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Research Article

Study of Air Purification System for HVAC Application to Fight Against Virus/ Bacteria to Maintain Indoor Air Quality (IAQ)

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ABSTRACT

The indoor environment is related to the HVAC system and HVAC system is directly related with the respiratory system of human body and for that by focusing the respiratory system, we have to regulate the indoor temperature, humidity, air flow and cleanness. Because they will be the conveyor of microbial contamination, bacteria. In Indoor environment microorganisms that may enter in HVAC system can be generated in many different ways. e.g. People talking, sneezing, carpet and toilet flushing process. And generated, spread by this many ways can survive in various HVAC components such as air ducts, filters, heat exchangers and fan coils. Other HVAC components and metabolism for various bacteria, microorganisms occupy. During the operation of the system bacteria and microorganisms obtain suitable environmental conditions such as temperature, moisture, nutrients conditions for their growth. And when their growth extents, these microorganisms and bacteria diffuse in system in form of bio-aerosols, accumulated dust and spread into indoors with supply air flow. In general, the microbial contamination source of HVAC system, so it is difficult to eliminate the microbial contamination at source. So some methods are able to kill microorganisms by air purification technology. The air purification technology includes different method by which we can maintain the good indoor air quality in HVAC system or applications to fight against the microorganisms, viruses and bacteria.

Keywords: Indoor Air Quality, Air Purification, HVAC, Bacteria

Introduction

In densely occupied buildings, airborne microbial contaminants can result in numerous adverse effects on human health and well-being, including inflammation and infections. Airborne bacteria and fungi have the potential to adversely impact human health by causing infections, allergic responses or toxic effects. Thus microbial growth in Heating Ventilation and Air Conditioning (HVAC) systems and subsequent contamination of the indoor air environment is of increasing concern. Pathogenic and toxin-producing fungi and bacteria thrive in dark, moist environments and the conditions in HVAC systems would appear to be ideal environments for the growth and propagation of microbes.[1] Air pollution has always remained one of the most serious environmental issues and has serious adverse effect on human health as well. Pollutants such as Ozone, Volatile Organic Compounds (VOCs e.g., gasoline, formaldehyde, toluene, xylene), Greenhouse Gases (mainly SOx and NOx) and the respirable airborne particulate matter (PM2.5 and PM10), have both acute and chronic effects on human respiratory and cardiovascular systems.[2,3] It has also become critical to understand the potential hazard of air pollutants and the need to minimize their impact using filtering medium. The traditional method to treat and purify the polluted air, involves methods such as mechanical filtration, High-Efficiency Particulate Air (HEPA) filtration, Activated Carbon (AC) technology, UV technology, Negative ion, Ozone etc., which are being practiced since a long time.[4,5] In recent years, environmental concerns regarding pollution and resource depletion have become major societal concerns. Air quality is directly linked to health hazards. Many of these health hazards are associated with volatile organic compounds (VOCs) and oxides of C, N and S in the air. VOCs and inorganic oxides (CO_2, NOx and SOx) may also travel long distances to produce secondary pollutants, such as acid rain or ozone[6] and facilitate global warming.

According to the United States Environmental Protection Agency (EPA), contaminated HVAC systems can serve as a breeding ground for bacteria and fungi, a substantial reservoir for viruses and fungal and bacterial spores. Numerous studies have documented microbial contamination of HVAC systems.[7]

Recently with the advancement in nanoscience and nanotechnology, along with the ongoing progress in the field of nanofibers, air filtration applications using Nano Fibrous (NFs) membrane has gained remarkable popularity. In particular, electro spun NFs membranes (produced using electrospinning technique) which is at the frontline of nanotechnology, has gained their due importance in the filtration field (both air and water filtration)[8] because of their outstanding properties including small diameter, large surface area to volume ratio, low density, controllable pore structures, high pore interconnectivity, flexibility in surface functionalities etc.[9] Electrospinning is a voltage-driven process to produce ultrafine (in nanometres) fibres from a polymeric solution. This approach produced polymeric nanofibers having diameters ranging between tens of nanometres to a few micrometres. Hence taking advantage of the integrated properties, a NFs membrane can effectively capture fine inhalable particles (PM2.5) with a filtration efficiency of ~99.9% and low air resistance.[10,11]

