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Impact of supplementary air filtration on aerosols and particulate matter in a UK hospital ward: a case study

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SUMMARY

Background: Aerosol spread of severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) is a major problem in hospitals, leading to an increase in supplementary high-efficiency particulate air filtration aimed at reducing nosocomial transmission. This article reports a natural experiment that occurred when an air cleaning unit (ACU) on a medicine for older people ward was switched off accidentally while being commissioned.
Aim: To assess aerosol transport within the ward and determine whether the ACU reduced airborne particulate matter (PM) levels.
Methods: An ACU was placed in a ward comprising two six-bedded bays plus three single-bed isolation rooms which had previously experienced several outbreaks of coronavirus disease 2019. During commissioning, real-time measurements of key indoor air quality parameters (PM1–10, CO_2, temperature and humidity) were collected from multiple sensors over 2 days. During this period, the ACU was switched off accidentally for approximately 7 h, allowing the impact of the intervention on PM to be assessed.
Findings: The ACU reduced the PM counts considerably (e.g. PM1 65.5–78.2%) throughout the ward ($P<0.001$ all sizes), with positive correlation found for all PM fractions and CO_2 ($r=0.343$–0.817; all $P<0.001$). PM counts rose/fell simultaneously when the ACU was off, with correlation of PM signals from multiple locations (e.g. $r=0.343$–0.868; all $P<0.001$) for particulates <1 µm).
Conclusion: Aerosols migrated rapidly between the various ward subcompartments, suggesting that social distancing alone cannot prevent nosocomial transmission of SARS-CoV-2 as this fails to mitigate longer-range (>2 m) transmission. The ACU reduced PM levels considerably throughout the ward space, indicating its potential as an effective intervention to reduce the risk posed by infectious airborne particles.

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Introduction

The coronavirus disease 2019 (COVID-19) pandemic has rapidly advanced understanding of how infections can spread within buildings. It is now known that small aerosol particles are dominant in the transmission of severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) [1–6] and, likely, many other respiratory viruses [7,8]. Aerosols are formed when exhaled respiratory particles <100 μm in diameter evaporate rapidly to approximately 20–34% of their original size [9–11]. These remain suspended in the air for many minutes [12] and can be readily inhaled, with those in the range 2.5–20 μm accounting for 90% of viral transmission at the nasopharynx [11]. As such, transmission of SARS-CoV-2 is thought to occur primarily when infectious aerosol particles of this size come into contact with angiotensin-converting enzyme 2 (ACE2) receptors in the nasopharynx [13]. In addition, ACE2 receptors further down the respiratory tree, including on the alveolar epithelial cells, are a likely portal of entry. Inhalation of smaller particles <5 μm down to the alveoli may therefore also contribute to acquisition of infection, and possibly heighten the severity of disease [14,15].

Infectious respiratory aerosols can be liberated in large quantities when talking, singing or simply breathing [16–18], and may build up to high concentrations in room air if the space is not ventilated adequately [12]. Consequently, poorly ventilated spaces containing infectious individuals, such as hospital wards, pose a considerable threat to patients and healthcare workers (HCWs) alike, with numerous nosocomial COVID-19 outbreaks reported [19–27]. The problem can be particularly acute on wards containing older and/or immunocompromised patients who are vulnerable to severe disease following viral infection [28]. Furthermore, in open-plan wards with multi-bedded bays, pressure gradients may exist due to room mechanical ventilation or wind pressure, causing respiratory aerosol particles to migrate considerable distances. As such, vulnerable patients some distance (>2 m) from an infector may become exposed [29]. Realization of this issue has promoted interest in non-pharmaceutical interventions, such as supplementary room air filtration [30], air disinfection [31,32], and the use of carbon dioxide (CO_2) monitoring to optimize ventilation [33,34].

This article reports the results of a natural experiment that occurred on a medicine for older people ward at an NHS university hospital in the UK, when a room air cleaning unit (ACU) containing high-efficiency particulate air (HEPA) filters and ultraviolet-C (UV–C) air disinfection lamps was being commissioned. It was possible to test the hypothesis that particulate matter (PM) levels in the air throughout the space were higher when the ACU was not in operation compared with a matched period on the following day when the ACU was switched on. The authors were also able to gain insights into the transport of aerosols around the ward by correlating the various PM signals from the respective sensors.

