



## PROGRESSES OF FILTRATION FOR REMOVING PARTICLES AND GASES POLLUTANTS OF INDOOR; LIMITATIONS AND FUTURE DIRECTION; REVIEW ARTICLE

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### ABSTRACT

Poor indoor air quality (IAQ) caused many problems for human; those problems can be classified into health problems which reduce the efficiency and output especially in workplaces. For example, health problems, like asthma and pulmonary inflammation, lead to low attendance level which affect the output. The main purpose of this paper is to review scientific literature on air filtration system effectiveness in improving indoor Air Quality (IAQ). These studies include topics such as: chemical, biological, gases, particle and bacteria. Indoor air pollution emitted by occupants, equipment, and furniture and building are also included. Portable air cleaning, filtration system and ventilation methods application in HVAC system, recent research relating filtration type and ventilation used in laboratory environments and the large space applications are also reviewed. The scope of studies investigated includes appropriate air filter technology and the compatibility between cost, the health problems, energy consumption and its relationship with filter pressure drop. Future studies are suggested to focus on cleaners and air filtration, ventilation and energy consumption in office buildings.

**Keywords:** particle and gases removal, filtration, air cleaning technologies.

### INTRODUCTION

The importance of indoor air quality (IAQ) to human health is to contribute to the better work outcome and high indoor air quality. Using the technology of air-cleaning to increase thermal comfort, more effective when it is targeting energy saving and reducing ventilation rate. Many of these technologies are developed and used, but without assessment (Zhang, Mo *et al.* 2011). The quality of the indoor environment has a direct impact on the occupants, users productivity, referred to the fact that more than 80% of people spend their time indoors (Graudenz, Oliveira *et al.* 2005).

In commercial buildings, the particles have a major influence that can affect health of occupants. Heating, Ventilation and Air Conditioning (HVAC) are used to lower outdoor and indoor particles whereby as an alternative to provide additional ventilation and lower particle matter (PM) concentration. It is also efficient even when outdoor (PM) concentration are high (Zaatari, Novoselac *et al.* 2014). However, the energy and environmental sustainability are a major global trend for the 21st century (Zheng, Jing *et al.* 2009). Also, outdoor air and environment are challenged by global warming and high pollution rates, especially in big cities and towns. Contaminations such of gases and particles affect the IAQ. The service life of gaseous filters in real built environment with low concentration of VOC and humid air was estimated in order to improve a methodology of Gas-phase filter breakthrough models.

HVAC systems consist of components such as ducts, filters, cooling coils and fans, which can work as reactive sink for ozone and have various participate to

remove ozone. As an example, HVAC ducts possibility is resulted in removing 4 to 36% at steady state (Zhao 2007). As the control of indoor air quality is very important to human health, many of the previous studies were geared to address this issue. Improving indoor air quality can be done by controlling the concentration level of indoor and outdoor contaminations.

This paper reviews research on particle pollutant removal, gases and indoor air quality control for human health. However, this paper will try to fill the gap through using multi filter method to increase indoor air quality and reduce resistance of air flow pressure in the same time. In addition, this study will try to fill the gap also through increasing indoor air quality and reducing energy consumption at the same time.

### Outdoor air pollution

High level of outdoor contaminant with local polluted source (vehicle exhaust and contaminant produce from building activities) resulted poor outdoor air, which make buildings' sector experts to suggest reduce intake of outdoor air ventilation rates. Otherwise, this consideration should be based on the possibility influence of poor outdoor air quality (AbuHafeetha 2009). Also Malaysia has become an industrial country. Factories and manufacturing process consume high energy and produce emitted vapors and production waste. This affects the environment and the increase pollution level. This pollution may include the nitrogen dioxide, carbon dioxide and sulphur dioxide (Liman 2011).



