

Impact of the air filtration on indoor particle concentration by using combination filters in offices building

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Abstract. Heating ventilation and air conditioning system (HVAC) is very important for offices building and human health. The combining filter method was used to reduce the air pollution indoor such as that particulate matter and gases pollution that affected in health and productivity. Using particle filters in industrial HVAC systems (factories and manufacturing process) does not enough to remove all the indoor pollution. The main objective of this study is to investigate the impact of combination filters for particle and gases removal efficiency. The combining method is by using two filters (particulate filter pre-filter and carbon filter) to reduce particle matter and gases respectively. The purpose of this study is to use minimum efficiency reporting value (MERV filter) rating 13 and activated carbon filter (ACF) to remove indoor air pollution and controlling the air change rate to enhance the air quality and energy saving. It was concluded that the combination filter showed good removal efficiency of particle up to 90.76% and 89.25% for PM₁₀ and PM_{2.5} respectively. The pressure drop across the filters was small compared with the high- efficiency filters. The filtration efficiency of combination filters after three months' was better than efficiency by the new MERV filter alone.

1. Introduction

Air-conditioned office buildings objectives is to provide a thermally satisfactory environment for human comfort and work that would enable better work productivity and less thermal dissatisfaction [1]. Location and design of the fresh air inlet for the HVAC system can be significant to decrease the outdoor particle influence on indoor. Thus, the HVAC system design plays an important role in reducing the concentration of particles indoors [2]. In commercial buildings, the particle matter can affect the health of occupants. HVAC systems are used to decrease indoor particles and to provide extra ventilation and lower particle matter concentration. It is also effective even when outdoor particulate matter concentration is high [3]. Ventilation and filtration system is used to reduce the risk of pollutants infection and diseases transmission, that depends on the nature of contaminated the aerosols and building [4]. There are many studies investigate on how to reduce the particle matter in



the indoor environment. Those studies found that the application of large scales and real places involving the high airflow rate need to be considered [5].

Mixing air filters with outdoor air may reduce the influence particles source of indoor particulate concentration indoor [2]. However, the ratio of fresh outdoor air to recirculation air is very important. More outdoor air may lead to more outdoor particles. In addition, increase outdoor air lead to increasing the energy consumption for air treatment.

The study by Azimi [4], found that filtration of recirculation air may be used to reduce airborne infectious diseases especially in the indoor, However, there is no direct relationship proved between the usage of mechanical filters in buildings and the reduced asthma symptoms even when using specific common devices [6]. High-efficiency particulate air (HEPA) can be used in the combustion particles pollution area and it can provide health benefits by reduction of these particles [7]. However, the high efficiency filter such as HEPA filter not only has high efficiency for particle removal compared to the other filters but also have high air resistant that provided high-pressure drop.

The main objective of this study, to assess the combination filters method for high removal efficiency and low pressure drop.

The initial cost of HVAC system is the first criterion in its system selection. This is a limited approach because it can be costly in the building economic life cycle of the HVAC system operation and maintenance cost and the influence on office workers' health and productivity are not duly considered [1]. In addition, the utilisation of both outdoor and mixing air filters can significantly influence and keep indoor particle concentration levels lower when compared to mixing air filters alone [2]. The study by Chatoutsidou [8], found that mechanical ventilation and filtration may remove outdoor particle more than 50%, in addition, the mass concentration of outdoor PM₁₀ was more than the indoor and the efficient removal was significant outdoor for the particulate matter. During the absence of occupants' activities, the outdoor air is a major source of particle matter and contributed total particles to indoor [9].

Many of researchers have discusses for measured particles in offices building [6], [8], [10]–[13]. Park [14], has found that mechanical filters can be removed up to 50% of particle outdoor exposures.

