Effect of Mechanical Ventilation System(s) to Indoor Chemistry Products in Air Conditioned Buildings: Quest for Tropical Research

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SUMMARY

The potential for reactions among indoor pollutants to generate reactive and highly irritating products is a reason to maintain adequate ventilation rates and clean ventilation filters. Terpenoid (from recirculated air, a scenario common in the tropics) captured by ventilation filters can react relatively quickly with ozone which may lead to downstream air supply that contain oxidized terpenoid and this may be perceived to be less acceptable than outdoor air. The chemical composition (water solubility and chemical reactivity) of these particles strongly governs their toxicity. The composition determines either how the respiratory tract reacts or how the body responds. There are few studies examining the impact of ventilation rate and ventilation filters on indoor chemistry. Studies documenting the effect of filters, ventilation and recirculation rate on ozone initiated chemistry in buildings utilizing recirculation of conditioned air are lacking. Thus the need to stimulate research in this area to better understand the effect, recirculation of conditioned air phenomenon could have on indoor air quality serves as the motive for the quest for tropical research. The paper demonstrates that reaction between reactive gases to generate highly irritating products may even be more important in mechanical ventilation system that utilizes recirculation of conditioned air.

Key words –: Filters; ventilation rate; recirculation rate; ozone initiated chemistry; oxidized terpenoid; secondary organic aerosols (SOAs).

INTRODUCTION

In various parts of the world, it has been documented that morbidity and mortality rates have continued to be on the larger scale due to the poor indoor air human beings are constantly being exposed to [1][2][3]. This gives indication that air we breathe in the indoor environment must be given due and consistent attention. In order to avoid outdoor environmental hazards and discomfort, human beings, whether consciously or unconsciously, do spend 90% of their time in this indoor environment (e.g. offices, homes, factories, buses, aircrafts etc) where chemical reactions of indoor gases do take place whether at the gas phase or on the interior surfaces (surface chemistry). Indoor chemistry is being recently recognized as a phenomenon important to IAQ perception, irritation, and health [4]. To ensure clean indoor air within buildings mechanical system(s) must expel stale air and replenish it with clean, "fresh" outdoor air. However, simple as this may seem, it is not always the case. If they are poorly designed, operated, or maintained, however, ventilation systems can contribute to highly irritating products resulting from indoor chemistry. In the tropics many buildings utilize high recirculation of conditioned air to minimize the energy required to remove the high humidity of outdoor air and media filters are the most commonly used filtration method for the removal of particles from outdoors and recirculated air. If these filters are not properly maintain they may be an important to issue to indoor air quality perception, irritation and health as a result of everyday occupant exposure. The presence of a used filter in a ventilation system can have an adverse impact on perceived air quality, SBS symptoms, and performance of office work [5]. In addition to removing particulate contaminants, they accumulate a particle layer that can react with ozone. Ozone particle cake reactions serve as a sink for ozone and a source of secondary carbonyls [6]. Of special note is oxidized terpenoid that could be formed due to reaction between recirculated air containing terpenoids and ozone captured on the filters to form oxidized terpenoids.

MOTIVATION OF THE STUDY

Building occupants may be chronically exposed to ozone-initiated chemistry oxidation products if appropriate measures are not taken. The toxicity potential of indoor air and particularly those where ozone-terpenes reaction have occurred could lead to several adverse health effects associated with both respiratory and cardiovascular health effect including mortality and morbidity [4][7][8]. It appears that from limiting ozone concentration and certain reactive volatile organic compounds (VOCs), maintaining clean filters, adequate ventilation rate, and recirculation air change rate under recirculation of conditioned air scenario are very important. The role of recirculation has been under estimated as compared to non recirculation scenario (where all studies have focused on), recirculated air may contain terpenoids which can sorb onto the surface of particles captured on ventilation filters. It can react relatively quickly with ozone to produce oxidize terpenoids which have great influence on perception and acceptance of indoor air [9]. Ventilation rate and recirculation air change rate could also influence the production of SOAs from ozone initiated chemistry and also its particle size distribution. The particle size distribution determines where deposition occurs in respiratory tract. The chemical composition of these particles (water solubility and chemical reactivity) strongly governs its toxicity. The composition determines either how the respiratory tracts react and of how the body respond. Surprisingly, despite the importance of recirculation of conditioned air scenario (commonly use in air- conditioned buildings in tropics) to indoor air which building occupants are exposed to everyday, there are little or on effect of filters, ventilation, recirculation on ozone initiated chemistry in air conditioned buildings. This review demonstrates that reaction between reactive gases to generate highly irritating products may even be more important in mechanical ventilation system that utilizes recirculation of conditioned air.