### Ambient air pollution

There are ambient air pollutions in the outdoor air in the form of multiple solid, liquid and gases. They are produced mainly from fuel combustion, gases and particles issued by the chemical and biological materials used in pesticides, as well as sources of chemical reactions, dusts and bacteria (Ncube and Riffat 2012). Indoor particle pollutant can be separated from indoor pollution sources and outdoor pollution source, the different of pollution sources of particle pollutant effect on absorptions and composition of indoor particle pollutants. As an example, smoking and cooking constitutes about 80% of indoor pollution source of residential sector (See and Balasubramanian 2006).

### Particle pollution

Particulate matter (PM) has various definitions, "aerodynamic diameter" is the main principle to classify the ability of transference in the atmosphere or inhaling through a respiratory organism. Environmental Protection Agency (EPA) grouping particles of two sizes based on their predicted penetration capacity for the lungs as:

- coarse particulate matter (PM<sub>10</sub>) with an aerodynamic diameter of 10 µm or
- fine particulate matter (PM<sub>2.5</sub>) with an aerodynamic diameter of 2.5 µm (Esworthy 2013).

Also the particles generated in indoor are from sources related to activity in the area such as: in office space through printers, photocopiers and computers and through cooking from cafeteria (Wallace, Wang *et al.* 2008). Outdoor particles can enter the residential buildings through windows or windows frames or through cracks (Lai, Fung *et al.* 2012). Study by (Spilak, Frederiksen *et al.* 2014) show that, human activities were more important than the individual of the dwelling. However, to reduce the average concentration values to one sixth removing the effect of peaks caused by human activities. Thus the study indicates that the average particle number value is not related for ultra-fine particles (UFP) coverage, due to the different event and concentration level of UFP and indoor source.

PM<sub>2.5</sub> enclosing organic carbon, that participates in promulgation and prevalence of bacteria. Thus, PM<sub>2.5</sub> put occupants' health at risk directly or indirectly, also bank dust on hot surfaces help in chemical release when warm-up (Yu, Hu *et al.* 2009). In many studies involving PM<sub>2.5</sub> or PM<sub>10</sub> with aerodynamic diameter smaller than 2.5 mm or 10 mm, and ultra-fine particle (UFP) 0.1 µm or less, were proved to have potential serious impact on health. To reduce PM of indoor level, particle filtration units called air cleansers were used (Spilak, Frederiksen *et al.* 2014).

### Chemical pollutants

The term chemical pollutants refer to gases (CO<sub>2</sub>, NO<sub>2</sub> and VOCs) which generated from building like furniture, wall and floor covering, office equipment and cleaning and consumer products (AbuHafeetha 2009).

### Biological pollutants

Bacteria, viruses, mold (fungi) and dust mite allergen known as biological pollutants, these pollutants generated from water pond or carried inside the building through infiltration. Biological pollutants lead to asthma and allergy symptoms for building users (AbuHafeetha 2009).

### Indoor air pollution sources

Carbon monoxide, particulate matter, cigarette smoke, cooking, volatile organic components (VOC) emission from building materials and finishing and furniture are sources of indoor pollution, in addition to outdoor air through natural and mechanical ventilation and pollution sources from air treatment devices (Bekö, Clausen *et al.* 2008). Table-1. shows the indoor pollutants and sources.

**Table-1.** Indoor pollutants and sources.

Pollutants	Sources
Radon and radioactive daughters ( <sup>222</sup> Rn)	Soil, ground water, building materials
Nitrogen oxides (NO <sub>x</sub> )	Combustion
Volatile organic compounds (VOC) including (HCHO)	Building materials, carpets, solvents, paints, personal care products, house cleaning products, room fresheners, pesticides, mothball, Humans
Carbon monoxide (CO <sub>2</sub> )	Combustion
Ozone (O <sub>3</sub> )	Outdoor air, photo copying, Machines, electrostatic air cleaners
Sulfur dioxide (SO <sub>2</sub> )	Combustion
Particle Matter (PM)	Combustion
Asbestos	Building material, hair drier
Bioaerosols	Air conditioners, cold water spray humidity

"First principles of meteorology and air pollution" (Lazaridis 2011).