A variety of commercial products on the market were designed to reduce biofilms and subsequent doors and health concerns associated with air conditioning systems. Some of these products have been tested under laboratory conditions and have demonstrated modest control of the growth of resident biofilms.[12] The inherent antimicrobial properties of copper and its alloys against both eukaryotic and prokaryotic organisms.[13-15] Uncoated copper surfaces are capable of killing bacteria, viruses and fungi in very short periods of time. Pathogenic bacteria die within 90 min at room temperatures, within a few hours as the temperature decreases.[16,17] Similarly fungi and some viruses are killed within hours of being exposed to metallic copper surfaces.[18] Most studies in this field have focused on photo catalytic processes that use semiconductor oxides, such as titanium dioxide (T_iO_2), cadmium sulphide (C_dS), zinc oxide (Z_nO),because of their efficiency for degrading compounds, such as VOCs and other inorganic oxides.[19,20] The use of photo catalysts in concrete is relatively new, and the majority of studies in this area involve the use of T_iO_2.[21] In 2011, Matt Stock and Steve Dunn[22] found that $L_iN_bO_3$ can produce more products under UV-vis irradiation in comparison with T_iO_2, which is a photo catalyst widely used in construction for indoor air purification. The use of $L_iN_bO_3$ in building materials induces artificial photosynthesis, which is one of the best approaches to producing O_2 from moisture and atmospheric CO_2 and simultaneously reduce global CO_2 levels. Evaluation of the removal of air pollution by photo catalyst incorporated into construction and building materials is a considerable necessity. Hence, this review aims to address relevant issues regarding sustainable construction using a photo catalyst for indoor air purification, sources of pollutants in the indoor environment, photo catalysis process and provides an overview of the current developments in this field. In addition, the process converts organic pollutants to water (H_2O) and carbon dioxide (CO_2) without requiring an additional carrier gas.[23,24] This technology shows a high removal rate toward numerous pollutants, such as hydrocarbons, chlorinated hydrocarbons, VOCs[25], sulphur dioxide, carbon monoxide, carbon dioxide[26], nitrogen oxides and other compounds.[27,28]

Indoor Air Pollution

Owing to a dramatic change in pollution sources, indoor pollutants that we are exposed to today are markedly different and chemically more diverse from those experienced 40 years ago.[29] Older, relatively inert construction materials have been replaced with new, technologically complex products (e.g. polymers, high performance paints). In addition, the development of new building techniques and designs devoted to effective energy saving can result in airtight indoor spaces with inadequate ventilation. The continuous increase in the

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number and type of compounds identified indoors is also a consequence of the emergence of more sophisticated and sensitive analytical instruments and an improvement in sampling strategies[30]

Sources of Indoor Air Pollution

Sources of indoor air pollution can be categorized into endogenous contamination, reaction products within the indoor environment and penetration of outdoor pollutants. Endogenous pollutants constitute emissions from building and DIY materials, cleaning and personal products, cooking, Environmental Tobacco Smokes (ETS), human metabolism and other biological sources such as mould, pets and house dust mites. The direct emission of primary pollutants from indoor sources is complicated by a wealth of predominantly uncharacterized indoor chemical transformations through which ambient pollutants can be degraded[31] and secondary pollutants can be formed from indoor gas-phase reactions.[32] Recent findings of indoor multi-phase chemistry include diffuse oxidation with possible reactive radical production when using chlorine bleach to wash work surfaces[33] and the oxidative ability of human occupancy to reduce O_3 concentrations[34] and at the same time rapidly increase carbonyl compounds.[35] Pollutants of particular concern that infiltrate from outdoors include particulate matter, and nitrogen dioxide (NO_2) produced from industry, road traffic, power stations as a consequence of the combustion of fossil Fuels, O_3 generated at ground level by atmospheric reactions of UV light with NOx and hydrocarbons.