Methods

Ward layout and ventilation

The study involved half a ward on the sixth floor of the hospital, which comprised three side rooms, each with a door, and two six-bedded bays open to a central corridor (Figure 1). The ward was ventilated by a central ducted mechanical ventilation system and openable aluminium sash windows, with the bed bays and side rooms positively pressurized with respect to the central corridor. As this study was retrospective, taking advantage of a natural experiment, the 'open/closed' status of the various windows and doors on the ward was not recorded. Anecdotally, both doors and windows were frequently opened and closed depending on the clinical, operational and comfort requirements of the patients and HCWs. Historical measurements taken by the hospital estates department in 2020 indicated that the ward ventilation rates ranged from 1.7 to 5.8 (median 4.0) air changes per hour. The ACU was sited in an open communal space, which was the most densely populated part of the ward, with HCWs tending to congregate there prior to individual patient care activities.

Air cleaning unit

A single ACU (AeroTitan3000; AirPurity UK Ltd, Cambridge, UK) was sited opposite the two six-bedded patient bays (Figure 1, Figure S1 and Table S1, see online supplementary material). The ACU was a hybrid system that combined HEPA filters and UV-C lamps (at 254 nm), and had a clean air delivery rate (CADR) of 2550–3000 m^3/h (Table S1, see online supplementary material). The unit produced a laminar flow that manipulated the air currents in the ward space at multiple heights at a distance >10 m, promoting greater mixing and enhancing the dilution effect.

The natural experiment occurred on 3rd and 4th August 2021. The ACU was switched off accidentally early in the morning of the first day; a mistake rectified by the afternoon of the same day.

Sensors

Seven sensors (AeroSentinel.v1; AirPurity UK Ltd) recorded indoor air quality data with the following accuracies: PM fraction <1 μm diameter (PM1) and PM fraction between 1 and 2.5 μm diameter (PM2.5) (±10 $\mu g/m^3$); PM fraction between 2.5 and 4 μm diameter (PM4) and PM fraction between 4 and 10 μm diameter (PM10) (±25 $\mu g/m^3$); CO_2 (±30 ppm); temperature (±0.4 °C); and relative humidity (±3%) (Table S2, see online supplementary material). Sensor A was situated close to the ACU at a height of 2 m, with the remaining sensors placed at heights ranging from 1.5 to 1.7 m depending on available electrical outlets (Figure 1).

Data

Data from the various sensors was sampled every 1 min, giving a total of 2782 data points per sensor over the 2-day period. In total, 7.6% of the data were missing, and this was imputed as the mean value of the adjacent data points.

Change point analysis and validation

As contemporaneous records were not kept regarding the precise points in time when the ACU was switched off and on, to avoid the use of any a-priori assumptions, change point (CP) analysis [35,36] was employed using pruned exact linear time methodology [37]. Sensor A was selected for this analysis as it