### Filtration

Filtration is one of many methods that used to reduce pollution in indoor. Filtration is used to reduce the effects of pollution from particles with all sizes, emissions of all gases and bacteria. There are many types of filtration such as single filtration, multi filtration,



absorption and photo catalysis. The literature review in this study address these mentioned types. However, the basic mission of filtration is to remove particle from air using filter media that works to purify air from different particles sizes. Some of the studies focused on particle removal efficiency, but the particulate matter studied were quite different, ranging from  $10\mu\text{m}$  to very small particles. These studies report positive effect with regard to particle removal (higher removal efficiencies for larger particles), but sometimes not as high as the manufacturers' data indicate. Gases removal includes VOC, was investigated in many studies, with results ranging from zero removal (no activated carbon) to some removal (with activated carbon) (e.g., Bekö *et al.*, 2008).

### Air particulate indoor

There are various different effective techniques which used to take away airborne pollution such as: filtration, activated carbon, ionization, and photo catalytic oxidation (Kim, Han *et al.* 2012). The outdoor air is one of main source of indoor air pollution through open windows, and air volume of mutual and windows open a significant impact in the reduction of exposure to fine particles (Spilak, Karottki *et al.* 2014).

The results of previous study were not useful to real application because the tests were under condition of high pollution concentration and low air flow rate (MOSTOF 2010). Charged particles give the filtration efficiency higher than non-charged particles. However in the particle size below  $2 \times 10^{-3} \mu\text{m}$  increases the spread of particles. Besides, for charged particles, the penetration was suppressed. The investigation showed that in case of particle size below  $0.1\mu\text{m}$ , the results did not show any effect of humidity on the filtration efficiency that is in charged state (Kim, Bao *et al.* 2006).

The Fiber Bundle Electret Filter (FBF) is designed to be helpful for fine dust. Specifically, the electrical charged components of FBF was maintained constantly at one level through the filter. In the large volume HVAC system the use of FBF filters is appropriate for removing particles. The weaknesses of FBF is unsteady efficiency for large particles size and the increase penetration with the time (Li and Jo 2010). To decrease  $\text{PM}_{2.5}$  levels filtration particle unit should be used (Spilak, Karottki *et al.* 2014).

According to (Azimi and Stephens 2013), to reduce airborne communicable diseases especially in the indoor, filtration air recirculation may be used. There is no direct relationship proved between the used mechanical filters buildings and the reduced asthma symptoms even when using specific common devices (Xu, Raja *et al.* 2010). On a certain basis of assumptions and size of infectious particles, the Wells-Riley equation was accurate for particulate removal through recycle of air filters and so to ASHRAE standard about Minimum Efficiency Reporting Value (MERV) products (Azimi and Stephens 2013). When using whole house method with high efficiency filter it led to increase the proposition of

efficiency of particles removal. Furthermore, the upstream-downstream method revealed another finding that the higher rated filters performance was unsuitable to the largest particles. However, in case of using whole house method with small particles the result was opposite. Therefore, the whole house method can provides a complete draw of particle reaction in the real environment (Stephens and Siegel 2012). Another study showed new outcome when using electrostatic fibrous filter where removal efficiency of small particles was higher compared to the large particles (Ardkapan, Johnson *et al.* 2014).

