack of data on whether introducing air cleaning devices as a widespread measure regardless of the status of the ventilation is likely to provide benefits. There is also a lack of practical information on the usability and acceptability of devices in a school context, including noise and draughts[34], installation practicalities and understanding of when

and how to use devices. There is a need to consider a range of aspects including electrical power requirements, positioning of devices and their suitability for the space, user interaction with devices, and maintenance of devices.

Consequently, there is a pressing need for a robust studyl to assess, not only the extent to which air cleaning can mitigate the transmission of infection including COVID-19, but also the practicality and feasibility of using GUV and portable HEPA filter devices in schools. With the ongoing societal challenge of COVID-19 in the UK and worldwide, and the concerns about escape mutations, where vaccination is less effective, there is an urgent need to evaluate technologies that could potentially be utilised to make schools, and public (hospitals, churches, mosques, etc.) and commercial (shops, bars, restaurants, etc.) buildings 'COVID-safer', thus allowing them to operate normally. We anticipate that this rapid study will yield data on the practical aspects of procuring, installing and operating over 700 air cleaning devices at scale across over 540 school classrooms, together with high-quality epidemiological data on the impact that devices have on infection rates within schools.

3 Protocol

The protocol was agreed by the ACT scientific team. The project will be overseen by an external scientific advisory group and will adhere to all legislative and ethical requirements of the host Universities and National Health Service.

3.1 Identification of suitable technologies and procurement

The ACT project was proposed and selected for acceleration funding at a DHSC workshop convened by Innovations and Partnerships (I&P), NHS Test and Trace (DHSC), in January 2021 as part of their Environmental Intervention Programme. The technology pipeline was drawn from scientific evidence, vendor offers, and market assessment. The workshop identified three broad types of engineering control: ventilation, air cleaning and surface technologies. Following an introductory overview of transmission routes, intervention types and confounding factors, technical overviews and propositions were presented by experts in four technologies: HEPA filtration, upper room-GUV, Far-UVC and anti-viral surfaces. Each technology and their relative proposition were then evaluated against set criteria by a panel drawn from an expert government group. The poll identified HEPA filtration as the most promising, followed by upper-room GUV.

The Centre for Applied Health Research within the Bradford Teaching Hospital NHS Foundation Trust (BTHFT) were identified during the workshop and considered an ideal host for managing the intervention trial in a real-world situation; the rationale for this is set out below. A team of independent experts were brought together to form the ACT team to provide scientific oversight of the project. A business case for trialling air cleaning technologies was subsequently developed with full co-operation and input from the ACT team working with the Commercial team in DHSC (who defined the allowable routes to market for each equipment type and trial management).

The associated specifications for the technologies (see below) were defined and approved by the ACT team as appropriate for each equipment type, and a letter of support received from the trial management authority. Legal oversight was sought prior to business case approval by the relevant parties within NHS Test & Trace. The appropriate levels of sign off were garnered and completed in accordance with government procurement processes. Budgetary estimates for the equipment were developed through market engagement with multiple suppliers. I&P collaborated with BTHFT to develop the necessary costings for the trial evaluation (contract awaiting signatures as of the first of December 2021). The final

business case was approved at the end of April 2021. All Procurement activity was completed under standard government procurement practices and OJEU protocols. The evaluation process was conducted in line with government procurement processes and moderated independently. The supply of UR-GUV and HEPA was subject to an Open procedure (OJEU) and published via Find a Tender. The evaluation process was conducted in line with government procurement processes and moderated independently. Following procurement, the DHSC arranged for suppliers to provide the appropriate technology to the schools (assisting with fitting and supporting risk assessments as and when appropriate and necessary) with oversight from the ACT team.