PARAMETERS AFFECTING OZONE INITIATED CHEMISTRY

The review focus only on ventilation filters and air change rate (ACH) while others may include ventilation ducts, building materials, relative humidity and temperature etc.

Ventilation Filters

Collected particles in clean filters if not removed from air stream, are the source of indoor air pollution [10][11][12][5]. Apart from ventilation filters negative impact on perceived air quality, the indoor air pollution from used filters could lead to other perception and even SBS symptoms after longer exposure [13]. In a field study by Wyon et al., (2000), significant improvement in self- estimated productivity of workers was observed when new filter were used as compared to used filter. Wargocki et al., (2004) did a well controlled field intervention experiment in a call-centre providing a telephone directly service. Their results agreed with earlier studied by Wyon et al., (2000) (uncontrolled field experiment). They reported significant improvement in some SBS symptoms and environmental perceptions with use of new filter. Used ventilation filters could also contribute to indoor chemistry to produce noxious compound [5].

Beko et al, 2006 studied contribution of sensory pollutant by oxidation process of ozone initiated chemistry from used filters. They observed that organic compounds that react with O_3 in the surface of filter cake are transform to more highly oxidized species which degrade the quality of perceived air quality as judged in the subjective evaluation.

Mysen et al. (2006) studied emission from different types of used ventilation bag filter and their impact on perceived air quality. New filter banks of cityflo filter and F7 filters were put into two similar ventilation systems with continous air flow (24hours per day). They found that the used F7- filter deteriorate the air quality significantly compared to new/no filters. The used F-7 filter deteriorated the air quality significantly compared to the similarly used cityflo-filters.

Hyttinen et al., (2006) did a study on removal of ozone by clean, dusty, and sooty supply air filters. The removal of ozone (O_3) on supply air filters was studied. Especially, the effects of dust load, diesel soot, relative humidity (RH), and exposure time on the removal of O_3 were investigated. Some loss of O_3 was observed in all the filters, except in an unused G3 pre-filter made of polyester. Dust load and quality influenced the reduction of O_3; especially, diesel soot removed O_3 effectively. Increasing the RH resulted in a larger O_3 removal. The removal of O_3 was highest in the beginning of the test, but it declined within 2 h reaching almost a steady state as the exposure continued. However, the sooty filters continued to remove as much as 25–30% of O3. Up to 11% of O_3 removed participated in the production of formaldehyde. Small amounts of other oxidation products were also detected.

Beko et al. (2005) measured ultrafine particle concentration upstream and downstream of filter sample when air passing through the filters either did or did not contain ozone. They conducted the experiment using small scale test equipment in low polluting office with very low background ozone level. They reported that the downstream/upstream ratio was higher when O_3 was present. This indicates the creation or growth of ultrafine particles after the air has passed through the filter.

Hytttinen et al (2003) conducted laboratory and field experiment (from nine different Finnish office buildings) to examine potential reaction of ozone on used filters. The filters had removal efficiencies (F5 to F8 ratings) and had been in service for approximately one year. Their study indicates that used filter removed a part of the ozone from supply air. This removal could lead to more chemical reaction on used filter surface.

Implications of these studies

Ventilation filters are employed with the primary belief that they improve indoor air quality and present building occupants cleaner air. Adequate filtration of ventilation air to indoor environment could enhance occupant health significantly. An example of this is using the filter to reduce the outdoor ozone concentration. However improper maintenance of these filters may produce adverse effects because it could be source for ozone-initiated chemistry. Ventilation filters serve as an absorption bed which in the presence of air passing over it, and may lead to production of other gaseous chemical products that might result in sensory irritation. The above studies provide evidence of oxidative transformation on used filter due to the presence of ozone and organic compounds. These oxidation products do result in supplied ventilation air that is less acceptable and highly irritating.