In general, the used Minimum Efficiency Reporting Value (MERV 7-11) low efficiency or (MERV 13-16) high efficiency filters, respectively are too costly compared to recirculation HVAC filtration, which will reduce the risk from natural ventilation (Azimi and Stephens 2013). For particle size above  $0.1\mu\text{m}$  the filter based air cleaners and Electrostatic Precipitator (ESP) are better than a negative Ion Generator (IG) at selected settings (Mølgaard, Koivisto *et al.* 2014). Effectiveness of particle removal using ion generator is lower compared to using HEPA filter and ESP. The measured range of particle diameters was  $4.61 \times 10^{-3}$ – $157 \times 10^{-3} \mu\text{m}$ , and three out of the five ion generators acted as steady-state net particle generators in nearly the entire measured range, and two ion generators in the range of approximately  $10 \times 10^{-3}$  to  $39 \times 10^{-3}$  to  $55 \times 10^{-3} \mu\text{m}$  (Waring, Siegel *et al.* 2008).

ESP, HEPA 1 and HEPA 2 filters produce clean air delivery rate (CADR) of  $284 \text{ m}^3/\text{h}$ ,  $188 \text{ m}^3/\text{h}$ ,  $284 \text{ m}^3/\text{h}$  respectively, while the ion generators CADR is  $41 \text{ m}^3/\text{h}$  and  $35 \text{ m}^3/\text{h}$  that in measured particles diameter range of  $12.6 \times 10^{-3}$  to  $514 \times 10^{-3} \mu\text{m}$  (Waring, Siegel *et al.* 2008). When using IG (a negative ion generator with no fan or filters) in the case of small particle size it is noticed that the CADR high. This indicate that it significantly depends on the particle size. There is similarity between the information provided by the manufactures and the results obtained from studies on CADR when using air cleaners (Mølgaard, Koivisto *et al.* 2014).

The Activated Carbon Filter (ACF) felt showed high efficiency 72% comparable to high efficiency filters, for particles  $0.25\mu\text{m}$  and more than 60% for fractional particles. Woven/knitted ACF was less efficient than ACF felt because internal design of fiber/area and paths between pores. However by improving woven/knitted to porous structure enhanced of the filtration efficiency and may be applicable to ACF felt as well. These filters were designed for VOC adsorption not for particles filtration. (Lorimier 2008). It was mentioned that the ACF/GF prototype nonwoven were more efficient than the ACF felt with an average 84%.

At submicron particle removal, the electrostatic precipitator efficiency is higher compared to conventional filters. In order to enhance the Electrostatic Precipitation Filters (EAC) to similar to High Efficiency Particulate Air (HEPA) filter in the total efficiency to remove submicron particle, pre-Filter (PF) must be added. This involve the



use of electrostatic precipitator under high recirculation air rate to decrease dangerous submicron particle indoor and used efficient strategy energy (Zuraimi and Tham 2009).

Ion generators emitting to ozone can produced secondary organic aerosol (SOA) after reacting with terpenes in the ultrafine and fine size ranges. In addition, the use ions generator to remove particles will increase the quantity of ozone emission inside building, and the ability of generating aldehyde will happen as secondary result (Waring, Siegel *et al.* 2008).

The condition of the particle concentration and particle sizes including ultrafine particles enhances the filter efficiency, ranging from 45% to 80% (Ardkapan, Johnson *et al.* 2014). Increasing the number of the dendrites formed on the fiber can increase the exposure, is help capture particles and then improve filter efficiency. When at high levels of exposure, the efficiency of the electrostatic fibrous filter improved (Ardkapan, Johnson *et al.* 2014).

Installation of air cleaning/ventilating unit (HEPAiRx) with HEPA filter can reduce particles and gases concentration. As a result it worked to control temperature and energy consumption. An experimental conducted, revealed that during the HEPAiRx operation, the enhancement in PM10 concentrate was 72%, the reduction percentage in VOC was 59%, CO concentration was 30% and CO<sub>2</sub> concentration was 19%. With regard to the health indicators, an enhancement appeared in Exhaled Breath Condensate (EBC) nitrate concentrations, acidic and basic level (pH), and Peak Expiratory Flow rates (PEF) based on the HEPAiRx (Xu, Raja *et al.* 2010). Moreover outdoor air exchange rate was considered as a significant factor, it may help to reduce the concentration of UFP level, but infiltration of ambient air can contribute a major source of particles in indoor air. In addition to using particle filtration unit as an effective way to reduce the indoor ultra fine particles, opening window by occupants classified as another effective solution too (Spilak, Frederiksen *et al.* 2014).

