Effectiveness of Air Purifiers on Reducing Particle Counts in Boynton Health Clinic Rooms

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Integrative Learning Experience
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Integrative Learning Experience Competencies

1) Evidence-based approaches to public health: Select quantitative and qualitative data collection methods appropriate for a given public health context
    a) Data was collected using a particle counter to count the number of particles per cubic meter. Particle counts from seven different unused rooms in the Boynton clinic were recorded over the course of eight days. Particle counts were collected at the room center, air intake, and discharge at various fan settings on the air purifier in each room, except for one room that did not have a device and was used as a control. Particle counts were collected three times, 10 seconds apart. Due to accessibility and time constraints, data from the control and first three experimental rooms were collected over the course of five trials, while data from the last three rooms were collected over the course of three trials. The first three experimental rooms were chosen based on proximity to the control room.
2) Evidence based approaches to public health: Analyze quantitative and qualitative data using biostatistics, informatics, computer-based programming and software
    a) Data was analyzed using the web version of SAS. The dataset's summary statistics were calculated, yielding measures such as means, medians, and quartiles. SAS was also used to run a two-way ANOVA test to determine if there was a difference in particle counts based on day or room number. A mixed effects model was also conducted to determine the difference in particle counts based on different fan settings on the air purifier.
3) Analyze factors that influence the presence and magnitude of hazards
    a) Factors such as fan setting, particle count on each day, and in each room all affect the presence of particle counts and the magnitude of hazard patients are exposed to. Results computed from the two-way ANOVA test determined whether day and room numbers are factors that influence the presence of particle counts and by how much. The mixed effects model was used to analyze the fan settings as a factor in reducing the number of particles and the magnitude of hazard in each room.

Introduction

Tuberculosis, among many other infections, can be transmitted through the air, potentially causing outbreaks in hospital settings (Eames et al., 2009). Natural ventilation helps dilute the bacterial load circulating. However, this is not always accessible in modern buildings that are air-sealed and require controlled climates. Air purification in healthcare settings became essential in reducing airborne particle concentration with the emergence of new infectious diseases like COVID-19. To prevent outbreaks and decrease transmission rates of COVID-19, HEPA filters have been deployed as an intervention in many facilities (Buising et al., 2021). According to the Environmental Protection Agency (EPA), HEPA (High Efficiency Particulate Air) filters, a type of filter used in air purifiers, can theoretically remove 99.7 percent of airborne particles that are 0.3 microns in size or larger.

The SARS-CoV-2 virus travels through airborne particles and droplets. With hospitals filled with patients positive for respiratory diseases, filtering out viral particles from the air is essential to limit the risk of transmission. HEPA filters and other air purifier systems have been shown to reduce particle counts in clinic rooms, thereby lowering the viral load in the air and mitigating the potential spread of infection. This contributes to creating a safer environment for patients and healthcare workers (Shrivastava et al., 2023). By combining HVAC (heating, ventilation, and air conditioning) systems that circulate air throughout the building with specialized air purifiers that clean the air, hospitals can effectively minimize hospital-acquired infections (Arikan et al., 2022).

Although effective in reducing particle counts, air purifiers all have different settings that can be controlled autonomously by management depending on needs. Other variables that need to be accounted for include the different rooms in the clinic potentially having different air quality. Furthermore, variation in outdoor air quality is a possible confounding variable as air flows in and out of the facility due to human activities. To evaluate hazards in different environments, data on particle counts in each examination room and on different days were collected and analyzed to identify the variables affecting air quality. Additionally, the effects of different fan speeds in air purifiers on particle counts in unused examination rooms at the Boynton Health Clinic will be explored to find the optimal setting that maximizes efficiency while still substantially reducing the risk of disease transmission in healthcare settings.

