

Comparison between Hospital Single Air Unit and Central Air Unit for Ventilation Performances and Airborne Microbes

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Abstract

Ventilation performance in two units equipped with a single, hanging air conditioner having no filter, and another two units equipped with a central air conditioner with HEPA filter were compared for the air change rate, air velocity profile, and microbe concentration in a 814-bed public hospital from February to May 2006. It was found that microbe concentrations in units using a single air conditioner were about two times higher than those in central air conditioner units. Within the same type of air conditioner, increasing ventilation rate resulted in decreased microbe concentrations.

Keywords: Bioaerosol; Airborne microorganisms; SF₆ tracer gas technique; Air velocity profile; Hospital environment.

INTRODUCTION

Air conditioning systems are well known for contributing to the microorganisms in an air-conditioned room through different mechanisms, especially when sufficient maintenance is not performed (Maus and Umhauer, 1997). The American Society of

Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (Kowalski and Bahnfleth, 1998), normally requires that hospital clean rooms have a series of filters for the air flowing in, such as 25%, 90% and 99.97% efficiency (HEPA) for an operating room, and a central air system. However, many hospitals, especially in developing countries, do not comply with this regulation. A single, hanging air conditioner is much more readily available than a central air conditioning system. Some models of the hanging kind of air conditioner do not have any

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air filter inside, and only a plastic grill and screen as the means of filtration. Filtration can reduce airborne microorganisms, removing as much as 99.9% of all bacteria present in a hospital using 90-95% efficient filters (ASHRAE, 2003). We are very concerned about hospital air quality with systems that have no filter. Therefore, this study was conducted in order to investigate the microbe concentrations along with ventilation performance in terms of the air change rate and air velocity profile in hospital units that are equipped with a single, hanging air conditioner with no filter, and units installed with a HEPA filter in a system. The results of ventilation performance and microbial concentrations were then compared.

METHODS

Air change rate measurement in this study was performed using a tracer gas technique (SF_6), while an air velocity profile was obtained from a hot wire anemometer (GrayWolf, Model AS-201). Four units in a 814-bed tertiary care public hospital were investigated: the new-born intensive care unit (NICU), pediatric intensive care unit (PICU), intensive care unit (ICU), and Burn Unit. The first two units use a 36,000 Btu/hr, 10.55 kW single, hanging air conditioner with no air filter inside, while the latter two use a central air system, equipped with a series of filters, a 25-30% efficiency pre-filter, a 60-65% efficiency medium filter, and a 99.99% HEPA filter. The single air conditioner was cleaned monthly and a study of 4 replicates was conducted soon after the cleaning, and at

the middle and end of the month before the next cleaning round. For the central air units, the filters were already installed for 8 months before this investigation was performed.

The room volume and the layout of NICU is similar to PICU, which are about 364.5 m^3 each ($9 \text{ m} \times 9 \text{ m} \times 4.5 \text{ m}$), whilst the room volume of ICU is approximately 240 m^3 ($6 \text{ m} \times 10 \text{ m} \times 4 \text{ m}$), and that of Burn Unit is 486 m^3 ($9 \text{ m} \times 12 \text{ m} \times 4.5 \text{ m}$). One hundred ppm of SF_6 gas (MESA International Technologies, Inc.) was released in the middle of each room at a rate of 5 L/min for 60 min, and thoroughly mixed by a fan, which was left on for another 15 min. The SF_6 concentration was then measured every 5 min with a MIRAN SapphIRe portable ambient air analyzer (Thermo Electron Corp., Model 205B) for an hour. The concentrations were plotted against measuring time to observe its linearity. The initial concentration (C_0) at time $t = 0$ min and the final concentration (C_t) at time $t = 60$ min were substituted in the equation of:

$$A = \frac{1}{\Delta t} (\ln C_0 - \ln C_t) \quad (1)$$

where, Δt is 1 hour to obtain air change per hour (A). Since air change rate is the ratio of air flow rate (Q) and the room volume (V_r), to achieve air flow rate, V_r was multiplied to the air change per hour as:

$$Q_{\text{dilution}} = A \left(\frac{\text{airchange}}{\text{hour}} \right) \times V_r \left(\frac{\text{L}}{\text{airchange}} \right) \times \frac{\text{hour}}{3600\text{s}} \quad (2)$$

Hence, the ventilation rate in units of L/s/person was obtained by dividing the Q_{dilution}

by the number of people in that room (McDermott, 2001). Each unit was checked for the air change rate once a month for 4 months (February-May 2006). During that time, the average temperature in each unit was in a range of 25-28°C and relative humidity was in a range of 58.8-64.5%. The average number of persons (and ranges) in the NICU, PICU, ICU, and Burn Units during the measurement periods were 11 (9-12), 14 (12-17), 13 (12-14), and 9 (8-9), respectively.