### Gases removal

Using HVAC filter in residential buildings for ozone removal, found that significant variation in ozone removal efficiency compared where used in commercial buildings (Zhao 2007). Ozone removal using combination filter removed more ozone from the air than the conventional fiberglass filter (F7), and partial efficiency depending on the carbon content (Bekö, Fadeyi *et al.* 2009).

During the time of elimination of ozone from HVAC filters, low ozone exposure regenerated partially or fully. Factors that limit of the efficiency of removal ozone in steady-state on HVAC filters are the spread process internal to particles (Zhao 2007).

In places where the high removal efficiency is required the medium combination filter (200 g/m<sup>2</sup> of carbon) or, better, the heavy combination filter (400 g/m<sup>2</sup> of carbon) should be considered. Relationships between

ozone removal efficiency and carbonyls generation on filter showed a positive correlation which indicated that a positive relationship between ozone removal efficiency and the amount of organic carbon on filters, and positive correlation among organic carbon filters and carbonyls generation (Lin and Chen 2014).

Light fiber glass filter with 100 g/m<sup>2</sup> of carbon afford air quality with the same results by unused filters, or using filters containing four times and more of carbon. In places where the high removal efficiency is required, the light combinations filter is one of the best options in filtration strategy. But we should be aware of the filter contamination. Additional fan is required to counter the pressure drop, however ozone removal from the air that passes through them have limited capacity (Bekö, Fadeyi *et al.* 2009).

Surface areas of dusts on filter showed no relationship with ozone removal efficiency or with carbonyls generation. Thus, the largest impact on ozone removal efficiency and carbonyls generation may be from chemical components to surface area of dusts on filter (Lin and Chen 2014). The use of activated carbon filters (ACF) which is the mostly used in air cleaners, which characterized with adsorption in removing gas-phase pollutions because of ease impenetrable and of its high adsorption capacity of gas-phase pollution (Bastani, Lee *et al.* 2010, Kim, Han *et al.* 2012). The ACF technology gives good results in removable of VOCs mixture in indoor. ACF made of cloth has a long adsorption life to remove VOCs in indoor with periodic regeneration can be used. Removal efficiency for VOCs through recirculation unheated outdoor air was 50% - 60% and energy consumption, also effective (Sidheswaran, Destailats *et al.* 2012). Multi system (activated carbon and HEPA filter) shows high efficiency VOC family removal with input indoor air and input without door air. During the low concentration of aldehyde in outdoor air mixture to indoor air, considered desorbed from the filter (Gallego, Roca *et al.* 2013). Result of mass balance model on a mixture of AFC air cleaning and 50% decreasing ventilation resolved reduction of indoor concentration of VOCs 60- 80% and reduced formaldehyde concentration by 12%-40%. In terms of the energy modeling results showed a reduction in the energy consumption for heating and cooling by 35% to almost 50% (Sidheswaran, Destailats *et al.* 2012).

Air relative humidity with over 80% ratio have found to decrease effect of activated filter adsorption, otherwise, 50% proportion have no big influence (Gallego, Roca *et al.* 2013).

Granular Activated Carbon (GAC) showed high efficiency of toluene removal compared with other two filters. Performance of the filter decreased saturating the GAC or when replacing part of the filter alumina. The coconut shell-based GAC showed better performance compared to other GAC types because of its small mean pores size and adoption of the coal (Bastani, Lee *et al.* 2010). In isotherm test, the GAC adsorption filter removed formaldehyde gases effectively (Shin and Song 2011).