Methods

To collect data on the number of particle counts with varying fan speed in air purifiers, seven examination rooms at the Boynton Health clinic were used. Examination rooms 214, 216, 232, 238, 243, 246, and 248 were all unused by the institution at the time of data collection. Room 214 did not have an air purifier and was used as the control room. The other six rooms had air purifiers, each using HEPA filters and were used as experimental rooms. Air purifiers were placed against the wall in examination rooms. The placement location of each device was prearranged by facility management before the study. Particle counts were measured using a particle counter over the course of 8 days between May 2023 and August 2023. Due to accessibility and time constraint, the number of particles in room 214, 216, 232 and 238 were recorded for 5 days while 243, 246 and 248 were recorded for 3 days. Rooms 216, 232 and 238 were chosen to have data collected for 5 trials based on proximity to room 214. To measure particle counts, the particle counter was automatically calibrated during initial start up before the number of particles per cubic meter was recorded. After initial count with the air purifier off, the fan speed in the experimental rooms were turned on to low for 10 minutes to stabilize particle counts before measurement. Particle count measurements were recorded at the room center 5 feet above ground, fan intake (located on the side of the air purifier, approximately 1 feet above ground) and fan discharge (located at the top of the air purifier). These steps were repeated for all rooms along with the medium and maximum fan setting. The average of 3 measurements taken 10 seconds apart for each fan speed and measurement location (room center, fan intake, and fan discharge) was used for accuracy. Additionally, a surgical mask was worn during testing to limit the impact of human respiratory activities on particle counts in the room.

The variables measuring location, days, and room number in this dataset are categorical variables. The independent variable fan speed is a categorical predictor for the dependent variable, particle count. To describe the effect of room number and day on particle count and to optimize the effectiveness of air purifiers, SAS was used to generate summary statistics, providing the mean, median, upper and lower quartile of recorded values. A box plot was generated to visualize the difference in particle count by fan setting. A mixed effects model using the variable fan speed as an independent categorical predictor, room number and day as random intercepts, and particle count as a dependent continuous variable was used to determine the difference in mean particle counts between fan settings at room center. A summary of particle count by day and room number was also generated. Finally, a two-way ANOVA test was carried out to determine if there were any differences in particle count by day and room number.

Results

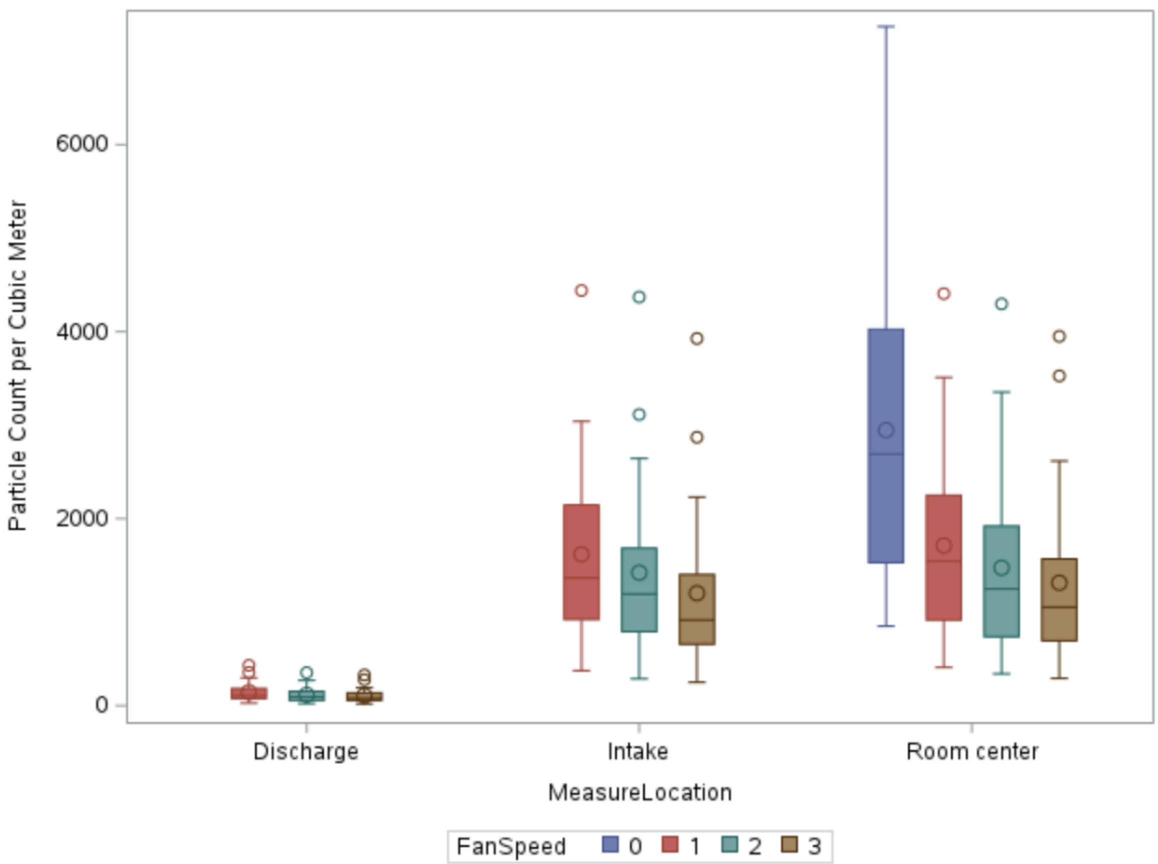

Figure 1: Box Plot Displaying the Range of Particle Count Recorded with Different Fan Speeds at Each Measuring Locations