To conduct an air velocity profile, the area of the NICU and PICU was divided into 3 × 3 cells and the middle of each cell at a height of 1 m was assigned as a sampling point, with a total of 9 points (Fig. 1).

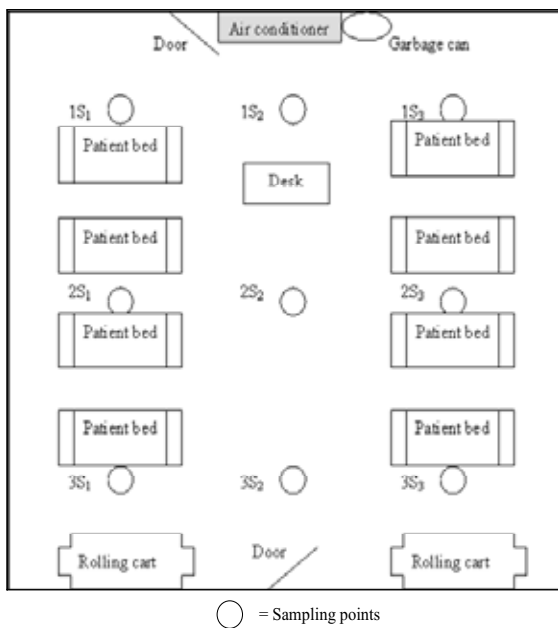


Fig. 1. Room layout and sampling points in the NICU and PICU.

Each point was about 1.2-1.5 m from each other. In the ICU and Burn Units, the room layouts are different, and 14 points were

sampled at a height of 1 m as shown in Figs. 2 and 3, respectively.

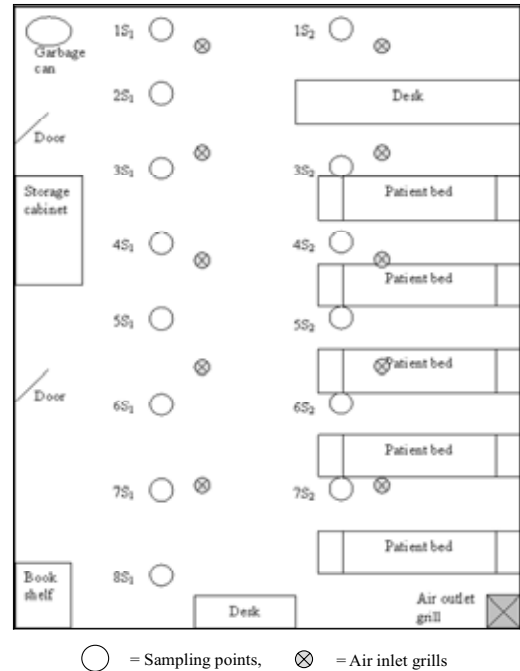


Fig. 2. Room layout and sampling points in the ICU.

The sampling points in the ICU were about 1 m from the air inlet grills and each sampling row (in vertical) was around 2 m apart. In the Burn Unit, the sampling points were about 0.5 m closer to the air grill inlets than those in the ICU. Each sampling point within the vertical row was about 1.5 m apart, but around 2 m from the left and right rows (Fig.3).

At the same time and points of measuring the air velocity, a viable Andersen impactor (N₆) (ThermoElectron, Corp.) equipped with Blood Agar (Oxoid Ltd., England) was used to sample total bacteria, while another one equipped with Sabouraud Dextrose Agar (BBL Becton Dickinson, USA) was used for total fungi, with flow rates of 28.3 L/min for 5 min. During each

run, the instruments were cleaned with 70% ethyl alcohol to prevent any contamination. All plates collected were incubated at 37°C for 24 hours (for bacteria) or 48 hours (for fungi). Only Staphylococcus and Aspergillus were identified by biochemical reaction and by performing slide culture, respectively, as recommended by the American Society for Microbiology and Bailey & Scott's Diagnostic Microbiology (Baron and Finegold, 1990).