During the feasibility component of the ACT study two issues were identified with the application of upper-room GUV devices. During initial assessment of school classrooms by the supplier, a substantial proportion of classrooms were found not to be suitable for upper-room GUV installation. These rooms typically had ceiling heights that were too low for installation to comply with NIOSH exposure guidances or they had protruding beams or other obstructions that would block the UV-C light. A gap was also identified in guidance/regulation relating to these GUV devices. Upper-room GUV devices which have an open UV-C field located above head height are manufactured and sold by several manufacturers worldwide. These organisations all install to the NIOSH guidelines, which sets out an 8 hr exposure limit based on the peak irradiance in a room at occupant eye height. These appear to have been adopted in most countries as appropriate safety standards and are referenced within reports on exposure. In the UK it appears that these are acceptable for many workplace settings which come under the Control of Artificial Optical Radiation at Work Regulations 2010. However, the applicability of these regulations within schools is not clear. This means that schools cannot be satisfied that theUV-C exposure for children is safe, with the values set out by NIOSH aimed at adults in workplaces potentially being too high. As a result of these challenges the ACT team needed to change the trialled intervention from UR-GUV to active air GUV devices where the UV-C lamps are fully enclosed and not visible.

3.2 Overview of Study Design

The study will be conducted in two components (see Figure 1). Component 1 will assess the feasibility and practical implementation of HEPA and GUV technologies in primary schools. Component 2 will use units installed in classrooms to carry out a randomised controlled cluster study with 3 arms, and 10 schools in each arm; Arm 1 being control, and Arms 2 and 3 intervention (HEPA and active GUV respectively). With approximately 12 classrooms in each school, this will yield 120 separate observations in each arm, thus enabling the study to be adequately statistically powered. Health data, absence data and environmental data will be collected to determine the impact of devices on Covid-19 and other infections as well as on classroom air quality.

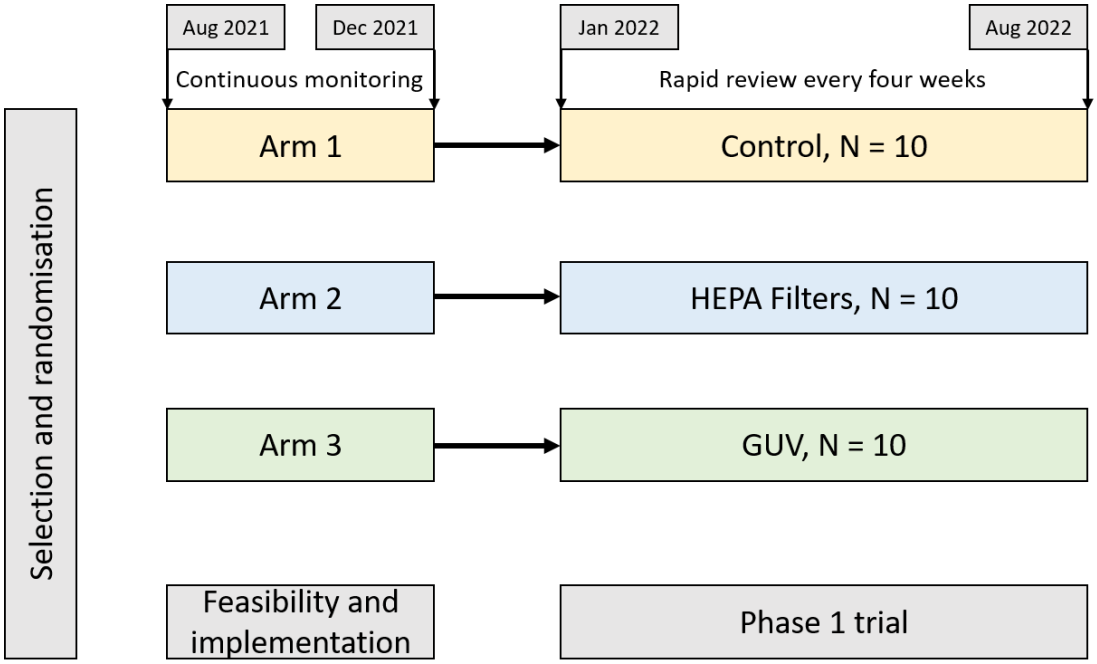

Figure 1. Bradford schools air cleaning study design

3.3 Schools

Schools were selected as the setting for this project because:

1. There is a priority to keep schools open and provide face-to-face teaching to reduce the negative impact of Covid-19 policies on children and young people's education and mental health, which disproportionately affects children from disadvantaged groups[35].
2. Children and young people themselves are at low risk from severe consequences of Covid-19 infection[36] (Covid-19 infection in children usually results in either asymptomatic or mild cases), so that schools are more likely to remain open during lockdowns.
3. Schools are a setting where there are consistent and regular numbers of the same people who use the same spaces on a regular basis, and this is comparable between different schools.
4. Schools being open is a significant factor in community transmission of Covid-19[37].
5. Schools were recognised as having challenges in managing ventilation during the pandemic.