Ventilation rate and recirculation rate

Ventilation rate

A measure of how quickly the air in an interior space is replaced by outside air by ventilation and infiltration. Air change rate is measured in appropriate units such as cubic meters per hour divided by the volume of air in the room, or by the number of times the home's air changes over with outside air. For example, if the amount of air that enters and exits in one hour equals the total volume of the heated part of the house, the house is said to undergo one air change per hour. The rates at which used air is exchange with outdoor air do have influence on secondary organic aerosols generated by ozone chemistry.

Recirculation rate

A measure of how quickly the air in an interior space is replaced with recirculated air. Recirculated air is defined as air that is returned from a heated/cooled space, reconditioned and/or cleaned, and returned to the space. Technically the recirculated air into the space is supposed to be clean but that is not usually the case if the ventilation filter is badly maintained. In the tropical context, recirculation of conditioned air is usually adopted to minimize the energy required to remove the high humidity of outdoor air. In Singaporean office buildings typically 90% of the air is recirculated while 10% is from outdoor air. To lower indoor space temperature the recirculated air can be moved at a faster rate or simply by passing over chilled water. It is important for the reader to note recirculation air change rate/ recirculation rate (ACH) is a different term from proportion (%) of air recirculated.

Relationship between recirculation rate and ventilation rate

If ventilation rate (outdoor air change rate) is kept constant and recirculation rate is varied (from low to high) in an experimental scenario, it means the residence time[4] in the system would basically be the same for all the experiments. The higher recirculation rate would simply be moving the air through a closed system at a faster rate. Thus, as recirculation rate increases, the boundary layer adjacent to the surface of the indoor space and recirculation loop becomes thinner. This presumably will affect deposition of particles and therefore resulting into larger surface removal of particles (reactants and reaction products). This is totally different from a situation when ventilation rate alone is used and varied, the residence time will be different for such set of experiments.

Effects on indoor chemistry

Weschler et al. (2000) did a study on the influence of ventilation on reactions among indoor pollutants. They use a one compartment mass balance model to simulate unimolecular and bimolecular reactions occurring indoors. The initial modeling assumes steady-state conditions. They also modeled a non-steady state scenario because at low air change rates, there may be insufficient time to achieve steady state. In the cases examined, the results demonstrate that the concentrations of products generated from reactions among indoor pollutants increase as the ventilation rate decreases. They also supplement the modeling studies with a series of experiments conducted in typical commercial offices. The reaction examined was that between ozone and limonene. The ozone was present as a consequence of outdoor-to-indoor transport while limonene originated indoors. Results were obtained for low and high ventilation rates. They observed a consistent result with the modeling studies. The concentrations of monitored products were higher at the lower ventilation rates even though the ozone concentrations were lower.

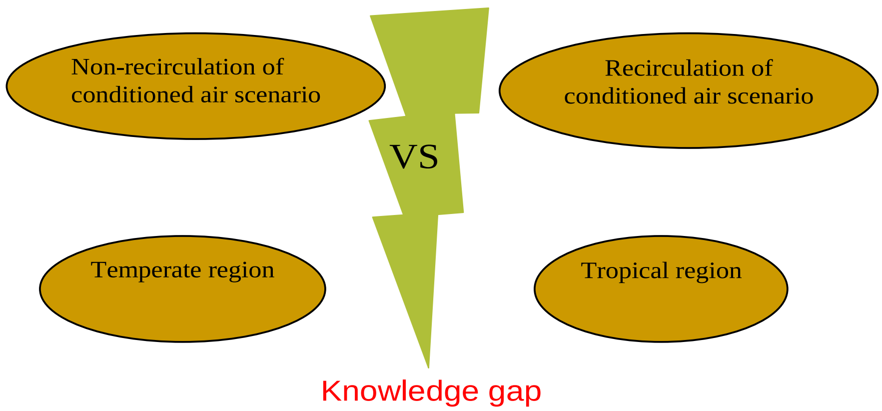
Weschler et al (2003) examine the influence of air change rates on the concentrations of secondary organic aerosols as well as the evolution of their particle size distributions. The experiments were performed in a manipulated office setting containing a constant source of d-limonene and an ozone generator but was remotely turned "on" or "off" at 6h intervals. The air change rates during the experiments were either high (working hours) or low (non-working hours) and ranged from 1.6 to >12h^{-1}, with immediate exchange rate. They observed evidence for coagulation among particles in the smallest size range at low air change rates (high particle concentrations) but no evidence of coagulation was apparent at higher air change rates (low particle concentrations). They also observed that at higher air change rates the particle count or size distributions were shifted towards smaller particle diameters and less time was required to achieve the maximum concentration in each of the size ranges where discernable particle growth occurred.