Factors Governing Indoor Air Quality

Factors governing pollutant concentrations, exposures and public health consequences in occupied indoor environments are complex in number and diversity. In simple terms they are categorized as follows: (a) attributes of the pollutants including their chemical structure, dynamic properties (e.g. reactivity of gases, size of particulates) and outdoor air concentration that in turn are influenced by ambient environmental conditions (e.g. temperature, wind speed/ direction); (b) the design, construction and state of repair of the building such as the types and condition of materials that comprise surfaces, floors and furnishings, the air-exchange rate (ventilation) and presence/ effectiveness of air cleaning processes; (c) the timing of presence within the indoor space, occupant density, lifestyle, habits and behaviours. The three widely recommended basic strategies to enhance IAQ are source control to avoid indoor and outdoor emissions, provision of adequate ventilation and air cleaning technologies to achieve further improvements when warranted. Whilst reducing the pollution source is the universally preferred approach, often this is not possible and ventilation increasingly presents challenges in terms of building energy use and because clean outdoor air is far from a given in many areas around the world. The use of air cleaners that do not involve the energy costs of moving and conditioning outdoor air are therefore receiving increasing attention as a strategy to remove unwanted particles and gases.

What is Acceptable Indoor Air Quality?

In 2010, the World health Organization (WHO) issued guidelines on protecting the public from health risks associated with exposure to chemicals commonly present in indoor spaces.[36,37] Other organizations have also adopted guidelines such as the US Environmental Protection Agency's (EPA) voluntary IAQ guidance for multifamily building upgrades[38] and schools.[39] In England, guidance on IAQ at home is currently under consultation and development.[40] Regulatory controls on indoor air pollution are limited to ventilation standards of building regulations that are widely believed to be inadequate in relation to health.[41] They are designed to meet acceptable air quality and comfort requirements, specified by a percentage that does not express dissatisfaction with IAQ or the intensity of odour. This is a subjective response that results in a measure of perceived air quality. Whilst comfort is an important parameter, some argue that it does not fully reflect serious health impacts (e.g. asthma, allergies, COPD, Diseases) that are associated with exposures to pollutants present in indoor air.[42]

Air Purification Techniques Found in the Market

The working principles for different brands of purifier would not necessary be the same (some may employ a combination of two or more technologies), but typical techniques include Ultraviolet Germicidal Irradiation (UVGI), ozone disinfection, filtration by High-Efficiency Particulate Air (HEPA) filter, photo-catalytic oxidation (PCO) with titanium oxide (T_iO_2) coating on material.[43] The following sections briefly account each of the technologies. Ultraviolet Germicidal Irradiation (UVGI) The use of UVGI for air disinfection has been studied since 1930s. Microbes are vulnerable to the effect of night near 2537 Angstroms (or 254 nm, i.e. UV-C segment) due to the resonance effect on the molecular structure of microbe.[44] The ultraviolet light can penetrate the organism's nucleus, and damage the DNA of the micro-organism by disrupting its molecular bonds. Under such irradiation, the microbe losses its reproduction ability, dies without leaving any new offspring.[45] Previous experiment in the literature[46] found that 97.19% of Staphylococcus aureus were killed by UV device in the ward space when two 552 W UV lamps were in operation. A higher UV irradiance results in greater reduction in bacteria concentration. Photo-Catalytic Oxidation (PCO) with Titanium Dioxide Photo-catalytic oxidation uses titanium dioxide (T_iO_2), a typical semiconductor catalyst, to generate hydroxyl radicals (OH-) for oxidation process. Hydroxyl radical has high oxidation power that can mineralise the bacteria.[47]