Formaldehyde and toluene from outdoor air concentration percentage are 25% through botanical air filtration, similar to 5% of outdoor air and 20% of air with filtration system. In the first four days the filter system resulted higher removal efficiency for formaldehyde which was 90% and 30% for toluene. Botanical filter tested for a period of 300 days proved effective and removal efficiency in the similar level at the end of test. Experiments in an office using botanical air filtration resulted decrease in temperature of 0.5 °C and increase of 17.7% RH (Wang and Zhang 2011).

The silver Nano-particles attached onto the surface of GAC (Ag-GAC) formaldehyde removed 2.4 column times higher than that experimental in the GAC column at RT of 0.5s; this indicates a significant improvement in the removal of formaldehyde and therefore more studies were needed (Shin and Song 2011).

The tea tree oil can be used for decontamination and disinfection of furniture that is difficult to clean manually, to substitute for steam. Compared with vapour using hydrogen peroxide found that the former used simple equipment and processes. Decontamination using tea tree oil was studied in hot and humid tropical climates, such as in Malaysian environment, the grow of fungi inside buildings raises concern (Yau, Phuah *et al.* 2013).

In an experimental of Kujundzic (2012) outdoor air is one of the bacteria sources in bio aerosol. Recent studies confirmed the bacteria clone in indoor building presence in a pool of water. Bacteria come from indoor through aerosol concentration are less than the existing culturable in indoor therapy pool. In the first stage, the effectiveness of HUVAF (HEPA filter - ultraviolet UV air filters) based on the level of total bacteria concentrations was 12% and based on culturable bacteria concentrations was 69%. While in the second period based on total culturable bacteria concentration the effectiveness higher up with 76% and 80% compared to the first stage. To optimize the productively of air filter operation in realistic environments, cost of energy and replacing filter media and UV lamps need to be assessed. Under standard conditions these filtration devices were able to reduce 60% of the aerosol bacteria. Furthermore, the use of new hybrid air filter generation, can reduce bio aerosol concentrations.

There are many factors that indicate the effectiveness of task ambient air conditioning system in removing the pollutants from workplace environment. One of these factors are level of CO<sub>2</sub> and benzene concentration, is lower than the other zones as it better indication (Zheng, Jing *et al.* 2009).

### Volatile organic components

Volatile organic compounds (VOCs) are odorous and toxic that released from industrial point sources (printing and coating facilities, chemical industries, waste and wastewater treatment), under sunlight they react with nitrogen oxides to form ozone and photochemical smog (Lin, Lee *et al.* 2011).

### CONCLUSIONS

Based on the review, many previous studies conducted the reduction the cost of HVAC system, avoiding health problems caused by the pollution, decreasing energy consumption and filter pressure drop. The main finding of these studies that some studies have achieved positive level of contaminant removal from indoor air, while some studies showed some negative effects and unwanted emissions. In addition, the review focuses on health procedure of indoor occupants' in places, as well as in different activities. Variant methods were used to achieve the study objectives by incorporate single filter and using multi filter.

In studies that were studied by the researcher, it can be notice that those who were used a single filter, focused only on removing the particle and mostly did not focus on eliminating gas pollution. While those who was used a multi filter focused on removing both particle and gas pollution. In addition, pressure drop and energy consumption were not be under consideration on these studies. Thus, from this study, we find that air filters installation in HVAC system is very important for pollutants removal because these pollutants have direct effect on human health, causing many of the diseases and negative effects for work and productivity.

The methods that used for improving indoor environments and control for pollutants, such as mechanical filter or adsorption filter are requiring identified first the particles size and pollutant concentration, and selection of high efficiency filter type. However, many of those studies that were applied for laboratory cases found that the application of large scales and real places involving the type of large airflow rate need to be considered. The major purpose of using air filter in HVAC system is that, the filters work on pressure drop, which involve energy consumption. To achieve objective of this paper (IAQ and conserve energy), suitable high efficiency filters and low-pressure drop need to be involved in the HVAC system.

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