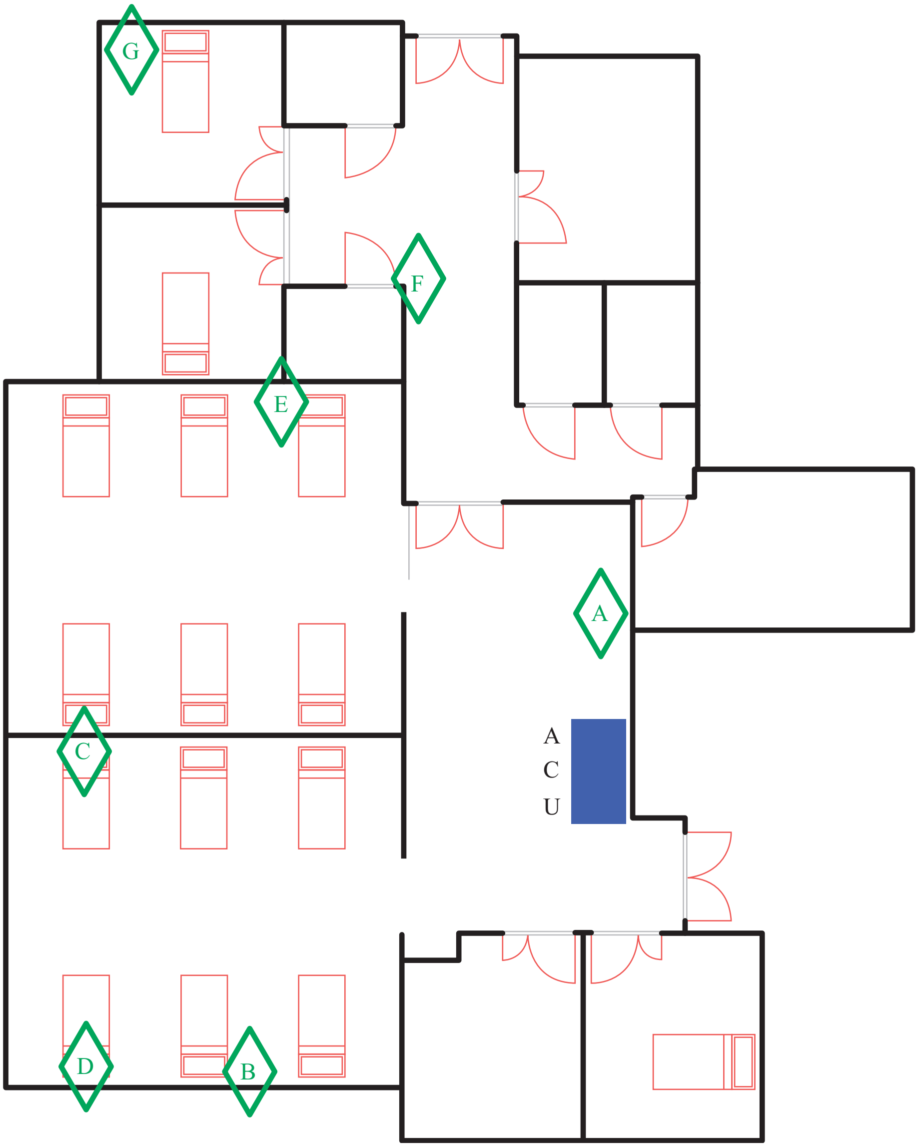

Figure 1. Layout of the medicine for older people ward showing the positions of the air cleaning unit (ACU) and sensors (green diamonds).

was best placed to monitor both occupancy levels and the ACU. CPs were identified by visual inspection, and tested statistically using the Chow test, with $P<0.05$ deemed to indicate significance.

Primary statistical analysis

The hypothesis tested was that the respective PM levels were higher when the ACU was not in operation on the first day compared with a matched period on the second day when the ACU was in operation. This was tested using an unpaired Mann–Whitney test in R (R Core Team, 2021; https://www.R-project.org/). The observed effect size was evaluated using Cliff's delta statistic, with the magnitude assessed using the thresholds provided by Romano *et al*. [38] (i.e. $|\delta|<0.147$ negligible; $0.147\leq|\delta|<0.33$ small; $0.33\leq|\delta|<0.474$ medium; $0.474\leq|\delta|$ large).

To assess the relationships between the signals from the individual sensors, Pearson correlation *r* values were computed, together with their statistical significance. This was done for each individual sensor using data for the entire study period. In addition, the extent to which airborne PM may be migrating around the ward was assessed by analysing the between-sensor correlations for each air quality metric, using only the data collected when the ACU was off. For all tests, $P<0.05$ was deemed to indicate significance.

Results

Change point analysis results

Five CPs were identified, as shown in Figure 2. Of these, Table I shows that CP1 and CP2 (representing when the ACU was accidentally switched off and turned back on again) closely coincided with the approximate time-stamps that were recovered from the ACU memory card in December 2021. CP4 occurred when the power/speed of the ACU was increased. The reasons for the changes observed at CP3 and CP5 are unclear. CP3 might reflect the downturn in activity that generally occurred on the ward after the evening meal.

Descriptive time series results

Figure 3 shows the collated PM1 time series data over 2 days from each sensor (A—G). Similar patterns for all other PM fractions were also observed (Figures S2—4, see online supplementary material). All sensors demonstrated large increases in particulates of all sizes throughout the ward when the ACU was off. Noticeably, all sensors around the ward detected similar signals with respect to PM and CO_2 levels at similar times (Figures 3 and 4, and Figures S2—4, see online supplementary material).