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The initial oxidative damage takes place in the cell wall of bacteria when it contacts with TiO2 material. A series of oxidisation will damage the inner cells of the microbe. Besides micro-organisms, hydroxyl radicals can also oxidise Volatile Organic Compounds (VOCs) and organic odorous substances adsorbed on the catalytic surfaces.[48] For pure titanium dioxide catalyst, the presence of UV energy is required to generate hydroxyl radicals. Filtration with HEPA Filter High-Efficiency Particulate Air (HEPA) filters is made of fibrous media that captures microscopic particles from air passing through the filter. Typical HEPA filters can remove 99.97% of particles with 0.3 microns (which falls within the most penetrating particle size region) that pass through the filter. The particles with either larger or smaller size than 0.1 to 0.3 µm are less penetrating.[49] The 'particle' size of typical pathogens is within 0.08 to 2 µm and theoretically HEPA is effective to bacteria and fairly effective on virus [44]. However, quantitative data on real-world efficiencies on pathogens removal is limited.[50-52] Pathogens may not behave as dry particulate, may have a low affinity for attachment to glass fibre.[44]

In addition, HEPA filters only capture particles on the filtration media, and the 'removal process' of bacteria and possibly virus from the building is not completed until the filter is disposed away from the air handling unit. Frequent replacement of HEPA filters is required in environment with large dust loading and microbial loading, which adds to the operating cost of the HEPA filtration system. In addition, the fan system in the air distribution system should be capable for the high pressure drop of HEPA filters. Ozone Disinfection Theoretical and empirical evidences suggest that most of the sterilisation effect of ozone is due to the radicals produced but not the gas molecule itself.[43] Room disinfection with ozone was performed in a study by Masaoka et al.,[53] Kowalski et al., reviewed the biocidal effects of low- to-moderate levels of ozone on bacteria and fungi.[54] However, ozone itself is an indoor air pollution imposing adverse effect on our health.[55] To control the ozone emission to an acceptable limit, special filters may be used in ozone disinfection system.[43]

Literature Survey

Following literature relevant to the above section was reviewed and discussed as follows.

Marvin Czarski et al.,[56] in this paper they did the study on the Heating, Ventilation and Air Conditioning (HVAC) system in the factory. For providing comfort condition to the employees and the equipment's, with the significant energy consumption without disturbing the air quality. HVAC system is the totally different than the production system. In this system there are different processes and cross influence occurs and they affecting on the efficiency and air quality. Observing these parameters analyse and understand the indoor air conditions, the goal is to enable future engineers and experts to design and set all the system in the way that improve human comfort and side by side reducing the energy consumption. And to achieve this goal they implement the cyber-physical system, means the all mechanism monitored by the computer based algorithm, building performance simulation with an integrated computation.

The system present the application of cyber-physical production system to produce comfort indoor air conditioning for the industry, with the help of learning factory environment for the practical extension of the current theoretical curricular.

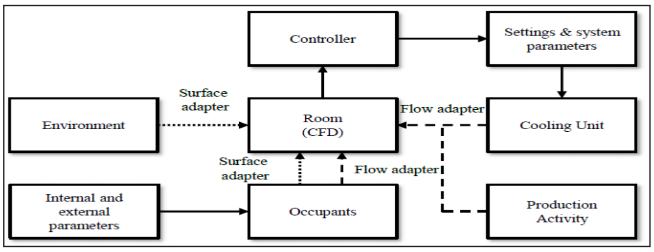

Figure 1.Abstraction of BPS and CFD Model for HVAC System Modelling

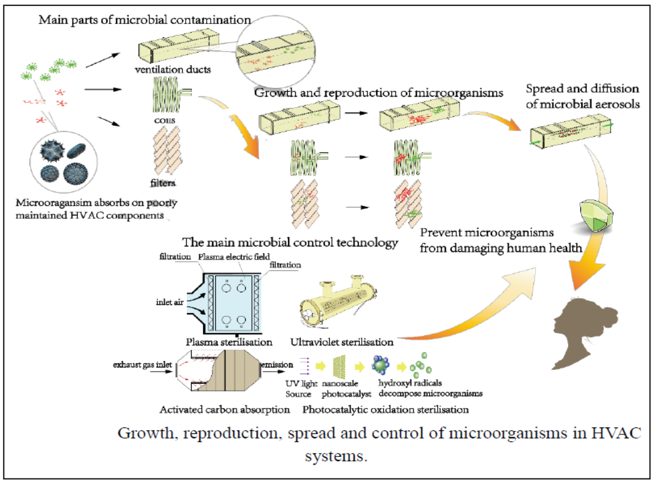

Figure 2.Growth, Reproduction, Spread and Control of Microorganism in HVAC System