According to Figure 1, on average, the mean particle count for each fan speed at each measuring location is higher than the median, indicating a right-skewed distribution. Overall, as fan speed increased, lower particle counts were observed across all measuring locations. The distribution range of particle counts is largest when the fan speed is 0 across different exam rooms and smallest for measurements at the air purifier's discharge.

Fan Speed	Estimates	P-Value	95% Confidence Interval	
0	7.8238	0.0001	7.6080	8.0397
1	7.2306	0.0001	7.0106	7.4506
2	7.0542	0.0001	6.8342	7.2742
3	6.9182	0.0001	6.6982	7.1382

Table 1: Mixed Effects Model Displaying the Least Square Means of Log Particle Counts Measured at the Room Center

Using the Mixed Effects model, it was estimated that when the fan is off, the average particle count at the center of an examination room will be the highest among all settings at log(7.8238) (95% CI: log(7.6080), log(8.0397)), or roughly 2499 particles per cubic meter on any given day in any given room. Turning the fan on to the lowest speed (1) is estimated to decrease the particle count to log(7.2306) (95% CI: log(7.0106), log(7.4506)), or roughly 1381 particles per cubic meter on average at the room center—a reduction of approximately 44.74 percent in particle counts in any given room on any day. The model further estimated that at medium fan speed (2), the average particle count at the center of any exam room would be log(7.0542) (95% CI: log(6.8342), log(7.2742)), or roughly 1158 particles per cubic meter on any given day. Fan speed set at medium (2) was estimated to decrease particle counts by 53.66 percent on average compared to having the fan turned off in exam rooms. At the highest fan speed, the estimated particle count was the lowest on average at log(6.9182) (95% CI: log(6.6982), log(7.1382)). The Mixed Effects model displayed a downward trend in estimated particle counts as fan speed increased in examination rooms. The p-values for all estimates were below 0.05, suggesting statistical significance in reducing particle counts when the air purifier was turned on at any setting.

Fan Speed	Fan Speed	Estimates	P-Value	95% Confidence Interval	
0	1	0.5933	0.0001	0.5074	0.6792
0	2	0.7697	0.0001	0.6838	0.8556
0	3	0.9056	0.0001	0.8197	0.9915
1	2	0.1764	0.0001	0.0902	0.2626

1	3	0.3124	0.0001	0.2261	0.3986
2	3	0.1360	0.0024	0.0497	0.2222

Table 2: Mixed Effects Model Displaying the Differences of Least Square Means in Particle Counts Measured at the Room Center

Results showed an increase in the difference in particle counts as fan speed increased compared to having the fan off. Table 2 indicated that the difference in particle counts between fan speed 0 and 1 was log(0.5933) (95% CI: log(0.5074), log(0.6792)), and between fan speed 0 and 2 was log(0.7697) (95% CI: log(0.6838), log(0.8556)). The largest difference in particle counts was observed between fan speed 0 and 3 at log(0.9056) (95% CI: log(0.8197), log(0.9915)). The difference in particle counts between fan speeds 1 and 2 was log(0.1764) (95% CI: log(0.0902), log(0.2626)), and between fan speeds 2 and 3 was log(0.3124) (95% CI: log(0.2261), log(0.3986)). The smallest difference was observed between fan speeds 2 and 3 at log(0.1360) (95% CI: log(0.0497), log(0.2222)).