Primary schools in Bradford were selected because:

1. The research team, through *Centre for Applied Education Research* (CAER), has strong links with all the primary schools in Bradford. CAER has an extensive community-education-healthcare epidemiological network that has been established as part of the '*Born in Bradford*' (BiB) project and which is actively supported by the City of Bradford District Metropolitan Council, the Department for Education (DfE), and NHS Track and Trace (T&T). Through this network, CAER can gain remote access to the medical and educational records of the children attending the schools and thus can rapidly collect data regarding school attendance and the reasons for absences without the need to disturb the day-to-day operation of the schools.

2. CAER's existing partnership with schools will enable rapid evaluation of air cleaning technology– something that would be difficult to achieve with other building types.
3. Multiple schools can be enrolled into the study, making it possible to evaluate both air cleaning technologies in a similar context with controls, as well as achieving adequate statistical power– something that would be difficult to achieve with other building types.
4. The children are relatively static (i.e. they mostly stay in one classroom) in primary schools, unlike in secondary schools where the students move from class to class between lessons, making it difficult to link specific students with particular interventions.

3.4 Two component study

There are a number of constraints which affect the study design: (i) the need to acquire robust data in a short a time scale; (ii) the timing of the school year which limits both the period in which the trial can be conducted and when devices can be installed; (iii) the need to source, install and commission appropriate HEPA and GUV devices and environmental monitoring; and (iv) the need to train school staff to appropriately use devices. It was decided to adopt the two-component design. Component 1 is a feasibility and implementation study that enables a phase 1 intervention trial. Component 1 commenced 28/4/21 (DHSC business justification) by defining a specification for air cleaning devices and environmental monitoring equipment to enable acquisition and installation of all equipment in a short time frame. The objectives of Component 1 are to rapidly acquire environmental and device performance data to identify and 'iron-out' implementation problems and optimise the technology ready for use in Component 2.

Because all the arms in the study will be continuous and cover the same time period, expected variations in the daily COVID-19 cases (due to vaccination and seasonal changes, etc.) as well as any changes in the government guidance to schools will affect all the arms evenly and thus should not influence the outcome. In order to eliminate bias, schools will be randomly allocated to the various control and intervention arms. In order to rapidly obtain results, the study (both Component 1 and 2) has been designed with predetermined (*a priori*) review points built-in to the programme. These will enable statistical analysis of the data collected (to date) to be performed at predetermined time points and thus give a rapid indication as to whether or not any effect is observed.

Running concurrently with both components of the study, will be supporting engineering, environmental analysis and modelling work (see details below), specifically aimed at: (i) supporting the project with regard to general engineering matters (e.g. performing necessary sound, ventilation (including air movement), UV irradiation, optimum location for devices, and electrical power calculations, etc.); and (ii) understanding the interaction of interventions with environmental conditions and ventilation airflows in the classrooms to support the interpretation of epidemiological data in Component 2.

3.5 Air cleaning devices

Specification of the performance of the two air cleaning technologies was based on published data on the efficacy of devices, knowledge of typical device specifications available on the market, and practical considerations around space and the number of units that it is feasible to install in a classroom. The performance requirement for the two technologies at the outset was not the same, as it is well recognised that upper-room GUV systems can provide higher equivalent air change rates than can be practically achieved for portable filter based devices where the number of devices is limited by the floor space

available. Classroom dimensions vary considerably between schools with volume of spaces ranging from around 120m3 to over 260 m3, and hence the number of devices will depend on both the total air volume and the physical layout of the space.

The HEPA filter units selected for the study are Philips 3000i Series AC3033/30. Two or three units will typically be located within each classroom, sized to give a performance equivalent to a ventilation rate of 3-6 air changes per hour (eACH) over and above the existing room ventilation. The number within each classroom will vary depending on the size of the room and floor space available. Devices can operate on different modes as shown in Table 1, however during the study only mode 1 or mode 2 are able to be used to ensure sufficient performance without excessive noise.