Statistical analysis results

The visual observations were confirmed by the means and standard deviations of the sensor signals for the periods before, between and after the identified CPs. These are shown in Table S3 (see online supplementary material) and, for all the sensors, the observed signal readings were much higher between CP1 and CP2 when the ACU was off compared with all other periods. In particular, Table II shows the respective signal levels were higher when the ACU was not in operation on the first day compared with a matched period on the second day when the ACU was in operation ($P<0.001$ for all sensors). With respect to this, a large effect size was observed for PM1, PM2.5, CO_2 and vapour pressure levels. In comparison, the effect size for the PM4 and PM10 signals was much smaller, although still significant.

Within- and between-sensor correlations

Within all sensors, strong positive correlations were observed between most of the signals (Figure S5 and Table S4, see online supplementary material). PM signals were strongly correlated with each other (r=0.718—0.996), and CO_2 and vapour pressure were positively correlated with the PM signals and each other, although not as strongly (r=0.387—0.732).

When the ACU was switched off, aerosol particle counts tended to rise and fall simultaneously throughout the ward space. Strong correlations were observed for all metrics between all the sensors (r=0.723—0.868), except for Sensor F (r=0.343—0.552) (Table S5, see online supplementary material). Sensor F was distal to the ACU and located in a narrow corridor space with a less predictable air flow.

Discussion

This natural experiment is the first of its kind to evaluate the sequential transport of airborne PM around a medical ward, and to assess the impact of an ACU on this. This study showed that particles up to 10 μm (beyond the 5 μm aerosol/droplet cut-off used previously) travelled considerable distances around the ward (beyond 2 m), and that the ACU reduced PM levels of all sizes throughout the space, not just in close proximity to the device. While the authors did not distinguish between bioaerosols and inert aerosols, it is likely that the monitored PM behaviour was indicative of any bioaerosols present in the ward air because viral particles tend to occur mainly in smaller respiratory aerosols <5 μm [39—41]. As such, these findings shed new light on the transport of aerosols around hospital wards, and increase understanding of airborne transmission of viruses such as SARS-CoV-2 in real-life clinical settings.

The considerable movement of particles of all sizes around the ward was evidenced by the simultaneous rise and fall in the PM counts measured by the multiple sensors when the ACU was switched off accidentally. This illustrates the potential for inhalational exposure to infectious agents at some distance from an infected individual. Although the authors did not measure bioaerosols or the presence of infectious agents directly, previous studies have shown that respiratory viruses are most likely to be recovered from particles <5 μm [39—42], suggesting that they are contained in exhaled bioaerosols that have undergone rapid evaporation [9]. When speaking, 80—94% of the respiratory particles produced are ≤100 μm [43], and

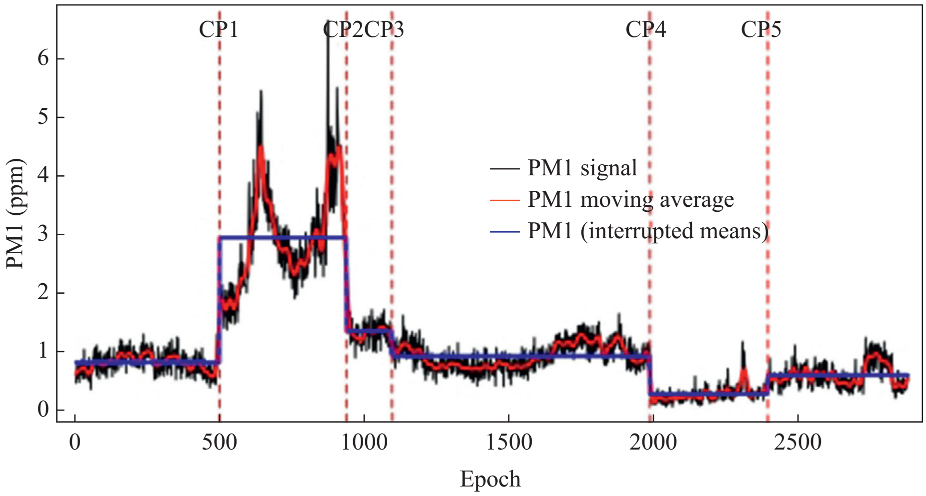

Figure 2. Particulate matter (PM) fraction <1 μm diameter (PM1) signal from Sensor A (black) with the interrupted mean signal (blue) for the sections between the major change points (CP). Major CPs were identified at epochs 497, 935, 1092, 1982 and 2389. Epochs are in min.