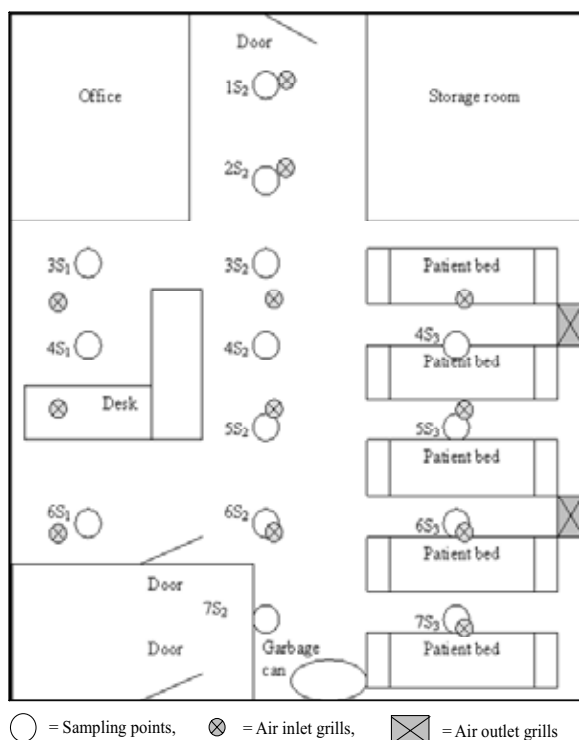


Fig. 3. Room layout and sampling points in the Burn Unit.

RESULTS AND DISCUSSION

The study revealed that non-uniformity of air velocity and microbe concentration occurred in both rooms that were equipped with a single air conditioner compared to those with central air conditioning. The average air changes per hour

Table 1. Ventilation rate (L/s/person) and airborne microbe concentration (cfu/m³).

Unit	Number of persons	Ventilation rate		Total bacteria		Staphylococcus		Total fungi		Aspergillus	
		Ave.(min-max)	Ave.(min-max)	Ave. ± s.d. (min-max)	Ave. ± s.d. (min-max)	Ave. ± s.d. (min-max)	Ave. ± s.d. (min-max)	Ave. ± s.d. (min-max)	Ave. ± s.d. (min-max)	Ave. ± s.d. (min-max)	
NICU	11 (9-12)	21.36 (14.8-25.5)	401.1 ± 221.6 (77.7-805.7)	167.8 ± 89.7 (28.3-339.2)	22.4 ± 14.0 (7.1-56.5)	14.1 ± 8.4 (0-42.4)					
PICU	14 (12-17)	17.92 (15.5-22.2)	492.7 ± 302.9 (42.4-1088.3)	203.0 ± 133.3 (21.2-473.5)	18.6 ± 11.2 (0-56.5)	11.0 ± 8.0 (0-35.3)					
ICU	13 (12-14)	10.87 (9.7-11.8)	248.9 ± 110.8 (84.8-579.5)	154.8 ± 79.3 (21.2-402.8)	9.2 ± 7.2 (0-28.3)	4.8 ± 5.9 (0-21.2)					
Burn Unit	9 (8-9)	37.50 (33.0-41.5)	152.1 ± 70.5 (35.5-381.6)	73.1 ± 44.8 (14.1-190.8)	6.7 ± 6.1 (0-21.2)	3.5 ± 4.5 (0-14.1)					