Table 1: Clean air delivery rate (CADR) and noise levels for Philips HEPA devices used within the study

Mode	CADR * [m3/hr]	Sound pressure ** [dB[A]]
Sleep	62	15
Mode 1	160	31
Mode 2	290	42
Turbo	520	56

*CADR values are measured according to the Chinese standard GB T 18801-2015 in a 30 m3 chamber.

** Sound pressure levels Lp at 1.5 meter from the device. Sound pressure values are calculated based with sound power levels measured according to IEC60704.

The initial specification for GUV devices was based on the original intention to use upper-room devices, with a requirement that the equipment should achieve an average UV-C flux in the upper-room irradiation zone in the region 35 – 50 µW/cm2 in all irradiated spaces. This would result in an equivalent air change rate of over 20 eACH on top of the existing room ventilation. When it was later established that upper-room GUV was not going to be feasible, the decision was taken to specify a performance requirement of 4 eACH which is based on what is achievable with active air units and selecting a performance which is comparable to that provided by the HEPA units. The units provided are Signify SM310C 2xTUV PLL 60W HFS units, with between 3 and 9 units installed in each room depending on the size of the space. These operate with a noise level of less than 55 dB[A] based on sound pressure levels at 1m from the device. Assuming hemispherical propagation this would give less than 51dB[A] at 1.5m .

3.6 Intervention study design

The proposed study has 3 arms, as shown in Figure 1. Arm 1 will be the control arm, while schools in Arm 2 and 3 will have HEPA filter and active GUV devices installed respectively. Schools enrolled to the study will be randomly allocated to each arm in equal numbers. The

interventions will be activated at the start of the Component 2 study and will be operational throughout, only being switched off when the buildings are unoccupied (i.e. overnight, at weekends, etc.). Automatic wireless sensors will also be installed in the schools to enable remote monitoring of the interventions and collection of environmental data (see below for details).

Air cleaning devices and sensors in the intervention arms, will be installed in all the classrooms for all the year groups 1 to 6. The decision was made to exclude 'reception class' (the year before formal education commences in English schools) due to its staged entry and other confounding factors. In order to obtain rapid results, *a priori* review points have been built into the programme at 4-week intervals. These will allow the data collected up to the review points to be statistically analysed in order to determine the magnitude of any effect that may occur.

3.6.1 Data collection

Health and absence data
Data about pupil and schools staff Covid-19 infection, and other infective morbidity (including asthma) will be collected, while minimising any burden on schools and parents.

Data already routinely collected

School level
1. Absences from school
2. Number of days absence
3. Reason for absence
4. Absence authorised or not

Primary Care
1. Visit to GP
2. Reason for visit
3. Diagnosis
4. Outcome of investigation (including covid-19 testing)

Hospital
1. Visit to hospital
2. Admission to hospital
3. Number of days admission
4. Diagnosis
5. Outcome of investigation (including covid-19 testing).

Additional data to be collected
1. When a parent contacts the school to report an absence, additional data will be sought to obtain more information about the reason for absence (see Absence Form – Appendix 1).
2. If a school closes a class, classes or the whole school, details will be recorded using the Closure Incident Form (Appendix 2).

In addition, these data will be supplemented with the results from any *ad hoc* lateral flow tests that may be carried out in the schools; these are not currently routinely used in primary school settings. 'Cross-referencing' will also be facilitated between the schools, primary healthcare providers, and NHS T&T via the CAER network, so that time-to-event data can be acquired directly linking events (e.g. absences, etc.) in the schools with T&T case-positive data.

It is expected that the same policies for absence and isolation will apply across all schools.

Environmental data

The following environmental data will be collected from all the study rooms (including in the Arm 1 control): air temperature; relative humidity; CO2 levels as a proxy for ventilation; particulate concentrations measured as PM1, PM2.5 and PM10. This will be collected automatically using wall-mounted sensors and will be wirelessly transmitted for remote analysis off-site. Wireless amp meters will also be fitted to the HEPA filter units and GUV lamp installations, so that operation of the respective interventions can be monitored remotely.