Table I

Occurrence of major change points (CP) in particulate matter fraction <1 μm diameter (PM1) signal for Sensor A, together with time-stamp data recovered from the air cleaning unit (ACU)

CP	CP epoch	CP time and date	Significance (*P*-value)	Time-stamp recovered from ACU	Reason for change
CP1	497	08:17 (3rd Aug)	<0.001	08:16 (3rd Aug)	ACU switched off
CP2	935	15:35 (3rd Aug)	<0.001	15:34 (3rd Aug)	ACU switched on
CP3	1092	18:12 (3rd Aug)	<0.001	N.A.	Not known
CP4	1982	09:02 (4th Aug)	<0.001	09:05 (4th Aug)	ACU speed setting adjusted
CP5	2389	15:49 (4th Aug)	<0.001	N.A.	Not known

these quickly reduce to 30% of their original diameter through evaporation under normal room conditions [44]. This means that the vast majority of exhaled particles become aerosolized, with only particles >100 μm behaving ballistically [45,46]. Given that median (range) aerosol particle emission rates of 135 particles/s (range 85–691) for breathing, 270 particles/s (range 120–1380) for normal talking and 570 particles/s (range 180–1760) for loud talking have been recorded [18], this suggests that, on a typical medical ward, many thousands of respiratory aerosols are likely to be liberated in the size range represented by the PM signals [43]. These are then likely to remain airborne and potentially migrate around the ward, as observed in this study. Thus, these findings may help explain why nosocomial outbreaks of COVID-19, including superspreading events involving multiple subcompartments, have occurred despite the application of social distancing measures between patients [21].

It is likely that the observed PM migration around the ward was assisted by the turbulent wakes formed as HCWs move, which can transport airborne particulates considerable distances [12,47]. The extent of this particle transport was somewhat unexpected because the ward ventilation system was designed to promote flow in one direction towards the corridor, which should have inhibited the movement of PM between the various bays. At present, the movement of individuals and equipment remains a significant blind spot in traditional computational fluid dynamics modelling, which usually models static scenarios. Thus, a strength of the current study is that particle movement was tracked in a real-world setting whilst ward business continued as usual. Collectively, this suggests that respiratory aerosols, many of which are <5 μm diameter, can be widely disseminated around wards, and that social distancing measures alone are unlikely to prevent the transmission of infection [29].

Interestingly, when the ACU was off, PM levels of all sizes were positively correlated with indoor CO_2 levels. This suggests that human activity such as movement, bed making, washing, etc. is key to generating particulates [48,49]. This is of particular interest given that CO_2 monitoring has been used to infer airborne infection risk in enclosed/shared spaces [50].

