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REVIEW

Fungal pollution of indoor environments and its management

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Abstract Indoor environments play important roles in human health. The health hazards posed by polluted indoor environments include allergy, infections and toxicity. Life style changes have resulted in a shift from open air environments to air tight, energy efficient, environments, in which people spend a substantial portion of their time. Most indoor air pollution comes from the hazardous non biological agents and biological agents. Fungi are ubiquitous in distribution and are a serious threat to public health in indoor environments. In this communication, we have reviewed the current status on biotic indoor air pollution, role of fungi as biological contaminants and their impact on human health.

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1. Introduction

All around the world, life style changes have resulted in a shift from open air environments to air tight,energy efficient environments at home and work places, where people spend a substantial portion of their time (Chao et al., 2003; Molhave, 2011). In these environments, improper maintenance, poor building design or occupant activities often result in a condition called as ''Sick Building Syndrome'' (SBS), where occupants experience adverse health effects that appear to link with the time spent in a building (Ebbehoj et al., 2002; Zeliger, 2003). The complaints may be localized to a particular room or widespread throughout a building and relief usually occurs soon after leaving the building (Bholah and Subratty, 2002; Bakke et al., 2008). Headaches, pressure on the head and throbbing, and feelings of tiredness are the most common signs of SBS.

Various abiotic agents like dust, particulate matter, wall coverings, synthetic paints, glue, polishes, and Voltile Organic Compounds (VOCs) may contribute to indoor pollution and cause SBS (Chao et al., 2002; Horner, 2003). Most of the air pollution comes from sources inside the building itself like, hair spray, perfume, room deodorizer, paints, thinners, home appliances, photo copiers, printers, computers, and air purifiers (Rossnagel, 2000; Wilson and Straus, 2002; Rylander, 2004). Use of disinfectants (linear alkyl benzene sulfonates) and fatty acid salts (soap) in cleaning agents (rug shampoo) can cause enhanced eye and air way irritation (Herbarth et al., 2003; Guo, 2011).

The release of gases from solvents used indoors, such as chlorine (used for drinking water disinfection), α-pinene, β-pinene (ingredients of synthetic paints and disinfectants) and formaldehyde (from building materials) can cause health problems (Hagmolen et al., 2007). Fiber glass or rock wool, floor coatings of linoleum, polyvinyl chloride, and use of gluteraldehyde can cause throat and facial dermal symptoms (McDonnell and Burke, 2011). Odors associated with bioaerosols may lead to anhedonic responses (Hiipakka and Buffington, 2000; Hintikka, 2004). Cigarette smoke is another source of not only VOCs, but also of toxic chemicals, carcinogens, and dust particles that may affect the lungs (Roussel et al., 2008). VOCs may become a problem in buildings that are being renovated or constructed.

The increase in temperature and humidity also affects the release of VOCs (Reijula, 2004; Hatfield and Hartz, 2011). The outdoor air that enters a building can be a source of indoor air pollution. For example, outdoor air may contain pollutants from motor vehicle exhausts (Reynolds et al., 2001). Physical and design characteristics of buildings such as lighting, ergonomics and noise may lead to chronic health effects. The nocturnal artificial lighting suppresses melatonin and may predispose people to breast and colon cancer (Li and Yang, 2004).

Bacteria, fungi, pollen, viruses, rat droppings, mites, insect body parts or bird droppings can be sources of biological contamination (Nevalainen and Seuri, 2005; Khan and Karuppayil, 2010). The indoor bacterium – *Legionella* causes both Legionnaire's Disease and Pontiac Fever (Nakayama and Morimoto, 2007). Common contributors to biological pollutants are water damage to homes during flooding or storm damage, leaks in plumbing, roofs or air conditioners, dehumidifiers, humidifiers, and bathrooms; and ice damming on building roofs allows water to seep through the roof sheathing (Cunningham et al., 2004; Mc Kernan et al., 2008). Humidifiers in the ventilation circuit provide place for proliferation of microorganisms (Farley and Franklin, 1992; Yamashita et al., 2005; Li et al., 2010).

An assessment of dust samples in schools and day care centers shows that dog, cat and mite allergens could cause severe health problems in children (Aydogdu and Asan, 2008). Allergens detected in mattresses, floor dust and curtains are found to increase the risk for asthma (Adgate et al., 2008). The design and operation of Heating, Ventilation and Air Conditioning systems (HVAC's) have an impact on the distribution of air borne infectious organisms (Mc Grath et al., 1999).

1.1. Fungal pollution of indoor environments

Fungi are ubiquitous in distribution and are a serious threat to public health in indoor environments (Samet and Spengler, 2003; Khan, 2009). Many fungi that are reported to cause allergy belong to Ascomycota, Basidiomycota or anamorphic fungi. There are many reports on fungi isolated from indoor environments (Table 1) (Portnoy, 2003; Khan et al., 2009). Fungi are able to grow on almost all natural and synthetic materials, especially if they are hygroscopic or wet. Inorganic materials get frequently colonized as they absorb dust and serve as good growth substrates for *Aspergillus fumigatus* and *Aspergillus versicolor* (Samet and Spengler, 2003). Wood is highly vulnerable to fungal attack. *Cladosporium* and *Penicillium* (*Penicillium brevicompactum* and *Penicillium expansum*) are reported to infest wooden building materials. Kiln dried wood surfaces are more susceptible to fungi (Sailer et al., 2010). Acylated wooden furnitures, wood polyethylene composites, plywood and modified wood products are susceptible to infestation by *Aspergillus*, *Trichoderma* and *Penicillium* (Thacker, 2004; Doherty et al., 2011).

Inner wall materials used in buildings, such as prefabricated gypsum board, highly favors the growth of *Stachybotrys*

Table 1 Studies on airborne fungi from the different countries.