Day	Mean	Standard Deviation
5/25	7.6043	0.4279
6/1	6.7764	0.5494
6/7	8.1592	0.4461
6/29	6.5458	0.4972
7/20	7.2224	0.3744
7/27	7.4289	0.3989
8/3	6.8809	0.3900
8/31	8.0606	0.4428

Table 3: Summary of Log Particle Count by Dates Measured at Room Center

Results from Table 3 showed that the log particle counts measured at the room center varied across different dates, indicating no consistent trend. The data demonstrated fluctuations in particle counts across the 8 different dates on which measurements were taken. The highest recorded mean log particle count was on 6/7 with a value of 8.1592, while the lowest mean log particle count was recorded on 6/29 at 6.5458. The highest variation was observed on 6/1 with a standard deviation of log(0.5494), and the lowest was on 7/20 at log(0.3744).

Room Number	Mean	Standard Deviation
214	7.6648	0.6462

216	6.9067	0.7673
232	7.4373	0.5904
238	7.3541	0.7670
243	7.4383	0.7190
246	7.3326	0.6885
248	7.5244	0.4812

Table 4: Summary Statistics of Log Particle Count by Room Number Measured at Room Center Without Active Air Purification

Table 4 displays the variation in log particle counts between room numbers. The mean log particle counts differ from room to room. The highest mean log particle count was in Room 214 at 7.6648, or roughly 2,131 particles per cubic meter, while the lowest was in Room 216 at log(6.9067), or roughly 999 particles per cubic meter. The highest standard deviation was also recorded in Room 216 at log(0.7673), indicating more fluctuation between measurements. Room 248 had the lowest standard deviation at log(0.4812), which indicates more consistent particle counts between recordings.

Variable	F-Value	P-Value
Day	17.32	0.0001
RoomNumber	4.03	0.0015
Day*RoomNumber	0.41	0.9821

Table 5: Two-Way ANOVA Test for Particle Count Between Day and Room Number

Based on the Two-Way ANOVA test results from Table 5, the large F-value for the variable Day indicates that there is a significant difference in particle counts between days. The p-value being lower than 0.05 provides sufficient evidence to reject the null hypothesis that particle counts are the same across all days. The F-value of 4.03 for the variable Room Number suggests a significant difference in particle counts between rooms, though this difference is less pronounced than the difference between days. With a p-value of 0.0015, which is lower than 0.05, there is enough evidence to reject the null hypothesis that particle counts are the same in all rooms. The interaction between Day and Room Number is not statistically significant, as the F-value (0.41) is low and the p-value (0.9821) is higher than 0.05. This indicates that the effect of the day on particle counts is consistent across different rooms.

Discussion

At all three measuring locations, increasing fan speed decreased the number of particles in the air. When particle counts were measured at the air purifier's discharge, the change in particle count between fan speeds was not as drastic as at the intake or in the room center. The range of particle counts was largest when the fan was turned off and smallest at the air purifier's discharge. Measurement position was a factor that affected particle levels as air circulated throughout the rooms. Data recorded at the center of the exam rooms were chosen to run the Mixed Effects model, as this was a consistent metric across all rooms. The results showed a clear downward trend in particle counts as the air purifier was turned on, even at the lowest fan setting, indicating the consistency and effectiveness of HEPA filters in removing particles to generate clean air, regardless of the initial concentration. As fan speed increased, particle counts in each examination room were further reduced.

The Mixed Effects model allowed for the estimation of particle counts based on fan speed while accounting for room number and day as random intercepts. Particle counts varied across different days of measurement, and each room had varying particle counts. It was estimated that the average particle count in any given room on any day, when the air purifier is not running, is log(7.8238), or roughly 2,499 particles per cubic meter. Turning on the fan at the lowest setting reduced this number to 1,381 particles per cubic meter, representing a 44.74 percent decrease. This reduction further increased to 53.66 percent at medium speed and 59.6 percent at maximum settings compared to when the fan is off. While the greatest reduction in particle counts was observed at the maximum fan speed, the incremental benefits between medium and high settings were smaller.

Based on the differences in least square means, the largest decrease in particle count was observed between fan speeds 0 and 3. At fan speed 3, it was estimated that there was a decrease of log(0.9056) (95% CI: log(0.8197), log(0.9915)) particles on average on any given day in any given room. The smallest difference in particle reduction was between fan speeds 2 and 3, with an estimated decrease of log(0.1360) (95% CI: log(0.0497), log(0.2222)) between these settings.

These results suggest that turning on the air purifier, even at the lowest setting, will lead to a substantial decrease in particle counts in examination rooms. Increasing the fan speed will further reduce particle counts and improve air quality, though the differences in reduction diminish at higher settings. The data collected can help facility management make informed decisions to balance air quality with other factors, such as noise levels and energy consumption. Further studies are needed to determine the clinical significance of particle count levels and their impact on patient health. However, these findings strongly suggest that air purifiers are crucial for controlling airborne particles and ensuring clean air in environments where minimizing particle counts is essential.