2. Method

This study was carried out using the environmental control chamber that can simulate a typical office environment. The chamber dimension is 4.8 m length, 4.8 m width and 2.65 m in height. The walls and the ceiling were made of polyurethane insulation board of 10 cm thickness, the design of the joint; the groove and the tongue were made from stainless steel metal (5 cm) and located in the chamber on both sides. The chamber was equipped with HVAC system; a compressor (10 HP), an outdoor condenser and a fan coil unit in the mixing room, which is located on the top of the chamber roof as the shown in Fig 1. The supply air duct located on the roof of the chamber. The main air supply duct links the fan coil unit to the chamber. The main supply duct was distributed in two main branches to provide air through ceiling diffusers (0.4 m x 0.4 m); moreover, there are two holes (0.55 m x 0.45 m) provided on the return air duct suspended on the top of the ceiling connecting the chamber and mixing box. A filter box (0.6 m x 0.3 m) was designed to house the new filters and to ensure good mixing of the air passage and cleaning through the filter before entering the fan coil unit. The outdoor fresh air intake was in the mixing room through the flexible duct, exhaust fan, and damper. The damper was connected by the flexible duct to warrant that sufficient supply of outdoor fresh air compatible to ASHRAE standard 62 [15]. Another damper was also connected to the exhaust fan at the top of the ceiling to control the exhaust air. The air flow through the system was adjusted to 560 CFM (951 m³/h) to achieve a face velocity 0.9 m/s and 0.8 m/s through diffusers 1 and 2 respectively, with air changes rate about 3 h⁻¹ (typical air change rate for an office building) as suggested by ASHRAE standard 62. The air flow rate was measured by using TSI 8371 AccuBalance 802082. The chamber environmental conditions were adjusted between 23 °C to 26 °C and 78% for RH, which is the indoor environmental condition that suggested in Malaysia by the previous studies of [16], [17]. The control

of the air temperature and relative humidity is by using AHU system, through temperature and relative humidity monitoring system.

The chamber case study was conducted by recording the environmental condition for daily in six months and simulating typical work hours from 8:00 am to 5:00 pm with four occupants in the chamber. Combination filter of MERV 13 pre-filter and ACF filter ($0.6 \times 0.3 \times 0.025$) m³ were placed in a filter box before the fan coil unit. The filter box was made from wood and metal, and then installed in mixing room before fan coil unit.

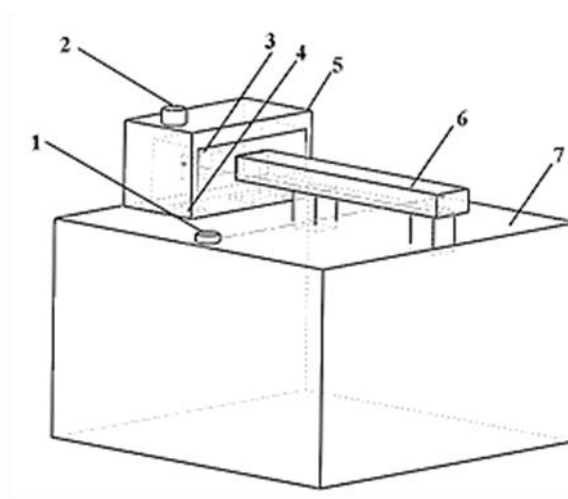


Figure 1 . Chamber schematic

1-Fresh air 2-Mixing room 3-filter box 4-Return air 5-supply duct 6- Chamber 7- Exhaust air

The filter cases ($0.6 \text{ m} \times 0.3 \text{ m}$) were located in the middle of the box face and include two holes of filters thickness of 2.54 cm. The measuring device for particle concentration in the chamber, which measured PM₁₀ and PM_{2.5}, is the TSI® DUSTTRAK Aerosol Monitor 8520 and TSI®TSI DUSTTRAK DRX-8534.

The parameters considered in this study were the contaminant concentration upstream and downstream, with filter and without the filter, air flow rate, pressure drop, humidity, temperature and air velocity. The investigator in the chamber was done to determine the efficiency of the filters and the ventilation system after modification on air handling unit (AHU), by installing box filter and flexible duct to added fresh air, and installing air damper to controlling of exhaust air from the chamber, which the exit of air using exhaust fan.

Airflow rate was controlled with duct cross section and air face velocity through filters. Temperature and relative humidity were measured during the period of the experiment. The pressure difference before and after the filter was measured using the pressure gauge. The scenario of the tests in this assessment was done by new filters, and after three months working and last after six months working. Thus, the analysis of results assessment including used combination filters with occupied and unoccupied, comparing with unused filters. In addition, the assessment included MERV 13 filter alone, compared with used combination filters. However, in this study, the results analysis was divided into two groups.

Particle concentration during occupied and unoccupied zone; was measured by using DustTrak Aerosol device inside the chamber. In this study, mass concentration mg/m³ it has been employed in the study to check the efficiency of the filters. The pollutants removal efficiency of the filters in the duct was calculated using the following equation (1) [18].

$$Eff = \frac{(C_b - C_a)}{C_b} \quad (1)$$

Where: C_b and C_a concentration of pollutants before and after the filter respectively.