Zhijian Liu et al.[57] In this paper they are done the study on the how to control the foreign particles, microbial contaminations in the HVAC system. Because HVAC system is the respiratory system of the modern buildings. So it is very important to avoid the growth and entry of the foreign particles, microbial contaminations in the HVAC system. For that reasons this paper gives comprehensive study of the distribution characteristics, growth and transmission modes of microorganisms in HVAC systems, as well as how to control the growth and control of the microbial contaminations. In specific, this study reviews the HVAC components where microorganisms primarily grow and the corresponding microbial species because there are some

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component where the growth of the bacteria and microbial contamination is takes place rapidly, due to the condition or atmosphere at the different components for eg.at the place of filter there is the humid place it is good for growth of the fungus and other harmful species which are scroll on the ducts and enters at the room, so these things are very harmful for the indoor environment.

Due to outbreaks of severe epidemic diseases microbial diseases microbial contaminations is the important subject in the HVAC system epidemiology fields. To effectively control indoor microbial contamination caused by HVAC systems, an overall understanding of the microorganism characteristics in HVAC systems is of vital importance. Therefore this paper overviews the microbial distribution characteristics, growth and reproduction, transmission mechanisms in primary HVAC components and corresponding control strategies.

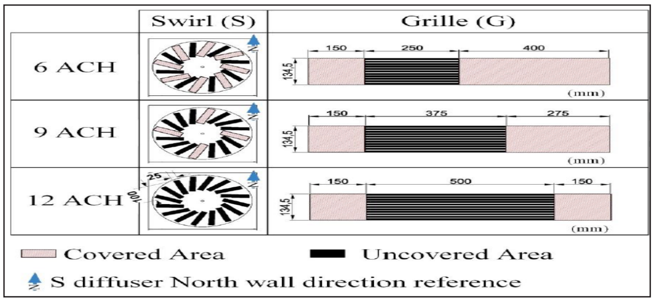

Figure 3.Supply Diffuser Covered Area for Each Test

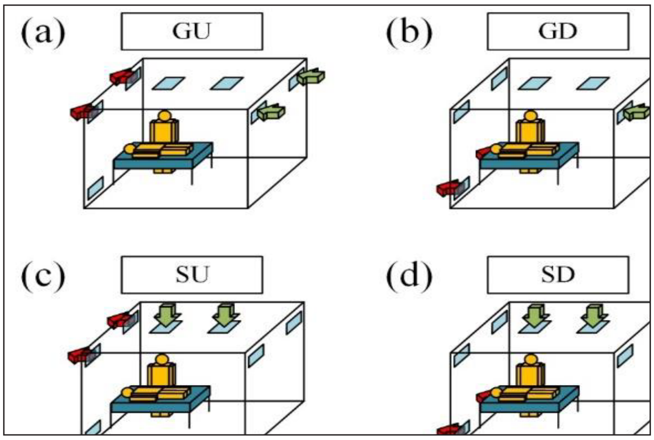

Figure 4.Ventilation System Configurations Tested in this Study: (a) Wall Grille Supply Combined with Upper Wall Exhausts (GU); (b) Wall Grille Supply Combined with Lower Wall Exhausts (GD); (c) Ceiling Swirl Supply Combined with Upper Wall Exhausts (SU); (d) Ceiling Swirl Supply Combined with Lower Wall Exhausts

FA Berlanga et al.[58] This investigation focus on the air flow study carried out in a hospital room by different mixing ventilation configuration influence performance exhaled or breath out contaminants distribution in hospital rooms using mixing ventilation strategies. This experiment indicates the, Thermal comfort indices and ventilation performance indices. By considering all the result in the experiment it has been found that using mixing ventilation strategy if perfect mixing not reached the Air Change per Hour (ACH), the position between the supply location finds the HW exposure. Also result obtained in this work is getting in specific experimental condition. If relative position of the source of contaminant, the different position of inflate and exhaust may change the conclusion obtain. The experiment setup has not carried out in the real hospital and only terats tracer gas to simulate small droplet nuclei not real biological contaminants.