Location	Country	Predominant Fungi		Health concern	Reference
International Center for Chemical and Biological Sciences (ICCBS) building, Karachi	Pakistan	*Cladosporium* spp. *Alternaria* spp. *Periconia* spp. *Curvularia* spp. *Stemophylium* spp. *Aspergillus* spp. *Penicillium* spp.		Diagnosis and treatment or preventive measures for allergy and asthmatic individuals	Hasnain et al. (2012)
Soybean and cotton mills, Giza	Egypt	*Aspergillus flavus, A. niger, A. parasiticus, Penicillium nigricans*, *Alternaria alternata*, *Cladosporium cladosporoides*		Inhalation of toxigenic fungi and production of mycotoxins in the lungs of workers	Abdel Hameed et al. (2012)
Green houses	Denmark	*Aspergillus fumigatus Beauveria* spp. *Trichoderma* spp. Penicillium *oslonii P. brevicompactum*		Exposure of vegetable growers to (1–3)-β-D-glucan, fungal spores and culturable fungi	Hansen et al. (2012)
Libraries and Archival settings	Portugal	*Stachybotrys* spp. *Aspergillus niger*, *A. fumigatus Fusarium* spp.		Indoor air quality in archives and libraries	Pinheiro et al. (2011)
Paper substrates, Genova	Italy	*Cladosporium sphaerospermum*, *Penicillium purpurogenum*, *Aspergillus melleus*,	FTIR-ATR analysis for identification of fungi		Zotti et al. (2011)
Jasna Gora (Bright Hill) monastery library in Czestochowa	Poland	Filamentous fungi *Acremonium striatum* *Acremonium* spp. *Alternaria* spp. *Aspergillus flavus* *Aspergillus niger* *Aspergillus versicolor* *Chaetomium elongatum* *Chaetomium* spp. *Oidiodendron rhodogenum* *Oidiodendron truncatum* *Penicillium aurantiogriseum* *Penicillium verrucosum* *Penicillium* spp. *Ulocladium* spp. *Wallemia sebi* Yeasts *Candida famata* *Geotrichum candidum* *Rhodotorula glutinis*	To check the degree of contamination of monastery library		Harkawy et al. (2011)
Hotel rooms in Asia and Europe	Asia China,Taiwan, Malaysia,Thailand, Vietnam, Japan, Cambodia and Iran Europe Spain, Italy, Sweden, France, Portugal, U. K, Norway, Denmark, Germany, Poland, Estonia and Iceland	*Aspergillus versicolor Stachybotrys chartarum* *Penicillium* spp.	Analysis of fungal DNA in 69 hotel rooms in 20 countries of Asia & Europe		Norback and Cai (2011)

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Table 1 (*continued*)

Location	Country	Predominant Fungi		Health concern	Reference
Child day care centers, Uppsala	Sweden	*Aspergillus* spp. *Stachybotrys chartarum Penicillium* spp.	To investigate relationship between building construction and indoor quality and exposure to fungi by qPCR	To reduce allergen levels and protect allergic children	Cai et al. (2011)
House dust samples, Riyadh	Saudi Arabia	*Aspergillus* spp. *Cladosporium* spp. *Penicillium* spp. *Acremonium* spp. *Botryodiplodia* spp. *Circenella* spp. *Myrothecium* spp. *Syncepalastrum* spp.	To study the occurrence and distribution of indoor fungi	Study showed the presence of potential human pathogenic fungi	Alwakeel and Nasser (2011)
Campus of the University of Sao Paulo	Brazil	*Aspergillus* spp. *Penicillium* spp. *Cladosporium* spp.	To determine possible correlations of bioaerosols (quantity of fungi)		Degobbi et al. (2011)
Poultry farmhouse, Burgundy	France	*Aspergillus* spp *Scopulariopsis* spp.	To represent fungal contaminants in air of animal facilities		Nieguitsila et al. (2011)
Air-Conditioning in Adult & Neonatal Intensive treatment units, Cuiaba city	Brazil	*Aspergillus* spp. *Penicillium* spp. *Cladosporium* spp.	To evaluate fungi in A/C units of hospitals	This study showed the risk factor for the acquisition of infection in ICU's	Simoes et al. (2011)
Indoor environments of Cave of Nerja	Spain	*Aspergillus* spp. *Penicillium* spp. *Cladosporium* spp. Ascomycota	Fungal spores in Cave and seasonal behavior were studied		Docampo et al. (2011)
Bakery, Bucharest	Romania	*Aspergillus* spp. *Penicillium* spp. *Alternaria* spp. *Fusarium* spp. *Ulocladium* spp. *Neurospora* spp. *Trichoderma* spp.	Conventional and molecular methods were used to detect fungi		Cornea et al. (2011)
Building with wood decay, Plouzane	France	*Serpula lacrymans Coniophora puteana, Trametes versicolor Donkioporia expansa Phlebiopsis gigantea Scleroderma verrucosum*	Capillary electrophoresis single-strand conformation polymorphism (CE-SSCP), denaturing high-performance liquid chromatography (DHPLC), PCR was used to detect fungi		Maurice et al. (2011)
Water damaged building, Ghent	Belgium	*Trichoderma atroviride*	To elucidate relationship between T. *atroviride* & Sick Building Syndrome	To investigate relation with SBS, the mucosal irritation potency of compounds by T. *atroviride*	Polizzi et al. (2011)
Dairy plant, Attica	Greece	*Penicillium* spp. *Cladosporium* spp	Microbiological methods and molecular typing techniques were used to detect the fungi in dairy plant		Beletsiotis et al. (2011)
Metro railway station, Kolkata	India	*Aspergillus flavus Aspergillus niger Penicillium* spp.	To evaluate prevalent airborne fungi in the indoor environment of railway station		Ghosh et al. (2011)