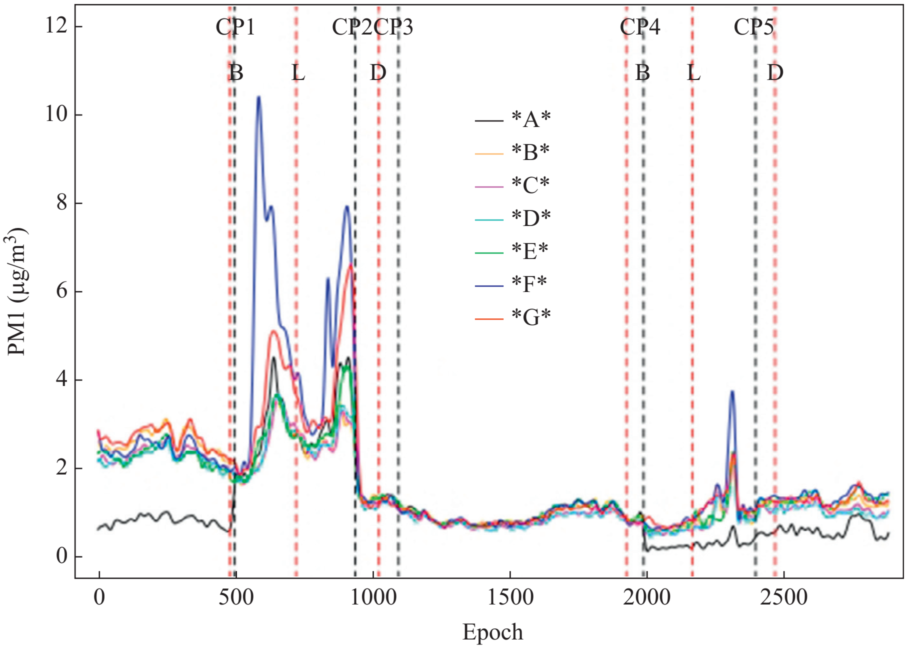

Figure 3. Collated smoothed particulate matter (PM) fraction <1 μm diameter (PM1) signals from all the sensors for 3rd and 4th August 2021. The black dashed lines denote where the change points (CPs) occurred, and the dashed red lines denote when breakfast (B), lunch (L) and dinner (D) were served to the patients on the ward. Noise from the PM signals was removed using a cubic smoothing spline in R (https://www.R-project.org/), with the smoothing parameter set to 0.1. Epochs are in min.

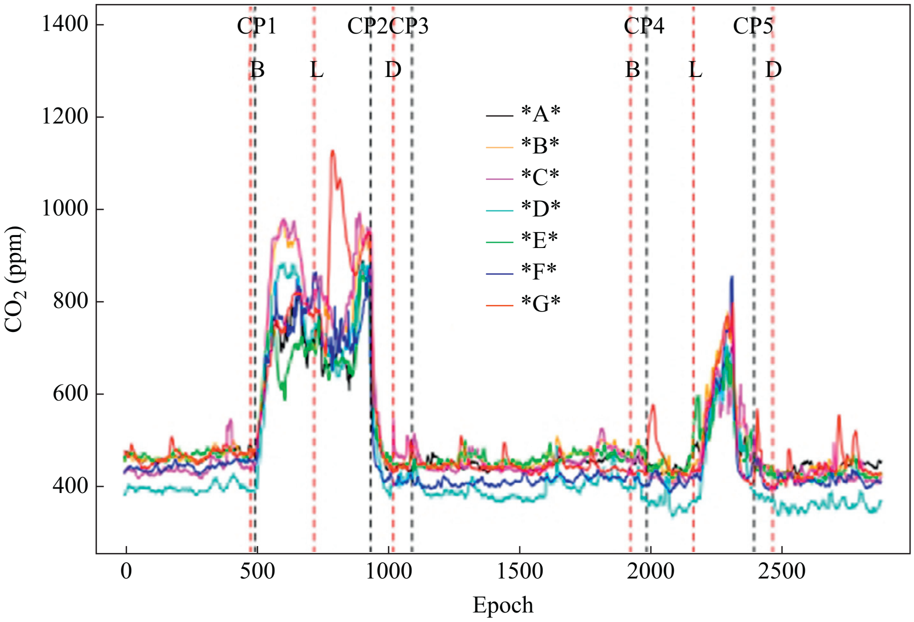

Figure 4. Collated CO_2 signals from all the sensors for 3rd and 4th August 2021. The black dashed lines denote where the change points (CPs) occurred, and the dashed red lines denote when breakfast (B), lunch (L) and dinner (D) were served to the patients on the ward. Epochs are in min.

Indoor CO_2 levels mainly reflect occupancy patterns [51—54], with exhaled CO_2 being positively correlated with respiratory aerosol emissions [55]. However, levels do fluctuate rapidly, likely due to the large volume space and changing shift patterns. The study data would not, therefore, support using CO_2 alone as a marker of safe ventilation.

When the ACU was in operation, PM levels reduced significantly across all sensors, including those distant to the unit, with the effect less pronounced for the PM4 and PM10 signals, reflecting the lower particle counts in this size range and the fact that larger particles tend to settle out of the air at a faster rate. This confirmed that the ACU cleaned the air as anticipated, but the extent of its impact, as a single machine, was unexpected. The installed ACU had a high velocity laminar discharge, which promoted good air mixing, and this, combined with a high CADR, extended its 'reach' and greatly assisted in PM removal throughout the ward. It is hypothesized that this likely extended the air cleaning impact of the unit beyond its immediate environment. Therefore, when installing units, it is important to ensure a similar extended cleaning effect, at least to the mid-point of any adjacent ACUs. Furthermore, it is important to validate the performance of any ACUs that are installed by nebulizing an inert saline solution into the air, and observing the impact of the ACU on the decay process [something undertaken on the study ward prior to the natural experiment, but not reported here (results available on request)]. Validation not only demonstrates the efficacy of ACUs, but also helps to inform their placement so that performance can be optimized.

