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The effect of portable air-purifiers in improving indoor air quality in pediatric intensive care units at two tertiary hospitals in Riyadh, Saudi Arabia

Waleed S. Al-Ghamdi*[1], Dr. Aiman El-Saed[1], Majid M. Al-Shamrani[1], Ali Al-Rabou[1], Dr. Abdullatif A. Neamatallah[2], Dr. Fahad Al-Mehmadi[2]

[1] King Abdulaziz Medical City | Ministry of National Guard Health Affairs | KSA

[2] Faculty of Meteorology, Environment & Arid Land Agriculture | King Abdulaziz University | KSA

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* Corresponding author: waleed_sa_000@hotmail.com

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Abstract: Background: A set of environmental preventive measures involving ventilation control within healthcare facilities is well established. Portable air purifiers have been introduced in recent years as one of alternative technologies used to prevent infection and other respiratory complications in indoor environment. Objective: To asses indoor air quality in pediatric intensive care units at two tertiary hospitals in Riyadh, Saudi Arabia in the presence and absence of portable air purifiers.Method: Fine particles (PM 2.5) and coarse particles (PM10) were obtained using optical particle counter and microbial counts were obtained using Andersen air sampler from outdoor and two patient rooms in pediatric intensive care units. Pollutants levels reduction between outdoor and indoor were calculated and compared using Statistical Package for the Social Sciences software (SPSS Version 27.0. Armonk, NY: IBM Corp) were utilized for statistical analysis. Results: In hospital A and B, non-protective environment room (NPE) had a significantly higher number of fine particles and total bacterial count (TBC) respectively than semi-protective environment room (SPE). Meanwhile, there was significantly higher reductions of fine particles (hospital A) and coarse particles, fine particles and TBC (hospital B) in SPE rooms compared with NPE room. Hospital-A had significantly higher reduction efficacy compared with matched rooms in hospital-B for fine particles, coarse particles, and TBC. Conclusion: This study demonstrated that portable air purifiers have a great impact in the reduction of indoor air pollutants in PICUs including fine particulate matters and TBC in particular. Furthermore, ventilation systems equipped with HEPA filters along with portable air purifiers significantly reduce the levels indoor air pollutants of outdoor sources. Moreover, this study showed that newer and well-maintained HVAC systems play a significant role in controlling the levels of airborne pollutants.

Keywords: Air purifiers, Bacterial, Coarse particles, Fungal, Fine particles, High Efficiency Particulate Air

تأثير أجهزة تنقية الهواء المحمولة في تحسين جودة الهواء الداخلي في وحدات العناية المركزة للأطفال في مستشفيين من الدرجة الثالثة في الرياض، المملكة العربية السعودية

وليد سعيد الغامدي*[1]، الدكتور / أيمن السعيد[1]، ماجد الشمراني[1]، علي الربوع[1]، الدكتور / عبد اللطيف نعمة الله[2]، الدكتور / فهد المحمادي[2]

[1] مدينة الملك عبد العزيز الطبية | الشؤون الصحية بوزارة الحرس الوطني | المملكة العربية السعودية

[2] كلية الأرصاد والبيئة وزراعة المناطق الجافة | جامعة الملك عبد العزيز | المملكة العربية السعودية