House dust samples, Turubah, Taif	Saudi Arabia	*Aspergillus flavus Aspergillus fumigatus Aspergillus penicilloides Aspergillus repens Penicillium glabrum*	Xerophilic, yeast, thermophilic, thermotolerant, keratinophilic fungi were isolated	Fungi identified were toxigenic, opportunists, pathogenic and antigenic	Al-Humiany (2010)
Residential buildings, Lodz	Poland	*Stachybotrys chartarum Aspergillus versicolor Penicillium chrysogenum*	High performance liquid chromatography/tandem mass spectrometry of six toxic strains proved their ability to grow on building materials and produce mycotoxins	The study showed toxic risk in buildings under study	Gutarowska et al. (2010)
Historic huts, Ross Island	Antarctica	*Cladosporium cladosporoides Pseudeurotium desertorum Geomyces* spp. *Antarctomyces psychrotrophicus*	To confirm fungal presence in huts		Duncan et al. (2010)
Mogao Cave, Gansu province	China	*Penicillium* spp. *Cladosporium* spp. *Aspergillus* spp. *Alternaria* spp.	Temporal, spatial distributions of airborne fungi in caves		Wang et al. (2010a,b)
Railway stations, Tokyo	Japan	*Penicillium* spp. *Cladosporium* spp. *Aspergillus* spp.	Understand the distribution of airborne fungi		Kawasaki et al. (2010)
Wine cellars, Graz	Austria	*Penicillium* spp. *Cladosporium* spp. *Aspergillus* spp.	Six stage Andersen-Cascade impactor was used for sampling of fungi and check the hygiene		Haas et al. (2010)
Archives buildings, Cuba La Plata	Cuba Argentina	*Penicillium* spp. *Cladosporium* spp.	To evaluate the microbial prevalence inside buildings		Borrego et al. (2010)
Houses of asthmatic patients Sari city	Iran	*Aspergillus flavus A. fumigatus Cladosporium* spp. *Penicillium* spp.	To study the distribution of fungi in indoor and outdoor air of asthmatic patients houses		Hedayati et al. (2010)
Newly built dwellings, Okayama	Japan	*Alternaria spp Aspergillus* spp. *Aureobasidium* spp. *Cladosporium* spp. *Eurotium* spp. *Rhodotorula* spp.	To explore the cause of sick building syndrome		Takigawa et al. (2009)
Flood affected materials from homes, New Orleans	USA	*Arthrinium, Ganoderma, Polythrincium, Torula, Aspergillus, Penicillium, Cladosporium*	To examine the aerosolization of fungi in flood affected homes	To restore and rejuvenate the flood affected areas	Adhikari et al. (2009)
Underground railway station, St. Petersburg	Russia	*Aspergillus, Penicillium, Cladosporium, Acremonium*	Indoor air of railway stations was examined for fungi over 4 months	Risk of mold allergic diseases for underground passengers was detected	Bogomolova and Kirtsideli (2009)
Child care centers, Singapore	Singapore	*Aspergillus, Penicillium, Geotrichum, Cladosporium*	Concentrations of culturable fungi were examined	Information provided was useful to determine etiology of wheeze and rhinitis	Zuraimi et al. (2009)

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Table 1 (*continued*)

Location	Country	Predominant Fungi		Health concern	Reference
Hospitals, Zarqa	Jordan	*Aspergillus, Penicillium, Alternaria, Rhizopus*	To investigate air quality and microbial quantity	To assess level of airborne pathogens	Qudiesat et al. (2009)
Noodle factory, Nantou	Taiwan	*Aspergillus, Penicillium, Cladosporium,*	To evaluate the levels of microorganisms	To minimize the biological hazards	Tsai and Liu (2009)
Feedstuff-manufacturing factories, Seoul	Korea	*Aspergillus, Penicillium, Cladosporium,*	To investigate the distribution patterns of airborne fungi		Kim et al. (2009)
Indoors, Brisbane	Australia	*Aspergillus niger Penicillium, Cladosporium cladosporioides*	To quantify the fungal fragments by Ultraviolet Aerodynamic particle sizer (UVASP) and Scanning fragmentation particle sizer (SMPS)		Kanaani et al. (2009)
Green waste windrow composting facility, Central England	UK	*Aspergillus fumigatus*	To study the particle size distribution of *Aspergilli* in compost operation	To evaluate potential health impacts	Deacon et al. (2009)
Dust samples, Kuopio	Finland	*Aspergillus, Penicillium, Paecilomyces*	To produce information of microbial concentrations using qPCR		Kaarakainen et al. (2009)
Maternity hospitals, Paris	France	*Aspergillus, Alternaria, Penicillium, Cladosporium,*	To examine spectrum and levels of airborne fungi in newborn babies homes	Purpose was to check the affect of mold on early childhood	Dassonville et al. (2008)
U.S. Lab module of International space station	USA	*Aspergillus flavus, Aspergillus niger,* A. *fumigatus,* A. *terreus, Penicillium chrysogenum, P. brevicompactum Fusarium solani Candida albicans*	DNA based method mold-specific quantitative PCR (MSQPCR) was used to measure the molds in dust	Potential opportunists and moderate toxin producers were detected	Vesper et al. (2008)
Moisture-damaged buildings, Leipzig	Germany	*Aspergillus versicolor Penicillium expansum*	2D-gel electrophoresis of spore proteins, Immunoblotting with patient sera to study indoor exposure to molds	Development of allergies were detected	Bennorf et al. (2008)
Child day care centers, Edirne city	Turkey	*Acremonium, Alternaria, Arthrinium, Aspergillus, Bahusakala, Beauveria, Ceuthospora, Chaetomium, Cladosporium, Curvularia, Drechslera, Epicoccum, Eurotium, Fusarium, Mycotypha, Myrotechium, Paecilomyces, Penicillium, Pestalotiopsis, Phoma, Ramichloridium, Rhizopus, Scopulariopsis, Stachybotrys, Stemphylium, Torula, Trichoderma, Trichothecium, Ulocladium, Verticillium*	Purpose of this study was to determine the concentration, in terms of monthly and seasonal distribution and in relation to meteorological factors, of indoor and outdoor microfungi		Aydogdu and Asan (2008)
Office buildings, Helsinki	Finland	*Aspergillus orchraceus Aspergillus glaucus Stachybotrys chartarum*	Levels of fungi were measured and comparison was made in mold-damaged and control buildings		Salonen et al. (2007)