In addition to filtering out PM, it was observed that the ACU reduced CO_2 levels unexpectedly when switched on. Given that neither HEPA nor UV-C affect CO_2 levels, it is postulated that better air mixing on the ward prevented the gaseous CO_2 from stratifying, thus reducing concentrations at the level of the sensors. Alternatively, the ACU may have increased air velocities within the ward space to such an extent that additional 'fresh air' may have been entrained in from outside. While both explanations appear plausible, it is difficult to explain the magnitude to the reduction in CO_2 levels observed in Figure 4 simply by better mixing alone, especially as the sensors were mounted $>$1.5 m above floor level. This requires further investigation.

Limitations

This study involved a single ward built before regulations required higher air change rates and the installation of doors to separate bays, something that likely influenced PM movement between the various ward subcompartments. Therefore, the authors cannot be certain that the results are generalizable to other settings, although wards of this age and design are not uncommon in the UK and other countries.

The authors were not able to determine the proportion of measured PM that comprised respiratory aerosols, and while historical ward ventilation data existed, the actual air change rates that occurred during the study were not known because it was a natural experiment. The various sensors on the ward were also not placed at the same height due to operational constraints, which may have influenced the PM counts observed. Furthermore, staff occupancy and movements, and window and door opening were not recorded. Therefore, conclusions concerning the mechanisms by which PM and CO_2 were generated and removed from the ward space remain hypothesis generating rather than confirmed.

Door and window opening can alter the airflow characteristics of ward spaces and the performance of the ACU. For example, closing doors to ward side rooms may isolate these spaces from the ACU, allowing the PM concentration to increase. Additionally, external wind pressure can contribute to the migration of aerosol particles indoors. The authors were not able to evaluate these factors, so further work is required

Table II

Results of statistical test of the hypothesis that the signal levels were higher when the air cleaning unit (ACU) was not in operation on 3rd August 2021 compared with a matched period on 4th August 2021 when it was in operation

Signal	Sensor ID	ACU off mean (SD)	ACU on mean (SD)	Significance *P*-value	Effect size Cliff's delta	Effect magnitude
PM1	G	3.73 (1.30)	1.03 (0.41)	<0.001	0.99	Large
	F	5.05 (2.35)	1.10 (0.71)	<0.001	0.96	Large
	E	2.83 (0.70)	0.89 (0.40)	<0.001	0.98	Large
	A	2.96 (0.87)	0.35 (0.24)	<0.001	1.00	Large
	B	2.61 (0.57)	0.90 (0.43)	<0.001	0.96	Large
	C	2.60 (0.57)	0.82 (0.38)	<0.001	0.98	Large
	D	2.64 (0.61)	0.82 (0.39)	<0.001	0.98	Large
PM2.5	G	0.39 (0.31)	0.06 (0.03)	<0.001	0.97	Large
	F	0.75 (0.65)	0.09 (0.16)	<0.001	0.92	Large
	E	0.22 (0.13)	0.06 (0.07)	<0.001	0.93	Large
	A	0.20 (0.14)	0.02 (0.01)	<0.001	1.00	Large
	B	0.20 (0.11)	0.06 (0.07)	<0.001	0.90	Large
	C	0.15 (0.08)	0.05 (0.04)	<0.001	0.93	Large
	D	0.17 (0.09)	0.05 (0.04)	<0.001	0.93	Large
PM4	G	0.15 (0.19)	<0.01 (0.01)	<0.001	0.59	Large
	F	0.37 (0.43)	0.022 (0.10)	<0.001	0.63	Large
	E	0.04 (0.07)	<0.01 (0.04)	<0.001	0.33	Small
	A	0.04 (0.09)	<0.01 (<0.01)	<0.001	0.27	Small
	B	0.04 (0.07)	0.010 (0.04)	<0.001	0.32	Small
	C	0.02 (0.05)	<0.01 (0.02)	<0.001	0.22	Small
	D	0.03 (0.06)	<0.01 (0.02)	<0.001	0.34	Medium
PM10	G	0.03 (0.04)	<0.01 (<0.01)	<0.001	0.55	Large
	F	0.07 (0.09)	<0.01 (0.02)	<0.001	0.60	Large
	E	0.01 (0.02)	<0.01 (<0.01)	<0.001	0.26	Small
	A	0.02 (0.04)	<0.01 (<0.01)	<0.001	0.26	Small
	B	0.01 (0.01)	<0.01 (<0.01)	<0.001	0.24	Small
	C	0.01 (0.03)	<0.01 (0.01)	<0.001	0.20	Small
	D	0.02 (0.03)	<0.01 (0.01)	<0.001	0.33	Small
CO_2	G	815.18 (139.89)	513.28 (109.67)	<0.001	0.90	Large
	F	734.24 (80.02)	479.59 (111.88)	<0.001	0.88	Large
	E	691.24 (72.78)	501.26 (72.28)	<0.001	0.92	Large
	A	713.82 (80.28)	499.45 (78.06)	<0.001	0.91	Large
	B	818.86 (115.04)	520.79 (105.35)	<0.001	0.93	Large
	C	833.17 (121.85)	494.87 (85.35)	<0.001	0.95	Large
	D	748.61 (113.94)	447.10 (102.95)	<0.001	0.93	Large
VP	All sensors	1.37 (0.05)	1.18 (0.06)	<0.001	0.98	Large