3.6.2 Supporting engineering and environmental analysis

The only installation guidelines in the UK for portable HEPA filter devices with respect to infection mitigation are those produced by CIBSE in July 2021 which are general and are not aimed specifically at schools. The only guidelines for upper-room GUV installation are those from NIOSH which are aimed at Tuberculosis control but are widely adopted elsewhere[38]. There is no guidance on the use of active air UV units. We will therefore undertake planned and *ad hoc* high-level engineering and environmental analysis to support the project. While recommendations from the device manufacturers will be helpful, it will be important to check and evaluate these carefully as little or no robust prior evidence exists as to how GUV and HEPA filter units should best be applied to mitigate the spread of COVID-19, especially in schools. For example, while a GUV device manufacturer should be able to estimate with reasonable accuracy the average UV-C flux that will be achieved in a given room space, without advanced computational fluid dynamics (CFD) modelling[39] and knowledge of the ventilation flows, they will not be able to calculate with any accuracy the likely UV-C dose provided to microorganisms in the room, or say for certain whether or not this is enough to inactivate the SARS-CoV-2 virus. Similarly, in the case of portable HEPA filters, the placement of such devices with respect to the ventilation of the room can be carried out using the expertise of those installing, but the actual flow patterns and filtration performance are hard to determine. Associated computer modelling work (ventilation network modelling, CFD, optimisation analysis, etc.) will be carried out to support the analysis of the device performance (e.g. establish the likely distribution pathways of the respiratory aerosols in the classrooms; identify the optimum locations for the devices; compute ventilation rates; compute likely UV-C dose administered; compute likely noise levels; identify whether or not supplementary ceiling fans would be beneficial, etc.). These are all important issues, which will need to be addressed if the interventions are to be applied effectively. In the case of the HEPA filter units, an aerosol challenge study using nebulised NaCl solution will be carried out in one of the school classrooms (when unoccupied) to acquire data on expected particle removal performance for a range of particle sizes and under different device operation and ventilation conditions. This will be supported by ventilation network modelling using CONTAM software. Furthermore, CFD modelling of the room ventilation and aerosol distribution patterns in typical classrooms are likely to assist in interpreting the epidemiological results of the study. Therefore a 6-month engineering modelling work-package will run concurrently with the study.

3.6.3 Study outcomes and statistical analysis

The primary outcome of Component 1 of the study is to generate data on feasibility and implementation of HEPA filter and GUV technologies in the school environment. This will enable generation of guidelines for this use, which currently do not exist. A log will be kept of all issues arising during the procurement and installation component, and how these are resolved.

The primary outcome of Component 2 of the study will be to determine whether or not the application of active GUV and portable HEPA filter devices have any detectable impact on COVID-19 transmission rates or other viral infections in the study settings and, if so, to quantify the magnitude of the effect.

Definitions of Covid-19 clusters and outbreaks

Covid-19 clusters and outbreaks will be defined according to UK government criteria[25], based on positive laboratory testing (for positive lateral flow tests only, the definitions will be qualified as 'likely'):

Cluster criteria: Two or more test-confirmed cases of COVID-19 among individuals associated with a specific school, with illness onset dates within a 14-day period - In the absence of detailed information about the type of contact between the cases.

End of cluster: No test-confirmed cases with illness onset dates in the last 14 days.

Outbreak criteria: Two or more test-confirmed cases of COVID-19 among individuals associated with a specific school with illness onset dates within 14 days, and one of: i) identified direct exposure between at least 2 of the test-confirmed cases in that setting (for example under one metre face to face, or spending more than 15 minutes within 2 metres) during the infectious period of one of the cases; ii) when there is no sustained local community transmission - absence of an alternative source of infection outside the setting for the initially identified cases.

Analysis will be performed at each four week period (see Figure 1) to determine whether there is a significant statistical difference between the 3 arms of the study for the following parameters: occurrence of clusters and outbreaks of Covid-19 in each school; cumulative number of children or staff testing positive for Covid-19 during the study period; cumulative number of student-days absent for any reason, and then broken down by reason; cumulative number of student illness-days for any reason, then by illness category, and also by level (absence only; seen GP; visited hospital; admitted to hospital).