Data on the log mean particle counts across dates showed significant variation in particle counts between days. Additionally, there was variability in log mean particle counts among different examination rooms. The two-way ANOVA test suggests that different days and room numbers affect particle counts, though there is no evidence of interaction between these factors. It is unclear why room 216 has a lower log mean particle count despite having the highest variability. This variation in mean log particle counts and standard deviation may be linked to external factors, such as differences in room airflow patterns, the room's positioning relative to the building's HVAC system, its location within the building, or other environmental influences. The fact that room 214 never had an air purifier initially could explain why it had the highest log mean particle counts. Ventilation rates, airflow direction, and airflow distribution are other factors to consider (Eames et al., 2009).

In this study, air purifiers were placed in different locations depending on the room. Additionally, room layouts and contents varied. The materials and objects in the rooms could have impacted airflow and particle counts. The location of rooms relative to the building and the main HVAC system also differed. Furthermore, particle counts per cubic meter in clinics are shown to be higher during certain seasons (Lee et al., 2020). This study was conducted during the summer months when temperature, humidity, and human activities differ from other seasons, potentially impacting the results. Particle counts were not measured at the same time intervals between days. During certain weeks in the summer of 2023, wildfires in northern Minnesota and Canada affected outdoor air quality on certain days. Room size also plays a significant role in particle counts and how effective air purifiers are in reducing those numbers but was not taken into account in this study. Lastly, only unused examination rooms were studied, which may result in different estimates compared to occupied rooms.

Ultimately, depending on the day and room patients visit the clinic, they may experience significantly better or worse air quality, which could influence their risk of disease transmission based on when and where their visits occur. However, air purifiers with HEPA filters have been proven to be highly effective in reducing particulate counts in the air, potentially decreasing airborne transmission in clinic settings. The findings of this study underscore the importance of identifying the factors that cause fluctuations in particle counts between days and rooms, as well as using air purifiers to remove airborne particles, in order to standardize and maintain clean air quality across different exam rooms.

Citations

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Appendix

```
/*Importing Data*/

proc import
datafile = "/home/u62266591/ParticleCountData.csv"
out=ParticleCounts
dbms=csv
replace;
getnames=yes;
Run;

/*Summary Statistics*/

proc means data=ParticleCounts q1 q3 mean min max median;
var ParticleCount;
class MeasureLocation FanSpeed;
run;

/*Box plot*/

proc sgplot data=ParticleCounts;
vbox ParticleCount / category=MeasureLocation group=FanSpeed;
yaxis label="Particle Count per Cubic Meter";
run;

/*Sort Variable*/

proc sort data=ParticleCounts;
by MeasureLocation FanSpeed;
run;

/*Histogram*/

proc univariate data=ParticleCounts;
histogram ParticleCount;
by MeasureLocation FanSpeed;
run;

/*Mixed effects model for room center*/

data ParticleCountsRoomCenter;
set ParticleCounts;
where MeasureLocation = "Room center";
LoggedParticleCount = log(ParticleCount);
run;
```

```
proc mixed data=ParticleCountsRoomCenter method=ml;
class FanSpeed Day RoomNumber;
model LoggedParticleCount = FanSpeed / solution;
random intercept / subject=Day(RoomNumber);
lsmeans FanSpeed / pdiff cl;
run;



/*Summary statistic of particle count by day*/

proc means data=ParticleCountsRoomCenter;
class Day;
var LoggedParticleCount;
output out=SummaryStatsLogged mean=MeanLoggedCountbyDay;
run;

/*Summary statistic of particle count by room number*/

proc means data=ParticleCountsRoomCenter;
class RoomNumber;
var LoggedParticleCount;
output out=SummaryStatsParticleCount1 mean=MeanCount;
run;

/*Two-Way ANOVA test for log mean particle count by room number and day*/

proc glm data=ParticleCountsRoomCenter;
class Day RoomNumber;
model LoggedParticleCount = Day RoomNumber Day*RoomNumber;
means Day RoomNumber / hovtest=levene; /* Levene's test for homogeneity of variances */
lsmeans Day RoomNumber / adjust=bon; /* Bonferroni-adjusted pairwise comparisons */
run;
```