Qilin feng et al.[59] In this paper the experiment is carried out to find the plume. In this study there is use of the robots to find the plum, which is produced by artificially by using machine. The robots are situated at the defined positions at the initial time and then departing from the starting position, the robots use a plume finding algorithm to search the plum for unknown area, until one of robot detect specific contaminants in the air. With the plume tracking algorithm robot continuously track the plume of the contaminant and move towards higher concentration until area is found with the plume confirming mode the robots use a source confirming algorithm to find whether the source has been found. By using this method we find out the plume and source of plume by using the algorithm and detect the source in the room. This is very necessary for the HVAC system or mechanical ventilation system.

Lei zhao et al.[60] In this paper study carried out on the impact of the various ventilation mode on indoor air quality (IAQ). So they obtain actual data on the performance of various ventilation modes forms of indoor air quality in the cold zone of china therefore they compare the different ventilation mode performance to compare indoor quality with the natural ventilation, natural ventilation with the filter mode and natural ventilation with air purification. And observe the impact of each ventilation mode on indoor air quality (IAQ) and energy consumption. This study carried out in Beijing-Tianjin-Hebei (BTH) region. After studying the long term data they conclude that indoor air quality is affected by outdoor particles, concentration and the indoor activities (walking, cooking, etc.). They conclude that natural ventilation with portable air cleaner can create good indoor air quality with long time operation.

Daniel de Robles et al.[61] In this paper they did the study on the improving indoor air quality through the use of the ultraviolet technology in commercial building. For that they use Ultraviolet Germicidal Irradiation (UVGI) in buildings HVAC of building many peoples are spending much more time in the buildings by using heating, cooling and ventilation system. This lack of the outside air cause of the different health problems like building related illness, sick building syndromes, there for rate of health and comfort complaints that are related to the indoor quality. Two main reasons for the poor indoor air quality induced 1) presence of the indoor pollution 2) poorly maintained and operated ventilation system. Ultraviolet radiation ranges from 2250 to 3020 angstroms is very dangerous to microorganism and has been used in various disinfection application in a process referred to UVGI. In the overall study they they collect the data regarding the people health, their problems, energy consumption, maintenance of the system after application of the UVGI system. They found that the UVGI system will installed with HVAC system, it gives better result than air filtration and low maintenance. But building owner will have to be making initial investment.

Ranjit k,Nath et al.[62] In this investigion study done on the use of the photo catalysts in construction material to reduce, eliminate indoor air pollution. In this the work done on the heterogeneous photo catalyst for potential solution. In this process organic pollutants converts into water and carbon dioxide, without any additional gases. This technique shows the high removal rate of the numerous pollutants such as hydrocarbons, carbon dioxide, carbon monoxide, nitrogen oxide. This study shows the relevant issues regarding sustainable construction using photo catalyst for indoor air pollution. In this paper they mentioned the photo catalyst process and how the pollutant degraded and converted into other element. The photo catalyst raises the decomposition of pollutants, prevents them from sick on the surface. It is useful for the manufacturing of the photo catalyst concrete ant the concrete blocks as a significant agent for air purification. It leads towards sustainable development and contribute for society. This leads to promote the clean building due to continuous oxidizing action of photo catalyst.