Indoor spaces of buildings, Styria	Austria	*Aureobasidium* spp., *Trichoderma* spp., *Rhizopus* spp., *Cladosporium* spp., *Alternaria* spp., *Aspergillus* spp., *Penicillium* spp.,	To evaluate growth of indoor molds on fungal spores in the air		Haas et al. (2007)
Coir factory Kerala	India	*Aspergillus flavus, A. niger Cladosporium, Penicillium citrinum*	To study the prevalence of airborne fungal spores in indoor and outdoor environments		Nayar et al. (2007)
Hospitals, Childcare centers, Elderly welfare facilities, Maternity recuperation centers, Kyunggi-do province	Korea	*Aspergillus* spp., *Penicillium* spp., *Cladosporium* spp.,	Characteristics of airborne fungi were surveyed with six-stage cascade impactor		Kim and Kim (2007)
Various working environments in hospitals, Genoa	Italy	*Aspergillus* spp., *Penicillium* spp.,	To assess the degree of fungal contamination in hospital environments	To demonstrate the effectiveness of air-handling systems	Perdelli et al. (2006)
Homes of patients with allergy to fungi, Barcelona	Spain	*Cladosporium, Penicillium, Aspergillus, Alternaria*	To study the distribution of fungi inside and outside the homes of patients allergic to fungi	Respiratory allergies were due to seasonal variability	de Ana et al. (2006)
Residential dwellings, Murdoch University, Perth	Australia	*Cladosporium, Penicillium, Aspergillus, Alternaria, Fusarium, Botrytis, Aureobasidium, Rhizopus, Epicoccum, Yeast, Nigrospora*	To investigate HEPA vacuuming of indoor particulates and fungi in residential environments		Cheong and Neumeister-Kemp (2005)
Pillows used for years in homes	UK	*Aspergillus fumigatus Aureobasidium pullulans Rhodotorula mucilaginosa*	To enumerate the fungal flora of used pillows and dust at homes	To check the allergenicity of fungi isolated from pillows	Woodcock et al. (2006)
Air conditioning units in operating theaters, Pune	India	*Aspergillus, Fusarium Penicillium Rhizopus*	To find the fungal colonization of A/C units in O.T	Post operative fungal infections from contaminated A/C units	Kelkar et al. (2005)
Coastal regions, Dammam, Jeddah, Jizan	Saudi Arabia	*Basidiomycetes*	Seasonal and diurnal variations of airborne fungi Basidiomycetous spore concentrations		Hasnain et al. (2005)
Homes of children with allergy, Boston, Massachusetts	USA	*Aureobasidium*, *Aspergillus*, *Alternaria, Cladosporium, Penicillium*	To demonstrate the sensitization of fungi in children	To understand the development of allergic rhinitis and asthma	Stark et al. (2005)
Aerobiology Al-Khobar, Abha, Hofuf	Saudi Arabia	*Alternaria, Ulocladium, Drechslera Cladosporium,*	Data were analyzed in relation to their allergenic capability and spore calendars were designed to correlate the patients symptoms		Hasnain et al. (2005)

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Table 1 (*continued*)

Location	Country	Predominant Fungi		Health concern	Reference
Multi-storey hospital	USA	*Aspergillus flavus, Aspergillus fumigatus, Aspergillus niger, Aspergillus ochraceus, Aspergillus sydowii, Aspergillus ustus, Aspergillus versicolor, Eurotium (Asp.)* spp	Monitoring *Aspergillus* species by qPCR during construction of a multi-storey hospital building	To assure new construction free from contamination of	Morrison et al. (2004)
Aerobiology,	Saudi Arabia	*Cladosporium sphaerospermum, C. macrocarpum, C. cladosporioides, C. herbarum*	To evaluate allergenicity to *Cladosporium*		Hasnain et al. (2004)
Saw mill Palakkad, Kerala	India	*Aspergillus, Cladosporium, Penicillium, Nigrospora, Ganoderma*	Concentration of airborne fungal spores in indoor and outdoor environments		Jothish and Nayar (2004)
Residence with water leaks, California	USA	*Penicillium chrysogenum, P. crustosum P. aurantiogriseum*	Evaluation of water leak buildings for mold damage		Morey et al. (2003)
Water damaged and mold infested building materials, Lund	Sweden	*Aspergillus penicillioides, Stachybotrys chartarum, Chaetomium globosum*	Gas chromatography-mass spectrometry/solid phase microextraction (GC–MS/SPME) to identify microbial volatile organic compounds (MVOCs) in water-damaged, mold-infested building materials		Wady et al. (2003)
Dust from carpets with A/C and without A/C, Osaka	Japan	*Cladosporium, Penicillium*	Fungal contamination in AC		Hamada and Fujita (2002)
Operating theaters and hematological units of hospital, Grenoble	Germany	*Cladosporium, Penicillium, Aspergillus fumigatus*	Surveillance of environmental fungal contamination in hospital		Faure et al. (2002)
House dust, Melbourne	Australia	*Cladosporium, Penicillium,*	Assess the influence of indoor levels of fungi on sensitization and asthma in adults		Dharmage et al. (2001)
Water damaged Building, Cincinnati, Ohio	USA	*Penicillium, Aspergillus, Stachybotrys*	Report the case of a worker with respiratory illness related to bioaerosol exposure in a water-damaged building with extensive fungal contamination		Trout et al. (2001)
Aerobiology Nagpur	India	*Cladosporium, Penicillium, Aspergillus, Alternaria*	Concentrations of airborne fungal spores in market environment		Kakde et al. (2001)
Air samples from hospital, Taiwan	Republic of China	*Penicillium, Aspergillus,*	Quantitative evaluation of fungal exposure		Wu et al. (2000)
Hematology ward, Lanarkshire	Scotland	*Aspergillus versicolor, A. fumigatus, A. niger, Candida albicans, C. glabrata,C. parapsilosis*	Air sampling and surveillance cultures for fungi were performed in a Scottish general hematology ward		Richardson et al. (2000)
House dust, Wageningen	The Netherlands	*Aspergillus, Penicillium*	To evaluate the association between indoor storage of organic waste and levels of microbial agents in house dust		Wouters et al. (2000)