المستخلص: الهدف: أصبحت التدابير الوقائية البيئية التي تشمل التحكم في التهوية راسخه داخل مرافق الرعاية الصحية. وقد تم إدخال أجهزة تنقية الهواء المحمولة في السنوات الأخيرة كأحد التقنيات البديلة المستخدمة لمنع العدوى ومضاعفات الجهاز التنفسي الأخرى. ومضاعفات الجهاز التنفسي الأخرى في البيئة الداخلية. وقد كان الهدف الأساسي لهذه الدراسة هو تقييم جودة الهواء الداخلي في وحدات العناية المركزة للأطفال في مستشفيين من الدرجة الثالثة في الرياض بالمملكة العربية السعودية في وجود وغياب أجهزة تنقية الهواء المحمولة. الطريقة: تم قياس كميات الجسيمات الدقيقة (PM 2.5) والجسيمات الخشنة (PM10) العالقة في الهواء باستخدام عداد الجسيمات البصري وتم كذلك جمع عينات الميكروبات في الهواء باستخدام جهاز أخذ عينات الهواء Andersen من المحيط خارج المستفيين وكذلك من غرفتين للمرضى في وحدات العناية المركزة للأطفال. وقد تم حساب انخفاض مستويات الملوثات بين البيئة الخارجية والداخلية ومقارنتها بعد ذلك باستخدام الحزمة الإحصائية لبرنامج العلوم الاجتماعية (SPSS الإصدار 27.0. Armonk، NY: IBM Corp) والتي تم استخدامها للتحليل الإحصائي. النتائج: في المستشفى A و B ، تحتوي غرفة البيئة غير الواقية (NPE) على عدد أكبر بكثير من الجسيمات الدقيقة وعدد البكتيريا الكلي (TBC) على التوالي من غرفة البيئة شبه الواقية (SPE). وفي الوقت نفسه، كان هناك انخفاض كبير في الجسيمات الدقيقة (المستشفى A) والجسيمات الخشنة والجسيمات الدقيقة و TBC (المستشفى B) في غرف SPE مقارنة بغرفة NPE. كان لدى مستشفى- A فعالية تخفيض أعلى بشكل ملحوظ مقارنة بالغرف المطابقة لها في المستشفى B للجزيئات الدقيقة والجزيئات الخشنة و TBC. الخلاصة: أظهرت هذه الدراسة أن أجهزة تنقية الهواء المحمولة لها تأثير كبير في تقليل ملوثات الهواء الداخلية في وحدات العناية المركزة PICU بما في ذلك الجسيمات الدقيقة و TBC على وجه الخصوص. علاوة على ذلك، تعمل أنظمة التهوية المزودة بمرشحات HEPA جنبًا إلى جنب مع أجهزة تنقية الهواء المحمولة على تقليل مستويات ملوثات الهواء الداخلية للمصادر الخارجية بشكل كبير. وقد أظهرت هذه الدراسة أن أنظمة HVAC الأحدث والتي يتم صيانتها جيدًا تلعب دورًا مهمًا في التحكم في مستويات الملوثات المحمولة جواً.

الكلمات المفتاحية: أجهزة تنقية الهواء، البكتيريا، الجزيئات الخشنة، الفطريات، الجزيئات الدقيقة، الهواء الجزيئي عالي الكفاءة

1. Introduction

Indoor air refers to the air inside our buildings that might poses an adverse health effect to the occupants if not properly controlled. An estimate of 3.2 million deaths have been reported in 2020 due to indoor air pollution (WHO, 2022). Nevertheless, people usually spend approximately 90% of their times indoor, which makes them exposed to indoor pollutants for a prolonged time ((CDC), 2009). Moreover, sources of indoor pollutants vary from one location to another based on occupants' life style and behavior. According to the Unites States Environmental Agency (EPA) indoor pollutants are mainly originated from indoor sources and to some extent outdoor sources that are infiltrated to indoor environment via doors, windows and ventilation system ((EPA), 2021). Once indoor pollutants scattered, they become suspended in the air for indefinite time as particulate matters (PM) and reside upper and lower respiratory system and blood stream based on the aerodynamic diameters. The magnitude of the health risk due to exposure to indoor air pollutants usually ranges from sensory annoyance to sever respiratory infection. Due to vulnerability, patients in healthcare facilities are at more risk. However, set of environmental preventive measures involving ventilation control within healthcare facilities have been established (Schoen, 2014).

In recent years, portable air purifiers have been introduced as one of the technologies used to prevent infection and other respiratory complications in indoor environment. There are different types of portable air purifiers in the market that are used to improve indoor air quality. However, EPA published a technical summary that classifies air purifiers based on the technology involved for each type (U.S. Environmental Protection Agency (EPA), 2018). Moreover, Association of Home Appliance Manufacturers (AHAM) has established pollutants' removal efficacy, which is a recognized certificate body by American National Standards Institute (ANSI). The method of testing removal efficacy is dependent on Clean Air Delivery Rates (CADR) of the three types of PMs; i.e. ultra-fine, fine and coarse particles ((AHAM), 2015).