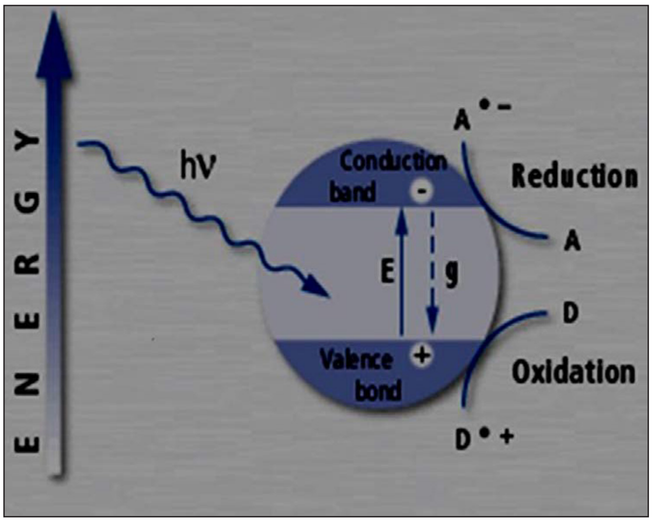

Figure 5.Mechanism of Electron-Hole Pairformationna Linbo3 Particle in the Presence of Pollutant Under UV Illumination

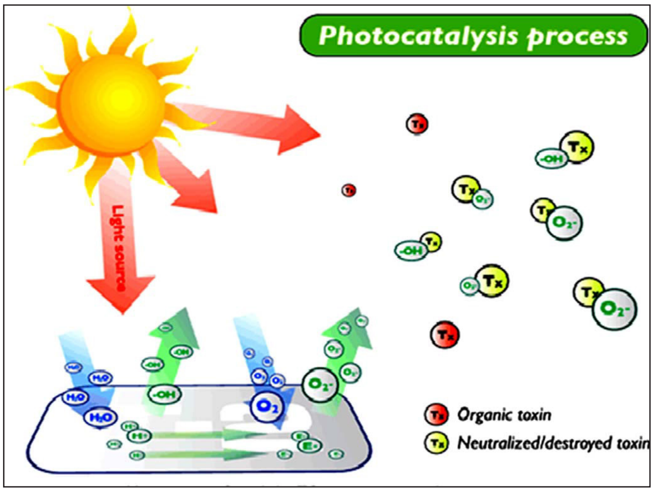

Figure 6.Photocatalytic Degradation Process

Mattin Moritz et al.[63] In this paper the examination is done on the capabilities of air filters to retain airborne outdoor microorganism was examined with experiment in the HVAC system. Under relatively dry (<80%R.H) and warm (12%C), outdoor condition filters show reduction of the airborne microorganism concentration. In the condition of the high relative humidity R.H (>80%RH) the spread of the bacteria on air filters occurs, these microorganism where mainly smaller than 1.1 microns. In the high RH provided by the two preheaters installed in front of the filters. The examination shows that microbial growth in the HVAC system 1. Low air temperature having <12 C and high relative humidity is more. In HVAC system 2. At the more air temperature (>12 C) and high RH prevented by two preheaters installed in front of air filters by this arrangement relative humidity reduces. Due to this microbial growth could not occur anymore on the filters. Therefore, it is evident that the air conditioner, which is a mechanical appliance, is now an integral part of buildings and has an effect on indoor air quality, which in turn has an impact on human wellbeing.[64-67]

Conclusion

In this review paper the different methods of maintaining the indoor air quality is maintained. Because HVAC system is the main important part of the indoor air quality, so it is necessary to improve the HVAC system by using different methods to achieve excellent indoor quality for the human health. There is number of different methods for eg.UVGI, cyber physical system, photo catalysts method. After studying these all methods it is to be found that implementing these methods in air conditioning system it will helps to solve the different issue related indoor air quality. In this review paper the different methods of the maintaining the indoor quality is explained. HVAC system is main important part of the Indoor air quality. In dense occupied buildings, industrial areas, airborne microbial contamination can result in numerous hazardous effects on the health. Airborne bacteria and fungi make adversely impact on human health in the HVAC system so it necessary to improve the indoor air quality through different methods. It is observed that the growth of microbial contamination takes place in the different components of HVAC system e.g filters ducts, region where the relative humidity is more, also region where the temperature is relatively less in these regions the rapid growth of the microorganisms is takes place. There are few methods are studied which can restrict the growth and spread of the microorganisms, bacteria fungi and also find the source.

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