Aerobiology Gwalior	India	*Alternaria, Aspergillus, Cladosporium, Helminthosporium Curvularia, Rhizopu*	To find out fungal flora and its impact		Jain (2000)
Indoor environments, Burdwan	India	*Alternaria, Aspergillus, Cladosporium, Drechslera,Curvularia, Fusarium*	Comparative survey of airborne fungal spores		Chakraborty et al. (2000)
Dust from carpet, Erfurt, Hamburg	Germany	*Alternaria, Aspergillus,Cladosporium, Penicillium*	To compare exposure to mold spores in two German cities		Koch et al. (2000)
Damp buildings, Lyngby	Denmark	*Penicillium, Aspergillus, Chaetomium, Ulocladium, Stachybotrys,Cladosporium*	To elucidate problems with fungal infestation in indoor environments		Gravesen et al. (1999)
Indoor environments	Uganda	*Mycosphoerella Yeasts, Fusarium, Penicillium, Aspergillus, Alternaria,Cochliobolus*	To identify and enumerate the different airborne fungi		Ismail et al. (1999)
Aerobiology, Riyadh	Saudi Arabia	*Cladosporium* spp., *Penicillium* spp.,*Aspergillus* spp., *Alternaria* spp., *Ulocladium* spp., *Drechslera* spp., *Rhizopus* spp.,	To identify and quantify allergenic fungi and their seasonal fluctuations		Al-Suwaine et al. (1999)
Aerobiology, Riyadh	Saudi Arabia	*Alternaria, Aspergillus, Cladosporium, Penicillium, Ulocladium, Drechslera, Fusarium, Rhizopus, Stachybotrys*	To identify and quantify allergenic fungi	provide valuable information for the diagnosis and prophylaxis of allergic diseases	Al-Suwaine et al. (1999)
Indoor environments	Kuwait	*Aspergillus, Penicillium, Bipolaris, Cladosporium, Alternaria*	Study provides information on the prevalence of allergenic fungi in indoor environments of Kuwait		Khan et al. (1999)
Water damaged buildings	Denmark	*Stachybotrys chartarum, Aspergillus versicolor, Trichoderma* spp.	To verify the production of mycotoxins from *A. versicolor, S. chartarum, T. harzianum, T. longibrachiatum* and *T. atroviride* grown on artificially inoculated building materials		Nielsen et al. (1998)
Indoor atmosphere, Ismailia	Egypt	*Aspergillus flavus,Aureobasidium pullulans,Cladosporium cladsporioides*	Fungal spore population was studied		Wahid et al. (1996)
Saw mills, Lucknow	India	*Alternaria, Aspergillus, Curvularia, Drechslera, Epicoccum, Fusarium, Penicillium*	Fungi in different seasons in saw mill and their allergic potential were studied		Tewary and Mishra (1996)
Household environments, Riyadh	Saudi Arabia	*Alternaria,Aspergillus, Cercospora, Chaetomium, Cladosporium, Curvularia, Drechslera, Embellisia, Fusarium, Mucor, Penicillium, Rhizopus, Scytalidium, Trichoderma, Torula, Ulocladium*	Fungi inhabiting household environments in the West, East and Central localities of Riyadh city were screened		Bokhary and Parvez (1995)
Hospital New Delhi	India	*Aspergillus flavus, A. niger A. versicolor Cladosporium, Alternaria, Fusarium oxalicum, Penicillium citrinum*	Fungal airspora of hospital		Singh et al. (1994)

chartarum (Breum et al., 1999). Gypsum support fungal growth as it is hygroscopic. Paper and glue used in indoor surfaces are very good growth substrates for most of the indoor fungi. Fiber glass insulation and ceiling tiles support the growth of a number of fungi, among them frequently isolated were *A. versicolor*, *Alternaria*, *Cladosporium*, and *Penicillium* species (Erkara et al., 2008). Polyurethanes used in composites for insulation are attacked by *Paecilomyces variotii, Trichoderma harzianum* and *Penicillium* species (Yazicioglu et al., 2004). *Aspergillus* and *Penicillium* grow superficially on painted surfaces, but *Aureobasidium pullulans* was found to deteriorate the paints (O'Neill, 1988; Shirakawa et al., 2002; Lugauskas et al., 2003). Acrylic painted surfaces are attacked by *Alternaria, Cladosporium*, and *Aspergillus* (Shirakawa et al., 2011). Air filters and ventilation ducts are also colonized by fungi (Noris et al., 2011).

1.2. Health hazards of indoor fungi

Inhalation or ingestion is a principal route of exposure to fungal propagules. Products of mold growth such as Microbial volatile organic compounds (MVOC) or Microbial volatile break down products may contribute to symptoms of illness or discomfort independently on exposure to fungal biomass (Beezhold et al., 2008). The role of indoor fungi in irritative disorders i.e. primarily non-infective diseases such as allergy and asthma, has long been recognized. Bioaerosols of fungal origin, consisting of spores and hyphal fragments are readily respirable and are potent elicitors of bronchial irritation and allergy (Britton, 2003). At least 600 species of fungi are in contact with humans and less than 50 are frequently identified and described in epidemiologic studies on indoor environments (Phipatanakul, 2003; Khan et al., 2009).

1.3. Respiratory symptoms

Sinusitis similar to the common cold due to inflammation of para nasal sinuses is reported in homes with visible mold or water damage. Damp concrete floors increased the risk of irritated stuffy or running nose, and itching, burning or irritated eyes. A study showed association between nasal polyps and skin reactivity to *Candida albicans* in patients exposed to indoor pollution (Burge and Rogers, 2000). Exposure to air borne fungal spores is associated with persistent cough in infants whose mothers had asthma (Bush, 2008). Mucous membrane irritation syndrome is characterized by symptoms such as rhinorrhea (running nose), nasal congestion and sore throat, and irritation of nose and eyes. This syndrome is common not only in agricultural environments, but also found in people exposed to damp buildings (Lanier et al., 2010).

An allergen exposure increased the chances of allergic sensitization and was a risk factor for an early asthma onset as well as enhanced disease severity (Jaakkola et al., 2002; Dutkiewicz et al., 2002). In a study of the patients with a history of respiratory arrest, 91% had positive skin prick test for *Alternaria alternata* whereas that proportion was only 31% for the 99 matched control subjects with asthma and no history of respiratory arrest (Downs et al., 2001). Thus, sensitization to molds especially to *A. alternata* may be involved in severity of asthma in children and young adults.

1.4. Hypersensitivity syndromes

Various environmental antigens in the air have been found as elicitors of hypersensitivity, including fungi. Majority of the fungi that mediate hypersensitivity are due to occupational exposures. In non-industrial, non-agricultural settings, some case reports suggested that high airborne levels of fungal particulates had caused hypersensitivity where patients exhibited pneumonia-like symptoms (Fung and Hughson, 2003). Hypersensitivity pneumonitis or extrinsic allergic alveolitis are a granulomatous lung disease due to exposure and sensitization to antigens inhaled. This disease can be acute or chronic. Exposure to buildings contaminated with fungi and mycotoxin (trichothecene) may develop hypersensitivity pneumonitis (Franks and Galvin, 2010).

Inhalation fevers or humidifier fever are a heterogeneous group of stimuli which result in influenza like syndrome. This is a potential problem of damp indoor environment (Cleri et al., 2007). Humidifier fever is an illness accompanied by respiratory tract symptoms and fatigue is common in industrial settings where workers are exposed to microorganisms growing in humidification systems (Gaffin and Phipatanakul, 2009). Organic dust toxic syndrome (ODTS) is a noninfectious illness after inhalation of heavy organic dust (mixture of fungi and bacteria) This occurs within few hours after exposure to dust and symptoms are similar to hypersensitivity pneumonitis but are not due to immune response. This problem is common in workers handling material contaminated with fungi (Jacobs and Andrews, 2003).