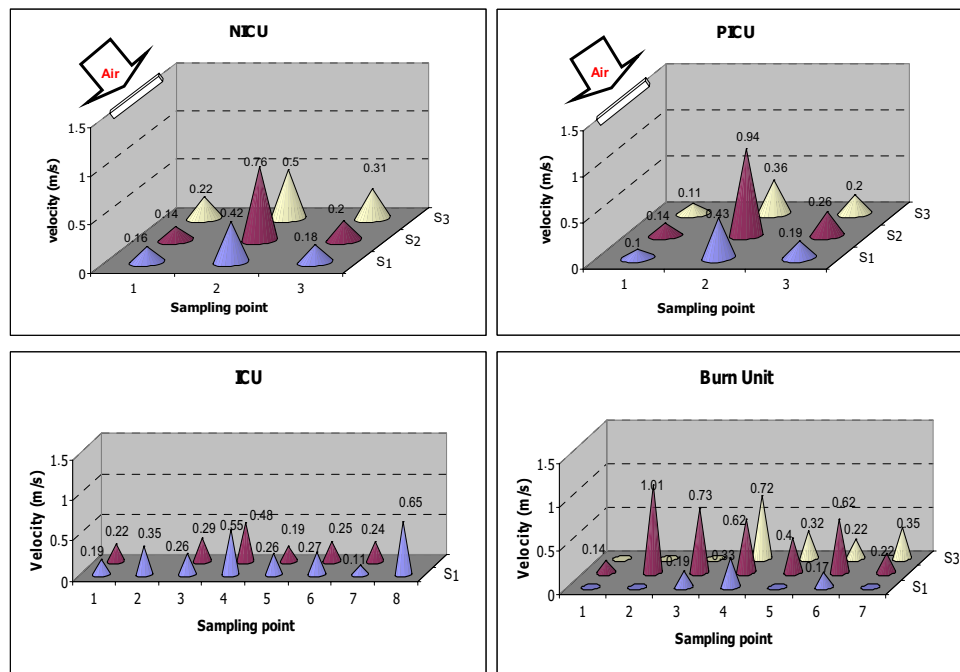


Fig. 4. Average velocity profiles in NICU, PICU, ICU, and Burn Unit.

for the NICU, PICU, ICU, and Burn Unit were in a range of 1.6-2.8, 2.1-3.1, 1.9-2.3, and 2.2-2.8, respectively. The ventilation rates, using the average number of persons in each room, were calculated as 14.8-25.5, 15.5-22.2, 9.7-11.8, and 33.0-41.5 L/s/person, respectively (Table 1). With a single air conditioner, a difference in ventilation rate of 1.2 times higher (between PICU and NICU) resulted in a decreased microbe concentration 1.2-1.3 times with the assumption that both units are identical in room layout and airflow pattern. In the central air system, an increase in ventilation rate of 3.5 times (between ICU and Burn Unit) yielded a decrease in bacteria of 1.6-2.1 times and of fungi 1.4 times.

The air velocity profile is shown in Fig. 4. Differences in air velocity from minimum to maximum velocity was 5-9 fold in the single air system and 6-7 fold in the central air system. In

a single air unit (NICU and PICU), the highest air velocity was in the middle of the room at point 2S₂. The average velocity varied from 0.14 m/s in the periphery area to 0.76 m/s in the center (s.d. = 0.21) in the NICU, and from 0.1 m/s in the periphery to 0.94 m/s in the center (s.d. = 0.26) in the PICU. The central air unit air velocity was high in the middle of the room at points 4S₁ and 4S₂, and also at the end of the room at point 8S₁ for the ICU; but the variation was lower (s.d. = 0.15), from 0.11-0.65 m/s, or about 6-fold difference. For the Burn Unit, the middle points, 4S₂ and 4S₃, were still high, with the highest point at 2S₂, and varied from 0.14-1.01 m/s (s.d. = 0.26) or a 7-fold difference. The sampling locations in the Burn Unit that were closer to the air inlet grills yielded higher air velocities than those in the ICU, especially in the middle row or row S₂.

Table 2. Air velocities (m/s) at the periphery and middle of the room

Unit	Periphery area		Middle area*	
	Average \pm s.d.	Range	Average \pm s.d.	Range
NICU	0.20 \pm 0.12	0.05-0.32	0.56 \pm 0.25	0.26-1.05
PICU	0.16 \pm 0.09	0.06-0.38	0.58 \pm 0.28	0.24-0.98
ICU	0.24 \pm 0.07	0.08-0.43	0.56 \pm 0.11	0.27-0.68
Burn Unit	0.23 \pm 0.14	0.12-0.37	0.63 \pm 0.23	0.27-1.28