3. Results and discussion

3.1. Efficiency of the new filters

The average indoor particle concentration for PM_{10} and $PM_{2.5}$ are listed in table 1 to 4.

Table 1. Particle concentration occupied/unoccupied test new combination filters

Test description	Occupied test		Unoccupied test	
	Average $PM_{2.5}$ concentration mg/m ³	Average PM_{10} concentration mg/m ³	Average $PM_{2.5}$ concentration mg/m ³	Average PM_{10} concentration mg/m ³
without filter	0.025	0.087	0.027	0.065
With new filter	0.0035	0.012	0.003	0.006
Particle different	0.0215	0.075	0.024	0.059
Efficiency	86%	86.2%	89.28%	90.76%

Table 1, shows the average indoor particle concentration inside the chamber. The average indoor particle concentration during occupied period was 0.025 mg/m³ and 0.087 mg/m³ for $PM_{2.5}$ and PM_{10} respectively, the concentration of the installing new filter reduce also the concentration after installing new filters reduce slightly. Thus the filtration efficiency during occupied period for PM_{10} and $PM_{2.5}$ was 86% and 86.2% respectively. The filter specification noted that filter removal efficiency for particle from (1-10) $\mu m > 90\%$. In addition, during unoccupied period, the particle concentration for PM_{10} and $PM_{2.5}$ was 0.065 and 0.027 respectively and filtration efficiency was 90.76% and 89.28% respectively. This result show that the filtration efficiency of $PM_{2.5}$ and PM_{10} for occupied and unoccupied test were not much of different. These results are in agreement with the previous study by Azimi [19], which the median value of MERV 12 and MERV 14 are 66% - 71% respectively.

3.2. Efficiency of filters after three months

The second evaluation of combination filters was done after three months. Table 2 shows the downstream air cleaned during occupied and unoccupied period. Therefore, the air cleaning inside chamber according to the test after three months' work was recorded less than the air cleaning at the new filters; hence the particle removal efficiency by the three-month-old filter was less than the removal efficiency by new filters. This indicates that the efficiency of the filter was decreased because the filter has become dirty. However, the filtration efficiency of PM_{10} and $PM_{2.5}$ was 85.38% and 85.18% with occupied period. Whereas, during unoccupied test the removal efficiency particulate matter was recorded 88.73% and 88% for PM_{10} and $PM_{2.5}$ respectively. Noted that the filtration efficiency for both diameters particles was still not much of difference. This indicates that the filter after three months was working well. However, the difference values between filtration efficiency at new filter and three months old filter was 0.7% to 0.82% for PM_{10} and $PM_{2.5}$ and 2% to 1.28% for PM_{10} and $PM_{2.5}$ during occupied and unoccupied period respectively. Also, the results indicate that human contributed more particle matter during working hours compare with non-working hours conditions. The results show that filtration efficiency of combination filter from zero working days to three months-old, for PM_{10} and $PM_{2.5}$ is noted much of difference.

Table 2. Particle concentration occupied/unoccupied test three months old combination filters

Test description	Occupied test		Unoccupied test	
	Average PM _{2.5} concentration mg/m ³	Average PM ₁₀ concentration mg/m ³	Average PM _{2.5} concentration mg/m ³	Average PM ₁₀ concentration mg/m ³
Without filter	0.027	0.130	0.015	0.071
With 3 months, old filter	0.004	0.019	0.0018	0.008
Particle different	0.023	0.111	0.0132	0.063
Efficiency	85.18%	85.38%	88%	88.73%

3.3. Efficiency of filter after six months

Table 3, shown the particle concentration inside the chamber measured after six months. The average concentration of PM₁₀ and PM_{2.5} during working days was 0.016 mg/m³ and 0.006 mg/m³ respectively. Whereas, the concentration without the filter was recorded high, also during non-working period the average value of PM₁₀ and PM_{2.5} was slightly low 0.007 mg/m³ and 0.006 mg/m³ compared with no filters the concentration were 0.05 mg/m³ and 0.036 mg/m³. Therefore, the particle removal efficiency recorded was 84.60% and 82.35% for removal of PM₁₀ and PM_{2.5} respectively, lower than the filter efficiency with three months-old; the efficiency during unoccupied period was 86% and 83.33% for PM₁₀ and PM_{2.5} respectively

Table 3. Particle concentration occupied/unoccupied test six months old combination filters