1.5. Respiratory infections

Exposure to a variety of fungi such as *Aspergillus* spp. and *Fusarium* spp. may result in serious respiratory infections in immunocompromised persons (Boyacioglu et al., 2007; Varani et al., 2009; Jain et al., 2010; Hedayati et al., 2010; Uztan et al., 2010). People with impaired immune system who spend most of their time in indoor environments contaminated by fungi may develop serious fungal infections (Marcoux et al., 2009; Wang et al., 2010a,b). Chronic obstructive pulmonary disease, asthma, cystic fibrosis are disorders among persons potentially infected with *Aspergillus* (Baxter et al., 2011). In cystic fibrosis or asthma patients, *Aspergillus* spp. can develop allergic broncho pulmonary aspergillosis, invasive or semi-invasive pulmonary aspergillosis and pulmonary aspergilloma (Kawel et al., 2011).

1.6. Rheumatologic and other immune diseases

Rheumatic diseases are due to inflammation and stiffness in muscles, joints or fibrous tissue. These diseases are exacerbated by environmental conditions, which include dampness, fungi, and their products indoors (Breda et al., 2010). Systemic lupus erythematosus, rheumatoid arthritis, ankylosing spondylitis, Sjogren's syndrome and psoriatic arthritis are found in persons who work in water damaged buildings with microbial growth which include molds (Muise et al., 2010). The effect of inflammatory marker in blood of non smoking persons in homes with high (>4 ng/m^3) airborne concentrations of (1–3)-β-D glucan indicate mold exposure (Pedro-Botet et al., 2007; Kalyoncu, 2010).

1.7. Allergy

The major allergic diseases caused by fungi are allergic asthma, allergic rhinitis, allergic sinusitis, broncho pulmonary mycoses, and hypersensitivity pneumonitis (Pieckova and Wilkins, 2004). Concern regarding human exposure to fungi in indoor environments is mainly related to direct mucosal irritation and elicitation of an IgE-mediated hypersensitivity response that precipitates rhinitis and upper airways irritation, eye irritation, and sinusitis that characterize allergic syndrome (Jaakkola et al., 2002; Yike, 2011). The symptoms of allergy are not manifested until sensitization, in which an individual is repeatedly exposed to an allergen. During this process, antigen specific IgE is produced that attaches to receptors on mast cells which are concentrated on gastric and respiratory mucosa. The principal fungal allergens are either cell wall components (1–3)-β-D glucan or water soluble glycoproteins. These allergens become airborne when these materials are aerosolized (Katz et al., 1999).

A link between respiratory exposure to fungal material and seasonal allergy was first proposed in 1873 by Blackley who listed 106 fungi genera including members who elicited allergy (Blackely, 1873). Allergenic enzymes are produced upon germination of certain fungal spores and exposure to these compounds resulted from inhalation of germinable propagules, followed by germination on upper respiratory tract mucosa. Allergenic cross-reactivity is a consequence of correlated exposures because mites may occur together with fungi on water damaged indoor materials (Lander et al., 2001). In addition, mite fecal pellets often contain large numbers of intact and partially degraded fungal spores because these materials are a preferred food for many dust borne mite taxa (Portnoy, 2003; Santilli and Rockwell, 2003; Khan et al., 2009). After exposure to fungal spores or mycelial particles, susceptible individuals may develop nasal allergy commonly called as – hay fever|| or allergic rhinitis (Husman, 1996). The symptoms of fungi induced allergic rhinitis are usually indistinguishable from those caused by inhalation of pollen, dust, animal danders, and insect allergens (Savilahti et al., 2010).

1.8. Neuro psychiatric problems

People who inhabit moldy buildings were reported with cognitive defects and difficulties in concentration (Yates et al., 1986; Drappatz et al., 2007). *S. chartarum* and *Aspergillus* spp. were identified in air samples when occupants of buildings were checked for neuro psychological tests (such as Grooved pegboard test and Verbal learning test) (Otto et al., 1990).

2. Fungal constituents of indoors

2.1. Volatile fungal metabolites (VFM)

During exponential growth, many fungi release VFMs as products of secondary metabolism. These compounds comprise a great diversity of chemical structures including, ketones, aldehydes and alcohols (Wilkins et al., 2003). Cultural studies of some common household fungi suggest that the composition of VFM's remain stable over a range of growth media and conditions (Nilsson et al., 2004; Moularat et al., 2011). Determination of VFMs has been suggested as a measure of fungal contamination monitoring in grain storage facilities (Weir, 2000). Limited evidence suggests whether exposure to low concentrations of VFMs may cause respiratory irritation independent of exposure to allergenic particulates (Weinhold, 2007).

Volatile organic compounds may also cause indirect metabolic effects. A well-known example of this is the fungal degradation of urea formaldehyde foam insulation (Shinoj et al., 2011). Fungal colonization of this material results in the cleavage of urea from the polymer releasing formaldehyde, contributing to a decline in indoor air quality (Kreja and Seidel, 2002; Asan et al., 2010). VOCs may have strong and unpleasant odors and exposure to these VOCs has been linked to symptoms such as headache, nasal irritation, dizziness, fatigue and nausea (Burton et al., 2008). The gas chromatography – mass spectrometry (GC–MS) is used for chemical analysis of air samples to assess volatile organic compounds produced by fungi as suitable markers which correlate with fungal growth (Bornehag et al., 2005).