Many studies have been conducted to assess portable air purifiers in the field. In one study, the effect of a portable air purifier provided with High Efficacy Particulate Air (HEPA) filter was evaluated for pets' allergens removal in homes with asthmatic occupants (Sulser, 2009). The result of this study revealed that despite the significant retention of pets' allergens present in the air, effectiveness of air purifiers used was negligible on asthmatic therapy. Another study compared the effectiveness of PM and Volatile Organic Compound (VOC) removal by several home air purifiers with different technologies (Berne P, 2019). The study concluded that air cleaners under showed effective removal of PMs over VOCs. Furthermore, portable air purifiers are used as one of the strategies to prevent and control airborne microorganisms infection within health care facilities as recommended by the Centers for Diseases Prevention and Control (Siegel JD, 2019). In line with this aspect, Bergeron, V., et al. evaluated opportunistic airborne pathogens reduction performance of a portable air purifier provided with a non-thermal-plasma technology in a high-risk patient area. It was indicated in this study that air purifiers used significantly reduced airborne microorganisms (Bergeron, 2007). Furthermore, Rutala, William A., et al. concluded that air purifiers provided with HEPA filters are effective in a rapid reduction of infectious droplet nuclei and hence may help to prevent risk of tuberculosis exposure (Rutala, 1995).

Further studies have been conducted to measure PM pollutants inside hospital buildings in particular. In most of European countries and Taiwan, fine and coarse particles where considrebily low (< 20 µg/m3 and < 25 µg/m3, respectively) ((Baurès, 2018; Jung, 2015; Loupa, 2016). However, in China fine particles were 98 and 124 µg/m3 and in South Korea coarse particles were 57 µg/m3 (Hwang, 2011; Wang, 2006). In Guangzhou, China the mean indoor coarse particles and fine particles concentration were 128.13 µg/m and 399 µg/m3 respictevely (Wang, 2006). Locally, the mean indoor and outdoor coarse particles concentrations reported in one hospital in the Eastern Region, Saudi Arabia were 255 µg/m3 and 344 µg/m3 (El-Sharkawy, 2014). On the other hand, measuring indoor and outdoor contaminants usually supports the invistegation of idintifying the source of those contaminants. Jung et al pointed out that the elevated indoor/outdoor (I/O) ratios indicated that the outdoor air is probably the main source (Jung, 2015; Lei, 2017; Loupa, 2016; Wang, 2006).

The aim this study is to evaluate the reduction efficacy of an air purifier provided with combined technologies (HEPA, UV and carbon filter) for airborne particles of PM and microorganisms in patient critical care areas.

2. Material and methodology

2.1. Materials:

Portable air purifiers used in this study are United States Food, Drug Administration (USFDA) approved, and AHAM certified. Each air purifier covers 60m^2 and is provided with three-combined technologies of airborne reduction and elimination **(Figure-1).** The three concepts of the technologies include: 1) HEPA filter that is used to filter particles down to 0.3 µm, 2) carbon filter that is used for the removal of molecular air pollutants such as; volatile organic compounds (VOCs), gaseous chemicals and unpleasant odors and 3) UV light that is used to eliminate microorganisms (Figure-1). New filters and UV lights were installed prior to the beginning of the study. The purifiers have five levels of fan speeds; the speed fan of each purifier was set on level three and kept operating during the entire period of the study.

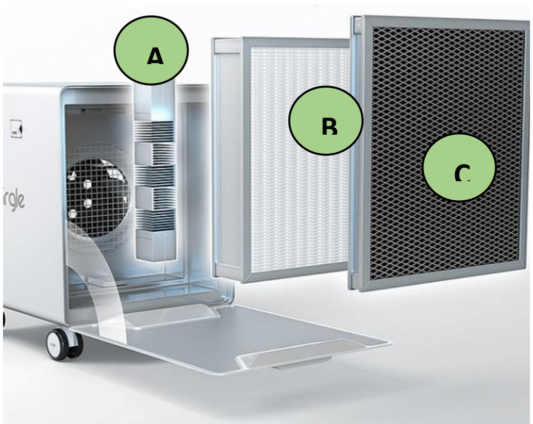

Figure-1: Airgle AG900 air-purifier (Airgle Co. 2018)
A)UV Light, B) HEPA filter, C) Carbon Filter

2.2. Study Design and duration:

Air sampling was conducted at the daytime during operational hours from January to April 2021. Two patient rooms at two different tertiary-care hospitals in Riyadh, Saudi Arabia were chosen for this study. Rooms were labeled based on their air specifications and HEPA filter status (Table-1) as follow: 1) semi-protective environment (SPE) and 2) non-protective environment (NPE) and the two hospitals were labeled as hospital-A and hospital-B. Both hospitals are equipped with advanced heating, ventilation and air conditioning (HVAC) systems. Both rooms in each hospital are located in PICU and connected to the same air-handling unit (AHU). Only in hospital A, a central HEPA filter is installed in AHU and feeding both rooms. In both hospitals, only SPE rooms were provided with portable air-purifiers that were placed within 3 meters of the patient's breathing zone (**Figure-2**).