The pattern of air velocity profiles in both systems was quite similar; high in the middle and low in the periphery as in Table 2. An ANOVA test was applied to the 4 units for both periphery and middle area and found that air velocities on the periphery of the PICU differed from those in the ICU at a p-value of only 0.04. The Health Technical Memorandum (HTM) by the UK National Health Service Estates recommends the minimum air velocity of 0.38 m/s at the periphery, while a velocity at least 0.2 m/s is required in order to remove the contaminants by the air streams (Chow and Yang, 2003; Hoffman *et al.*, 2002). If compared to the air velocity of 0.2 m/s, the area in a single air system would have a problem over 33-44% of the total area, while that problem would be limited to 21% in a central air system. However, at too-high of an air velocity, such as 0.5 m/s, spores of *A.fumigatus* and *Penicillium* could be released from conidiophores, and *Cladosporium* could be released at 1 m/s (Pasanen *et al.*, 1991). This study experienced high total fungi (7.1 cfu/m³) and *Aspergillus* (5.5 cfu/m³) in the Burn Unit at points 4S₃, although that point had a high air velocity at 0.72 m/s. Since the sampling point was almost right under the air discharge grill, fungi might have been directly

released from the filter packs, since fungi spores, unlike bacteria, could live indefinitely on the air filter (Kowalski and Bahnfleth, 2002).

When comparing microbe concentrations to the velocity profiles, it was found that the points that showed high-flow velocity would yield low microbe concentrations, and vice versa. Therefore, the associations between microbe concentrations and air velocities were performed. Figs. 5 and 6 show ranges from minimum to maximum velocity from 9 sampling points in the single air unit (Fig. 5) and 14 sampling points in the central air unit (Fig. 6). It should be noted that the order of velocity bars in the figures do not comply with the position numbers in Figs. 1-3, but in the order of low to high velocity instead. Strong inversion between those two factors is obvious in NICU and PICU, especially for total bacteria and *Staphylococcus* (Fig. 5). However, in the central air system, especially in the Burn Unit, the pattern was less distinct. Also, correlations were performed and, not surprisingly, a strong relationship was found in the single air units ($r = 0.62-0.92$, p-value < 0.05), while those in the central air unit were weaker ($r = 0.44-0.69$, p-value < 0.05), particularly for total fungi and *Aspergillus* (Fig. 6)

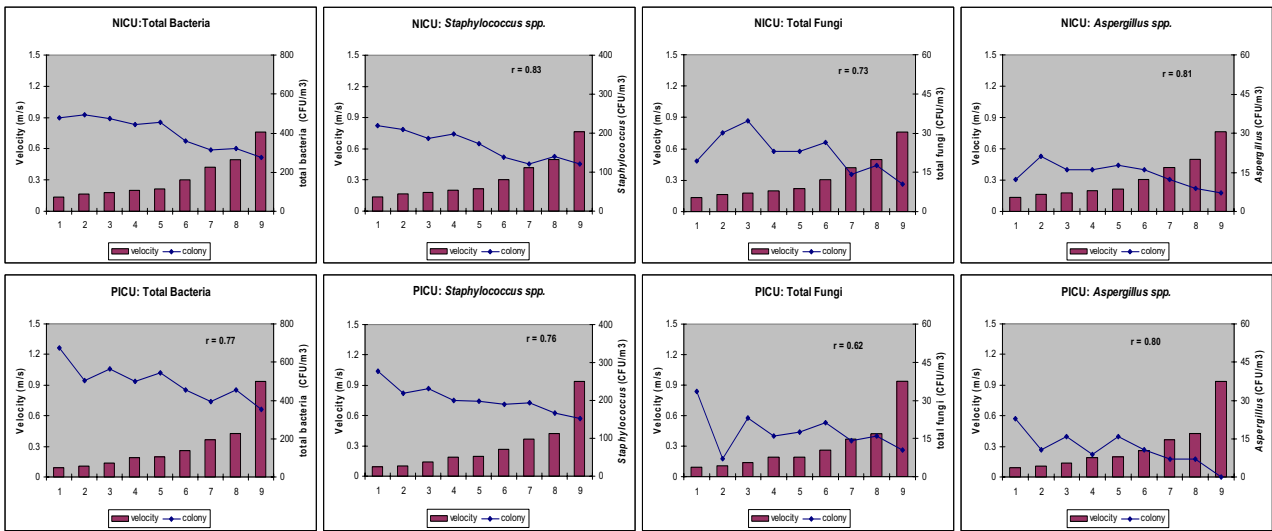


Fig. 5. Association between microbe concentration and air velocity in NICU and PICU.