2.2. (1–3)-β-D glucan

This is a cell wall component of filamentous fungi and yeasts. In moisture damaged building materials, (1–3)-β-D glucan levels are found in the range of 2.5–210 μg/g (Rylander and Holt, 1998; Rylander et al., 1998; Wan et al., 1999). The mean concentrations of 1.55–2.22 μg/g (1–3)-β-D glucan in dust are positively related to the culturable fungi isolated from buildings (Wan and Li, 1999). (1–3)-β-D glucan may cause inflammatory air way reactions and also affect the immune system when inhaled (Rylander and Lin, 2000; Fogelmark et al., 2001). The biological activities of (1–3)-β-D glucan include host-mediated anti tumor activity, adjuvant effects, activation of neutrophils, eosinophils, macrophages and complement (Walinder et al., 2001). There is the increasing evidence that (1–3)-β-D glucan causes non-specific inflammatory reactions (Beijer et al., 2002; Rylander et al., 2010; Tercelj et al., 2011). The (1–3)-β-D glucan is responsible for bioaerosol-induced respiratory symptoms observed in both indoor and occupational environments (Srikanth et al., 2008; Douwes, 2003). (1–3)-β-D glucan levels are readily detected in house dust samples and the presence of textile floor coverings is strongly associated with increased levels of (1–3)-β-D glucan (Mork, 2002; Reponen et al., 2010; Rylander, 2010; Sykes et al., 2011).

2.3. Ergosterol

This is the most important sterol found in the cell membranes of fungi (Hyvarinen et al., 2006). The presence of ergosterol in the indoor environment indicates fungal contamination. The content of ergosterol in spores differs between different fungal species and cannot be considered as a good marker. < 62 μg/g of ergosterol in house dust indicates that the counts of fungi are very high (Park et al., 2008; Heinrich, 2011). Quantitative measure of ergosterol in fungal biomass in indoor environments by gas chromatography – mass spectrometry (GC–MS) provides a measure of total fungal matter (Cone, 1998).

2.4. Mycotoxins

These are non volatile, secondary metabolites of fungi. Routes of mycotoxin exposure include – inhalation, ingestion or skin

contact. The most well documented mycotoxins in indoor environments are aflatoxins, trichothecenes and ochratoxins (Kilburn, 2004; Zain, 2011). Humans may be exposed to these toxins by airborne or toxin containing spores in agricultural settings or moldy buildings (Vojdani et al., 2003a; Gottschalk et al., 2008). Aflatoxin B1 is the most thoroughly studied mycotoxin produced by *Aspergillus flavus* and *Aspergillus parasiticus* and is one of the most potent carcinogens (Thacker, 2004). *A. flavus* and *A. parasiticus* are not commonly found on building materials or in indoor environments (Etzel, 2001; Bhetariya et al., 2011).

Much of the information on the human health effects of inhalation exposure to mycotoxins comes from studies done in the work place. Human health effects attributed to inhalation of mycotoxins include: mucous membrane irritation, skin rash, nausea, immune system suppression, acute or chronic liver damage, acute or chronic central nervous system damage, endocrine effects and cancer (Olsen et al., 1988; Karunasena et al., 2010).The presence of fungi in a building does not necessarily mean that mycotoxins are present or they are in large quantities. Exposure to mycotoxins can occur by inhaling air borne particulates containing mycotoxins, including dust and fungal components (Vojdani et al., 2003b; Halios and Helmis, 2010).

Toxigenic fungi have been isolated from building materials and air samples in buildings with moisture problems, where the residents have suffered from nonspecific symptoms possibly related to mycotoxin production, such as cough, irritation of eyes, skin, respiratory tract, joint ache, headache and fatigue (Gottschalk et al., 2008; Bonetta et al., 2010). Few studies have established a casual relationship between mycotoxin exposure and building related illnesses (Kuo et al., 2008; Sen and Asan, 2009; Giulio et al., 2010; Asan et al., 2010). Even though some fungi can grow on almost any natural or synthetic construction material, mycotoxin production occurs preferentially on materials that allow these fungi to grow and provide the conditions for mycotoxin production (Soroka et al., 2008). Analysis of mycotoxins from contaminated materials, such as a dry wall, carpet or house dust can be done by GC–MS or liquid chromatography – mass spectrometry (LC–MS) (Chao et al., 2002).

3. Factors influencing fungal colonization

Moisture, nutrients and temperature are the most important factors that influence the growth of fungi on building materials (Rajasekar and Balasubramanian, 2011). Availability of water is expressed in terms of water activity (aw). The requirement for moisture depends on the fungal genus or species. Usually fungal growth is favored at aw of 0.95–0.99, while 0.65–0.90 and 0.88–0.99 are reported to be required for the growth of xerophilic fungi and yeasts (Leong et al., 2011). Nutrients in house dust and water favor fungal growth on building materials. Fiberglass, galvanized steel accumulated with dust or lubricant oil residues, allows the growth of fungi (Kennedy et al., 2004; Rene et al., 2010; Yau and Ng, 2011). The temperature in buildings of about 20–250 °C, promotes the growth of mesophilic fungi. However, the temperature below optimum level slows down the growth of fungi. pH range of 5–6.5 in building materials allows the best growth of most of the fungi (Vacher et al., 2010; Hoang et al., 2010). Sufficient light and oxygen are also critical for the growth of fungi in indoor environments (Zadrazil et al., 1991; Airaksinen et al., 2004; Voisey, 2010). Separate collections of organic as well as non-organic house hold waste is a common practice in many countries (Curtis et al.,2004, 2005). This often involves indoor storage of organic waste, including fruits, vegetables and food remain in apartment buildings in densely populated areas until they are disposed off. As a result, decomposition of organic waste may begin inside the waste bin and may act as a source of fungal spores inside the house (Husman, 1996).

4. Quantitation of fungi

In non culture based methods, microscopic counting of spores or cells can determine fungi in the samples (Table 2). Light, epifluorescence and scanning electron microscopy are used for identification of fungi. The choice of microscope type depends on sample preparation. Light microscopy provides the basis for morphological identification (Moularat et al., 2008; Krause et al., 2003). Components or metabolites of fungi can also be used to quantitate fungi population in an environment. Extra cellular polysaccharides can be detected by specific assays for partial identification of fungal genera in indoor environments (Jovanovic et al., 2004). Polyclonal antibody based assays detect a broad range of fungal antigens but cannot detect the spores (Mitchell et al., 2007). Molecular methods for quantitation of fungi include the use of genus/species specific probes, Polymerase chain reaction (PCR) based methods, Restriction endonuclease analysis and Karyotyping (Dean et al., 2005). Mitochondrial DNA (mt DNA) can be used for restriction enzyme analysis and DNA finger printing for fungal identification.

5. Sampling methods

For isolation of fungi, surface and air sampling techniques are used (Asadi et al., 2011). Bulk sampling of materials such as settled dust, pieces of wall board, duct linings, carpets etc.

Table 2 Methods of quantitation of indoor fungi.