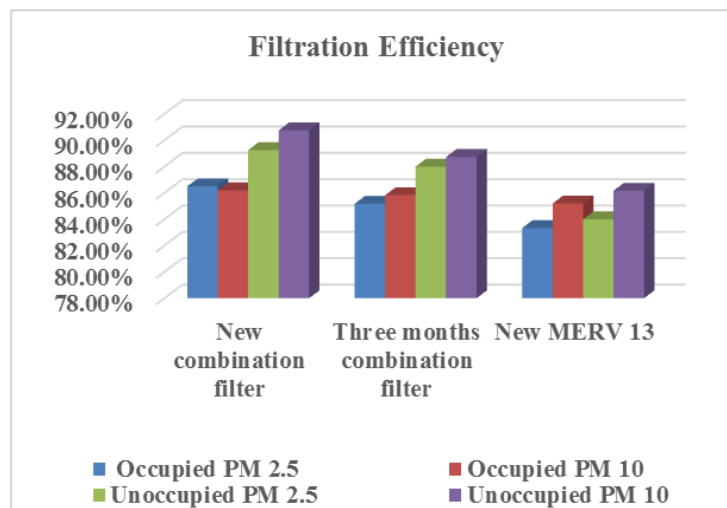
Test description	Occupied test		Unoccupied test	
	Average PM _{2.5} concentration mg/m ³	Average PM ₁₀ concentration mg/m ³	Average PM _{2.5} concentration mg/m ³	Average PM ₁₀ concentration mg/m ³
Without filter	0.034	0.104	0.036	0.05
With 6 months, old filter	0.006	0.016	0.006	0.007
Particle different	0.028	0.088	0.030	0.043
Efficiency	82.35%	84.60%	83.33%	86%

Table 4 shows the particle concentration for occupied and unoccupied period during the test with only MERV 13 filter. The efficiency of the filter during occupied period was recorded 85.20% and 83.33% for PM₁₀ and PM_{2.5} respectively. However, the efficiency during unoccupied period was recorded 86.17% and 84% for PM₁₀ and PM_{2.5}; the results indicated that the filtration efficiency of new single MERV 13 filter was less than the efficiency of combination filter. Further, the filtration efficiency of combination filter after three months worked better than the new single MERV 13 filter. These results were in agreement with the study finding by Azimi [19]. In addition, the study by Michal P. Spilak et al., (2014) found that; when the HEPA filter was used the particle removal efficiency resulted more than the removal efficiency by combination filter. Although, HEPA filter has high efficiency for particle removal efficiency than the filters, but also have high air resistant that provided high-pressure drop.

Table 4. Particle concentration occupied/unoccupied test used MERV 13 filter

Test description	Occupied test		Unoccupied test	
	Average PM _{2.5} concentration mg/m ³	Average PM ₁₀ concentration mg/m ³	Average PM _{2.5} concentration mg/m ³	Average PM ₁₀ concentration mg/m ³
Without filter	0.09	0.115	0.05	0.094
With new filter	0.015	0.017	0.008	0.013
Particle different	0.075	0.098	0.042	0.081
Efficiency	83.33%	85.20%	84.00%	86.17%

Figure 2 shows the different filtration efficiency between combination filters and new MERV 13 filter. The diagram shows the efficiency after three months working better than new MERV 13 filter occupied and unoccupied period. The advantage of combination filter method, resulting from compiling two filters (MERV filter and ACF filter). ACF has a high capacity to absorb gases pollutants and small particle because of its advanced and high porosity and large surface area.

**Figure 2.** Different filtration efficiency combination filter and single MERV 13 filter

4. Conclusion

The indoor air quality can be improved by using a simplified method with the combination filter of MERV 13 filter and ACF. MERV filter cannot be reliable for removal of ultra-fine particle and PM_{2.5} when each of them is applying to HVAC system as a single filter. Thus, to improve indoor air quality and efficient particle removal the combined filter was installed. The filtration efficiency for combined filter was 86.20% to 84.60% for PM₁₀ and for PM_{2.5} was 86% to 82.35%, during occupied period. While the filtration efficiency for unoccupied periods recorded 90.76% to 86% for PM₁₀, and 89.28% to 83.30% for PM_{2.5}. However, the filtration efficiency of the three-month-old filter was recorded less than the new filters by 0.82%, 0.82%, 1.28% and 2.03% for PM₁₀ and PM_{2.5} occupied and unoccupied periods respectively. However, the big value different was recorded after six months due the filter has become dirty, but the efficiency as in this range is acceptable because the decreased of efficiency was a little. Furthermore, the result showed that the efficiency after three months installation is better than new single MERV 13 filter during occupied and unoccupied period.

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