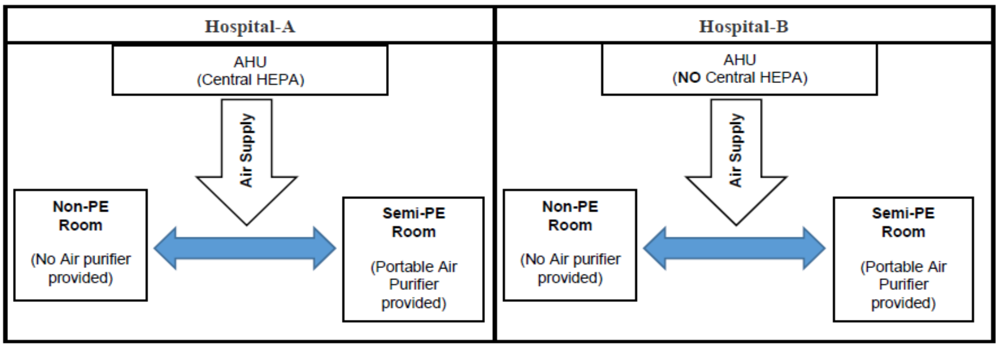

Figure-2: A schematic diagram of portable air purifiers' location in patient rooms within the two hospitals

HEPA, high-efficiency particulate absorbing; AHU, air-handling unit; SPE, semi-protective environment; NPE, non-protective environment

Details of HEPA filter locations, air purifiers' distribution, temperature, relative humidity (RH) and relative pressure of each room is shown in table-1.

Table-1: HEPA filter status and air specifications of the patient rooms in the two hospitals

Hospital	Room	Central HVAC HEPA filter	Room HEPA filter	Portable Air-Purifier	Room Pressure
A	SPE	Yes	No	Yes	Neutral
	NPE	Yes	No	No	Neutral
B	SPE	No	No	Yes	Neutral
	NPE	No	No	No	Neutral

Neutral; No air flow from or into the room, HEPA, high-efficiency particulate absorbing; AHU, air-handling unit; SPE, semi-protective environment; NPE, non-protective environment, HVAC; Heating Ventilation and Air Conditioning.

2.3. Data collection:

2.3.1. Study tools

Indoor and outdoor air samples were collected in each visit from both rooms (indoor) and AHU air-intake (outdoor). Air sampling included obtaining the readings of PMs and collecting samples for total bacterial count (TBC) and total fungal count (TFC) from all sites indoor and outdoor. Both devices (microbial sampler and particle counter) were placed side by side in each room and within patient breathing zone and 1 meter from the floor. Moreover, number of people (patient, housekeepers, visitors, medical team) in each room, weather status were observed and recorded during the sampling process manually.

2.3.2. Particular Matter Counting

A previously calibrated optical particle counter (Lighthouse Handheld 3016 six-channel laser particle counters) was used to measure the number of particles in six diameter ranges: 03um, 0.5um, 1.0um, 2,5um, 5.0um and 10.0um for 1 min at a flow rate of 2.8 l/min, according to the manufacturer's instructions. The number of particles for the six sizes was recorded and then categorized into coarse and fine particles with diameters ≤10 um and ≤ 2.5 μm respectively. The device also displays Temperature/Relative Humidity along with particles counts reading which were recorded throughout the study. Outdoor reading was obtained from the air-intake of the AHU feeding the all targeted rooms.

2.3.3. Microbial Air Sampling

Air samples for TBC and TFC were obtained using Spin air IUL sampler, based on the Andersen air sampler principle with a sampling rate 100/L. A 90 mm Petri dish plates of Sabouraud and blood agar for TFC and TBC isolation respectively was used. Outdoor air samples were obtained from the air-intake of the AHU feeding the targeted rooms. The volume of air sampled from SPE rooms NPE rooms and outdoor were 500L, 200L and 200L respectively according to the laboratory guidelines in both hospitals. Air sampler was calibrated prior to starting the study and the stage head used to be sterilized with 70% alcohol swab after every sampling process to avoid cross-contamination.