PM, particulate matter; PM1, PM fraction <1 μm diameter; PM2.5, PM fraction between 1 and 2.5 μm diameter; PM4, PM fraction between 2.5 and 4 μm diameter; PM10, PM fraction between 4 and 10 μm diameter; CO_2, carbon dioxide; VP, vapour pressure; SD, standard deviation.
All results were strongly significant after Bonferroni's correction.

to investigate their impact on ACU performance. Notwithstanding this, given that the study utilized data collected on two consecutive days on the same ward, it is unlikely that door and window opening or staff behaviour were systematically different between the two time periods. Furthermore, local weather conditions throughout the study period were fairly constant, with a light breeze from the south-east occurring on both days. Therefore, although no data on window/door opening exist, this represents a relatively minor limitation which does not change the overall conclusions of the study. In particular, given the nature of microbial bioaerosols in hospitals [11,39–41], it is highly likely that a reduction in these by any mechanism will improve indoor air quality. As such, this work offers important insights into the effect of ACUs on an inpatient ward.

In conclusion, this study builds on previous work showing that ACUs reduce microbial contamination in ward air [39], demonstrating that the application of a combined HEPA/UV-C ACU on an older adult inpatient ward reduced airborne PM levels substantially, most notably in the size range associated with respiratory viruses, such as SARS-CoV-2. Therefore, such devices may be applicable not only to pathogens traditionally considered airborne, such as measles and tuberculosis, but also where aerial dissemination contributes to the transmission of fungal and bacterial infections, such as with *Clostridioides difficile* spores [56].

This study found that airborne particulates associated with human activity migrated considerable distances around the ward, indicating that social distancing measures alone are unlikely to prevent the transmission of respiratory viral infections and possibly other infections that are aerially disseminated. Collectively, this suggests that appropriately sized ACUs have the potential to reduce nosocomial infections, especially in inadequately ventilated hospital wards. Further work is needed to investigate this, and inform the placement and commissioning of ACUs to ensure optimum performance.

Author contributions

Conceptualization: MJB, VLK, CBB.
Data curation: DS, CBB.
Software: CBB.
Formal analysis: CBB.
Funding acquisition and project administration: VLK, MJB.
Investigation and validation: DS, MJB.
Methodology and supervision: MJB, VLK, CP, ACM, CBB.
Resources: TG, RT, DS.
Writing – original draft preparation: CBB.
Writing – reviewing and editing: all authors.

Conflict of interest statement

Darren Sloof is the founder, director and shareholder of Air Purity Ltd. Air Purity designed and supplied the air cleaning units and air sensors used in this study. Air Purity Ltd had no role in the study design or analysis of the data. Darren Sloof did collect the data and liaise with other authors over its interpretation. Dr Andrew Conway Morris is a member of the scientific advisory board of Cambridge Infection Diagnostics. Dr Theodore Gouliouris has received materials from Shionogi for conducting a laboratory evaluation. The other authors report no conflicts of interest.

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Ethical approval

The work presented in this manuscript did not constitute research under the UK Policy Framework for Health and Social Care Research and was not subject to formal ethical review.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhin.2023.02.006.

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