If at any 4-week review, there is a significant difference between groups at the 5% probability level, the Study Implementation Team will consult with the Steering Group to review what action should be taken: continue only; continue with formal interim reporting; discontinue and report.

In addition, the study is expected to produce secondary outcomes, which might also yield valuable insights into the factors that influence COVID-19 transmission. For example, the environmental time series data collected from the sensors will yield valuable information regarding temperature, humidity and CO2 levels which will provide data on ventilation rates and air quality as well as any relationships to COVID infection rates. Likewise, the additional healthcare and absentee data collected from the schools should reveal insights into the impact of the interventions and environmental conditions on other paediatric diseases.

3.7 Statistical power calculation and sample sizes

When performing statistical power calculations it is usual to look at similar past studies to gain an estimation of the effect size that is likely be encountered. With this in mind, we studied the 1954 MRC UV air disinfection study[28], which is one of the only studies of its kind. The reductions in average annual absence rates amongst infant and junior school children achieved through GUV are presented in Table 1. From this it can be seen that the effects

range from 0% reduction for influenza amongst the infants, up to 47.9% reduction for chickenpox, also for the infants.

Table 1. Reduction in the average annual absence rates for various viral infections at the infant and junior schools in the 1954 MRC GUV study[28].

Virus	Infants Reduction (%)	Juniors Reduction (%)
Chickenpox	47.9	NA
Mumps	37.9	37.1
Measles	18.0	NA
Influenza	0.0	4.8

Given the data in Table 1, the estimated likely reduction might be around 20%. If we further assume that the pooled standard deviation is 34.1% (i.e. a normal distribution and a worst case scenario), the effect size (Cohen's d) will be 0.587 (i.e. a medium effect). If we now assume that alpha = 0.05 and that the desired statistical power is 80%, then this indicates that each arm of the study should have a minimum of 23 observations (i.e. classrooms). However, if a conservative reduction of 10% is assumed, then the effect size becomes 0.293 and the number of observations required in each arm increases to 92. We therefore included approximately 120 classrooms in each arm in order to ensure that the study was adequately powered.

4 Data confidentiality

Data pertaining to the school and pupil/ staff personal data will be protected by the Data Protection Act 2018, and the General Data Protection Regulations. It will be handled subject to well established standard protocols for the Centre for Applied Education Research.

The research findings will be published anonymously, and no study participant or intervention site will be identifiable from reports or scientific publications.

5 Dissemination plans

Key findings will be reported back to participating schools, in the form of individual site reports. Findings will be reported to the DHSC in the form of reports. Presentations at scientific meetings and conferences as well as peer-reviewed open access publications will be used to disseminate the wider findings of the study.

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Disclaimer: The contents of this paper, including any opinions and/or conclusions expressed, are those of the authors alone.

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Appendix 1 - Absence Form

Reason for absence

- Non-health reason
- Isolation
    - Isolation due to Covid-19 in any household member or childcare bubble (suspected or test positive)
        - Symptomatic but no test result yet
        - Lateral flow test positive
        - Laboratory test positive
    - Isolation due to child testing positive for Covid-19 but no symptoms
        - Lateral flow test positive
        - Laboratory test positive
    - Isolation due to testing positive for Covid-19 with symptoms
        - Lateral flow test positive
        - Laboratory test positive
    - Isolation for other health reason
- Medical/dental appointment
- Illness (mental or physical health) (one or more of the following):
    - Asthma
    - Hayfever
    - Respiratory symptoms (not including asthma) (any cough, cold, difficulty breathing, sneeze, ear infection, sore throat, chest infection)
    - Diarrhoea and /or vomiting
    - Fever
    - Other illness or symptoms
- Other (please specify)……

Seen GP?

- Yes
- No
- Which GP? (specify)……..

Hospital – acute visit?

- Yes – visited for <4 h
- Yes – admitted or >4 h
- No
- Which hospital? (specify)……..

Appendix 2 - Closure incident form

To be completed when a whole class/year/school is sent home.

Name of school …….

Which class/classes affected?

- One class (name……)
- Several classes (names . ……, ……., ……..)
- Whole school

Reason for sending home?

Covid related

outbreak (specify details)…….

other (specify details)…….

Other health reason (specify details)……

Non-health reason (specify details)…….