2.3.4. Culture processing

The guidelines of both laboratories at the two hospitals were followed. The air-sample media were incubated at 30 °C for 5-7 days and 35°C for 48 hours for fungal and bacterial count respectively. Plates then counted and identified for the number of colonies on each plate in colony forming unit per cubic meter (CFU/m^3) using the following formula; CFU/m^3 = CFU Counted area on the agar /Sample Volume (Liter) X 1000 (Liter)

2.3.5. Statistical Analysis

Statistical Package for the Social Sciences software (SPSS Version 27.0. Armonk, NY: IBM Corp) were utilized for statistical analysis and Microsoft Excel were utilized for statistical analysis. Airborne pollutants including particulate matters and microbial counts were presented as means and standard deviations (SD). Airborne pollutants were compared between different room setups. Outdoor to indoor average reduction percentages of different room at both hospitals was calculated. The reduction percentages were calculated using the following formula: Reduction Percentage = 100 - (indoor count/outdoor count X 100). Data normality were checked using Kolmogorov-Smirnov normality test, which is used to test the null hypothesis that the data comes from a normal distribution (as evidenced by non-significant p-value). A non-parametric test was used to fit the data that were not perfectly normal. Differences in airborne pollutants between different rooms within each hospital and between the same rooms between the two hospitals were compared using Mann-Whitney test. This test is used to examine the differences between two distributions that do not necessarily meet the normality assumptions. All P-values were two-tailed. A p-value <0.05 was considered significant.

3. Results

Table 2 shows the average number of airborne pollutants counts in PICU rooms at the two hospitals. The average count levels of fine particles, coarse particles, TBC, and TFC in both hospitals were much higher in outdoor than indoor rooms. In hospital A, the average levels of fine particles in NPE room and SPE room were 5858.1±19900.9 and 917.5±921.5 respectively and was significantly higher in NPE room (p<0.001). On the other hand, the levels of coarse particles, TBC, and TFC were not significantly different between the two rooms. In hospital B, the average levels of fine particles and TBC in NPE room were 15668.9 ± 20807.1 and 68.8 ± 69.1 respectively and in SPE room were 4606.3±4745.1 and 68.8±23.0 and were significantly higher for fine particles (p=0.001) and TBC (p=0.006). With exception of TBC in SPE room, hospital B had significantly higher levels of fine particles, coarse particles, and TBC compared with matched rooms in hospital A. On the other hand, TFC was not significantly different in matched rooms in the two hospitals.

Table 2: Average of absolute count levels of particulate matters and microbial counts in pediatric intensive care units at the two tertiary care hospitals

	SPE		NPE		Outdoor		P-value[1]	P-value[2]	P-value[3]
	Mean	SD	Mean	SD	Mean	SD			
Hospital-A									
Fine ≤2.5 um	917.5	921.5	5858.1	19900.9	225352.7	152970.2	<0.001	<0.001	<0.001
Coarse ≤ 10 um	16.7	15.9	14.6	18.4	1413.8	1471.4	0.857	0.004	<0.001
TBC (CFU/m^3)	17.9	23.4	16.8	19.4	379.5	464.1	0.635	0.755	0.001
TFC (CFU/m^3)	0.5	2.2	0.3	1.1	20.8	12.6	0.443	0.554	>0.99
Hospital-B									
Fine ≤2.5 um	4606.3	4745.1	15668.9	20807.1	131887.3	50615.7	0.001	<0.001	<0.001
Coarse ≤ 10 um	33.0	19.6	62.1	32.6	1356.4	1421.8	0.001	0.004	<0.001
TBC (CFU/m^3)	21.7	23.0	68.8	69.1	80.5	55.7	0.006	0.755	0.001
TFC (CFU/m^3)	1.0	4.0	0.3	1.1	31.8	26.1	0.014	0.554	>0.99

SD, standard deviation; TBC, total bacterial count; TFC, total fungal count; CFU, colony-forming unit; SPE, semi-protective environment, NPE, non-protective environment. P-value 1 tests the difference between the two rooms within each hospital and P-value 2 test the differences of the SPE and NPE (respectively) between the two hospitals.