Implications of these studies

Above studies demonstrate that low ventilation rate, in addition to allowing accumulation of indoor pollutants leads to larger concentration of SOAs derived from reaction among such pollutants as well as for particles to accrete organic materials and undergo coagulation process. Relationship between ventilation rate and recirculation air change rate could also affect ozone initiated chemistry and health. Despite recirculation of conditioned to air indoor chemistry and health there are only very few studies examining the influence of ventilation rate on indoor chemistry (e.g.[21][22]), and with little or no study on the effect of ventilation rate and recirculation rate on indoor chemistry under recirculation of conditioned air scenario.

Knowledge gap

There are little or no studies documenting the *effect of filters, ventilation and recirculation rates on ozone initiated chemistry in buildings utilizing recirculation of conditioned air*



Understanding the impact, ventilation filters & air change rate could have on O_3 & ozonlysis concentration and particle size distribution under recirculation of conditioned air scenario is needed.

Figure 1: Knowledge gap

INDOOR CHEMISTRY IN TROPICS:

Research from IAQ unit of Centre for Total Building Performance, NUS

Given the above review, the role of filters, ventilation and recirculation rates could have on ozone and ozone initiated chemistry products' concentration and its particle size distribution (mass and number concentration) under recirculation of conditioned air (scenario common to tropical regions) clearly warrants further research. This understanding would help prioritize efforts to improve indoor air quality of air-conditioned buildings in the tropics. To this effect, The Indoor Air Quality research unit of Centre for Total Building Performance, National University of Singapore is interested in understanding the effect, filter, ventilation and recirculation rates could have on ozone initiated oxidation products (especially formation of oxidized terpenoids) under recirculation of conditioned air scenario. This section summarizes preliminary findings from 2 separate studies conducted in a large field environmental chamber (FEC) with its own Air Handling Unit (AHU). But, it is important to note that the research group has planned series of experiments focusing on AHU to be able to achieve controlled experiments as compared to using FEC as a primary experimental setup, which by its nature, there are lot of confounders that might be affecting the results. However, as a supplement to AHU experiments, FEC experiments would be conducted to give big picture of what could happen in indoor environment. The first study examines the effect of recirculation rate on the concentrations of SOA resulting from reactions between indoor limonene and ozone. In the second study, 3 experiments (without filters, with clean filters and with used filters in the AHU room) were conducted at constant recirculation rate and fresh air supply. The First study has shown that the rate at which air is recirculated through a room can have a significant effect on the Particle count, Size distribution and concentration of SOAs and oxidation products of ozone-initiated indoor chemistry [23][24][25]. For second study, the fact that the used filter has very little effect on the particle levels in the FEC compared to "no filter" at the initiate stage of the experiment suggests that two separate processes are occurring – 1) the used filter is removing SOA from the air stream and 2) chemistry is occurring on the surface of the used filter that contributes SOA to the air stream downstream of the filter. The chemistry that is occurring on the surface of the used filter includes ozone oxidation of organics associated with the captured particles/SOA, as well as ozone oxidation of limonene and limonene oxidation products such as 4-AMC (4-Acetyl-1-methylcyclohexene) and IPOH (3-isopropenyl-6-oxoheptanal) sorbed to the used filter. In terms of differences between a new filter and a used filter, one would expect greater sorption of limonene and its oxidation products on a used filter than on a new filter. This, in turn, would lead to more SOA being produced as a consequence of ozone passing through a used filter compared with a new filter [25][26].

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