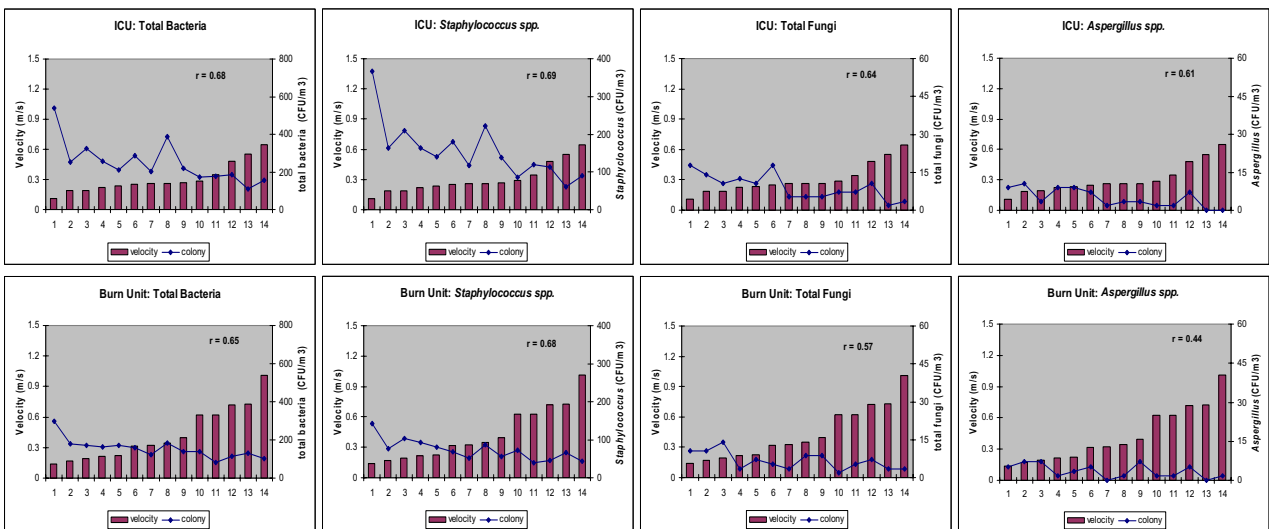


Fig. 6. Association between microbe concentration and air velocity in ICU and Burn Unit.

In comparison of microbe concentrations between a single air unit with no air filter and a central air unit with a HEPA filter (Figs. 5 and 6), it is clearly seen that the amount of total bacteria in a central air unit was about half of that in a single air unit (150-250 cfu/m³ vs. 400-500 cfu/m³), and similar to the amount of total fungi (7-9 cfu/m³ vs. 19-22 cfu/m³) and Aspergillus (4-5 cfu/m³ vs. 11-14 cfu/m³). In

this case, ventilation rate has less advantage than a filtration mechanism. The ventilation rate in the ICU was half the rate in the NICU and PICU, but the microbe concentrations were still lower by a factor of two. If compared between the same systems, then ventilation rate plays a role. When the ventilation rate increased from 10.9 L/s/person in the ICU to 37.5 L/s/person in the Burn Unit, bacteria concentrations were

reduced 1.6 times for total bacteria, 2.1 times for *Staphylococcus spp.*, and 1.4 times for both total fungi and *Aspergillus spp.* Li and Hou (2003) stated that the lowest airborne fungi concentration and the smallest particles were found in the areas with the highest air changes in a two-filter system (> 95% efficiency). However, *Staphylococcus* in the ICU was not obviously lower than that in the NICU. This might be a result of the number of people in that room since during conversation, coughing and sneezing, particle droplets can spread around 100-100,000 particles (Kowalski and Bahnfleth, 1998), thus so spreading *Staphylococcus*.

Bacterial counts were higher than fungal counts in every situation. This was similar to the study of Li and Hou (2003) who did a field survey in hospital clean rooms and noted that this is probably related to human sources, since high particle concentration depended on local human activity, air change rate, and efficiency of filtration. They found high concentration of particles at patient beds much more than that at air inlets. Moreover, bacteria when intercepted by filters would die eventually from dehydration or natural causes (Kowalski and Bahnfleth, 1998). Results from this study showed that filtration can reduce bacteria by about half or more.

CONCLUSION

A single air unit without a filter could provide similar results for ventilation rate or even better than a central air unit in terms of air changes per hour, although the air velocities at

the periphery of rooms were lower than those in a central air system. However, microbe concentrations in a single air unit were double those for a central air system, filtration being the main reason for the difference. An air conditioner with no filter should not be used in a hospital unless a portable filtration unit is added on.

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