Table 3 and figures 3, 4, 5 and 6 show the average relative reduction of the levels of airborne pollutants in PICU with different ventilation setups in the two hospitals. In hospital A, fine particles count reduction efficacy was significantly higher in SPE rooms compared with NPE room (p<0.001) with average reduction percentages of 99.4 ± 1.0 and 93.7 ± 25.1 respectively. However, the efficacy was not significantly different between the rooms with regard to coarse particles, TBC, and TFC. In hospital B, the efficacy was higher in SPE rooms compared with NPE room with regard to fine particles 96.2 ± 3.1 and

87.3 ± 14.1 respectively (p=0.001), coarse particles 96.1 ± 4.3, 87.7 ± 17.2 and 93.0 ± 5.8 respectively (p=0.011), and TBC 52.4 ± 76.0, 54.9 ± 68.7 and -26.8 ± 127.6 respectively (p=0.044). With exception of TFC in NPE rooms, hospital-A had significantly higher efficacy compared with matched rooms in hospital-B for fine particles, coarse particles, and TBC.

Table 3: Average relative reduction in the levels of particulate matters and microbial counts in pediatric intensive care units in two tertiary care hospitals

	SPE		NPE		P-value[1]	P-value[2]	P-value[3]
	Mean	SD	Mean	SD			
				Hospital-A			
Fine ≤2.5 um	99.4	1.0	93.7	25.1	<0.001	<0.001	<0.001
Coarse ≤ 10 um	97.7	2.9	98.0	3.6	0.833	0.053	<0.001
TBC (CFU/m^3)	90.8	16.2	93.3	8.0	0.839	0.047	<0.001
TFC (CFU/m^3)	97.5	11.2	99.0	4.5	0.443	0.564	0.941
				Hospital-B			
Fine ≤2.5 um	96.2	3.1	87.3	14.1	0.001	<0.001	<0.001
Coarse ≤ 10 um	96.1	4.3	93.0	5.8	0.011	0.053	<0.001
TBC (CFU/m^3)	52.4	76.0	-26.8	127.6	0.044	0.047	<0.001
TFC (CFU/m^3)	97.6	7.9	98.2	7.6	0.015	0.564	0.941

SD, standard deviation; TBC, total bacterial count; TFC, total fungal count; CFU, colony-forming unit; SPE, semi-protective environment, NPE, non-protective environment. P-value 1 tests the difference between the two rooms within each hospital and P-value 2 test the differences of the SPE and NPE (respectively) between the two hospitals.

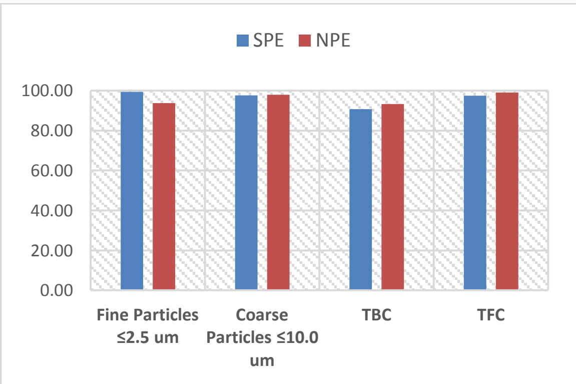

Figure-4: Pollutants reduction percentages comparison between SPE and NPE rooms in hospital-A

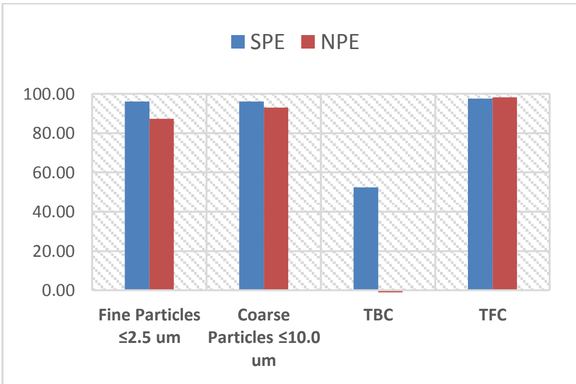

Figure-5: Pollutants reduction percentages comparison between SPE and NPE rooms in hospital-B

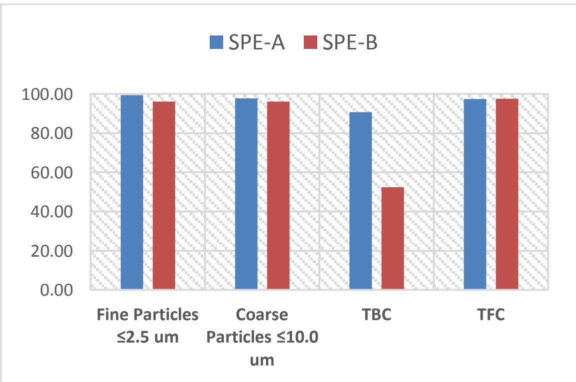

Figure-6: Pollutants reduction percentages comparison

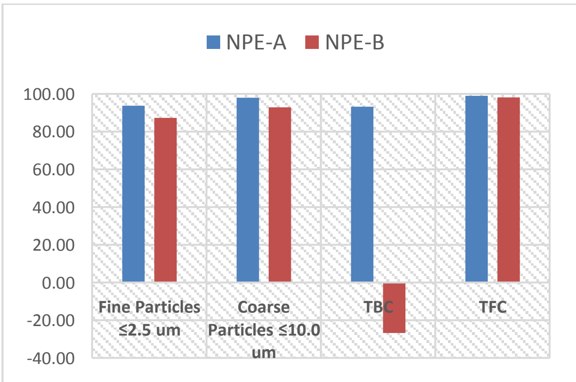

Figure-7: Pollutants reduction percentages comparison

between the same room types in hospital-A (SPE-A) & hospital-B (SPE-B)

between the same room types in hospital-A (NPE-A) & hospital-B (NPE-B)

4. Discussion

The findings of this study indicated that portable air purifiers can play a significant role in terms of fine particulate matter and TBC reduction. Compared to NPE rooms, SPE rooms showed an improved relative reduction in the levels of fine particulate matter in both hospitals. Moreover, NPE rooms showed a decreased relative reduction for TBC compared to SPE rooms in Hospital B that revealed less filtration efficacy. These findings are in agreement with Verde et al. (Verde, 2015) and Wu et al. (Wu, 2021) who demonstrated that hospital rooms equipped with HEPA filters showed a significant reduction in the bacterial concentrations. The results we obtained denote that rooms which are equipped with portable HEPA filters; namely SPE rooms in both hospitals have relatively lower relative reduction for TFC compared to NPE rooms. These results are not in agreement with Tan et al. who revealed that hospital rooms equipped with HEPA filtration system could significantly control the presence of airborne fungi (Tan, 2022) .

In this study, there were significate variations of the amount of pollutants within the rooms in each hospital. These variations could be related to certain factors that affected the levels of indoor pollutants, including number of people in the room and cleaning activities. For this study, we recorded the number of people (patients, housekeepers, visitors, and medical team) in each room during air samples' collection. A number of studies measured the levels of airborne microorganisms in intensive care units and suggested that the number of patients in the room can lead to increased levels of airborne counts (Huang, 2013) and (Yu, 2015). Moreover, studies that assessed the concentrations of airborne particulate matter in a neonatal intensive care unit found a strong association between the levels of indoor particles counts and human occupancy (Licina, 2016).

The results of this study also showed that the levels of indoor air contaminant including fine particulate matter, coarse particulate matter, TBC, and TFC could vary significantly based on the filtration system along with the additional placed portable air purifier. Accordingly, hospital A demonstrated a better indoor air quality compared to hospital B in terms of contaminants levels reduction. The newer HVAC system in addition to the central HEPA filter installed in the AHU feeding the targeted rooms in hospital A have significantly decreased the levels of fine and coarse particles and TBC.

5. Conclusions

This study demonstrated that portable air purifiers have a great impact in the reduction of indoor air pollutants in PICUs including fine particulate matters and TBC in particular. Furthermore, ventilation systems equipped with HEPA filters along with portable air purifiers significantly reduce the levels indoor air pollutants of outdoor sources. Moreover, this study showed that newer and well-maintained HVAC systems play a significant role in controlling the levels of airborne pollutants.

Strengths and Limitations: To the best of our knowledge, this is the first study to assess the portable air purifiers' filtration efficacy of patient rooms with different ventilation setups for particulate matter and microbial counts in PICU in Saudi Arabia. In addition, in this study, we took into considerations factors that may disrupt the effect of HEPA filters within the targeted rooms such as number of people and cleaning activities. As for the limitation of this study, we did not consider the effect of temperature and relative humidity and relative pressure on airborne pollutant.

Ethics approval: The study obtained all required approvals from the Institutional Review Board of King Abdullah International Medical Research Center and King Faisal specialist Hospital Research Center.

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