Method	Assessment
Culture based	
Air Sampling	
Impactor	Organisms are collected on culture medium
Liquid impinger	Organisms are collected in collection fluid
Air filtration	Organisms are collected on filter
Non Culture based	
Air sampling	Microscopy
Liquid impinger	Simple microscopy
Air filtration	Epifluorescence microscopy
	Electron microscopy
	Flow cytometry
	Fluorescent in situ hybridization (FISH)
	Fluorechrome labeled nucleic acid probes
	Ergosterol or Fungal extracellular polysaccharides
	GC–MS Specific enzyme immunoassays
	Volatile fungal metabolites (1–3)-β-glucan mycotoxins

are tested to determine the contamination with biological agents (O'Meara and Tovey, 2000; Reponen, 2011). Suction devices are used to collect samples of loose materials like carpet dust. Surface sampling is used to confirm the nature of the suspected microbial growth on environmental surfaces to measure the relative degree of contamination and identify the types of present fungi (Cabral, 2010). In this approach, samples are collected by pressing contact plate or adhesive tape onto a surface, suction device and wet swab. Therefore surface sampling can be of four types that is - contact sampling, agar contact sampling, adhesive tape sampling and surface wash sampling (Yamamoto et al., 2011). Adhesive tape sampling is an important method to examine the fungi in the specimens using a compound microscope. The samples provide the hyphal fragments and the reproductive structures which may help for identification (Ahlen et al., 2003; Aydogdu et al., 2010).

Air sampling for fungi can be done by three standard methods including: impactor, liquid impinger, and air filtration methods (Table 3).

In the impactor method, the air stream is passed through a slit into a culture medium and adhesive microscopic slide or tape strip is used to collect the sample (Zhen et al., 2009). Slit samplers, single stage impactor, multistage impactor, Burkard, rotorod, Andersen, SAS, casella, sierra marple impactor and centrifugal samplers are the common impactor samplers used. The air flow rate is about 2–180 L/min (Engelhart et al., 2007).

Liquid impingers collect the samples directly into the fluid and the microorganisms are retained in the liquid until they are cultivated on media or evaluated by techniques like biochemical or immuno assays (Jo, 2011). Shipe sampler, AGT–30, midget, multistage and micro impingers are common impinger devices. The air flow rate is 0.1–55 L/min and the sampling time ranges from minutes to hours. Centrifugal samplers such as RCS, aerojet cyclone are devices with 40–100 L/min air flow rate (Gralton et al., 2011).

Among the three standard methods, air filtration is used to collect the samples of indoor air in volume. In this method after sampling, the filters are agitated or sonicated in a solution (Bazaka et al., 2011). The solution is used for the cultivation of microbes or examination with analytical techniques. In air filtration sampling, glass, cellulose ester, polycarbonate and Teflon filters are used. The air flow rate for this sampling is 1–1000 L/min (Muilenberg, 2003). Tilak air sampler is a modified Panzer's slide spore collector. The air is sucked through a projecting tube at the rate of 5 L/min and passes onto a transparent cello tape on the slowly rotating drum (Tilak, 1986; Frazer, 1998; Moularat and Robine, 2006).

Gravitational settling is a much earlier approach to collect the particles that settle passively on the open Petridish containing the growth medium (Bartlett et al., 2004; Cook et al., 2011). The choice of sampling technique and exposure assessment depends on the purpose of measurement. Air sampling as well as samples of settled dust, surface and contaminated material is used to monitor the environment (Gabrio et al., 2003; Jung et al., 2011).

Table 3 Commonly used air sampling methods for indoor fungi.

Method	Sampler	Air flow rate (L/min)
Impactor	Slit Single stage Multi stage Burkard Rotorod Andersen SAS	2–180
Liquid impingers	Shipe AGT-30 Midget Multi stage Micro	0.1–55
Centrifugal	RCS Aerojet cyclone	40–100

6. Practices contributing to indoor biotic pollution

The habit of switching off Air Conditioning (A/C) units is a very common practice to save electricity during off business hours (Hsu et al., 2011). This may lead to condensation of water and rise in relative humidity and temperature favoring fungal growth. In rooms where the A/C units are switched off for long periods of time, frequent cleaning of the A/C filters or rooms is necessary (Yau et al., 2011). It is advised to keep the A/C units switched on continuously. To conserve energy, the temperature can be set or programed as per the manufacturer (Hibbett et al., 2011).

A/C filters need to be replaced or cleaned periodically since the filter can be clogged due to dust load and fungal infestation (Ruping et al., 2011). Potted plants kept in A/C rooms may be a risk factor for the residents since soil may act as a reservoir of fungi (Guieysse et al., 2008). Isolation of pathogenic fungi from soils of potted plants kept in A/C rooms is reported (Robbins et al., 1999; Haas et al., 2007). Places where carpets are furnished need periodic shampooing and vacuum cleaning is necessary since carpets can be home to dust borne fungi (Khan and Karuppayil, 2011).

7. Control and precautions

Spore infiltration from outside can be reduced by closing the outlets and using air conditioning for cooling. In one study, the use of window air conditioner with the vent closed showed effective exclusion of spores (Ayoko et al., 2004). The most effective way to manage fungi in a building is to remove the conditions that favor the establishment and growth of fungi (de Blay et al., 2000; Khan and Karuppayil, 2010).

Elimination of growth can be achieved by avoiding available moisture (Barnes et al., 2007). The steps to reduce moisture include, maintenance of indoor relative humidity to less than 50%, sealing the leaks to prevent water intrusion, increasing bathroom and kitchen ventilation, vent cloth dryers to be kept outside, to keep house plants that are watered regularly healthy, keeping the moisture sensitive materials dry, use of dehumidifier in the basement, etc. (Cole and Cook, 1998).

Carpets increase the fungal levels, hence frequent vacuum cleaning may reduce the spore levels (Ferguson et al., 2009). When a carpet is extensively contaminated cleaning may be difficult and it must be replaced with hardwood, tile or firm flooring materials (Ewers et al., 1994; Khan and Karuppayil,

2010). Washable wall papers and paneling can be treated with fungicidal compounds or antimicrobial products. Wall paper or paneling may be removed to reduce the severity of fungal contamination. Contaminated air ducts and filters may be cleaned to reduce fungal prevalence (Burr et al., 2007). Elimination of sources of indoor air borne pollutants can be achieved during the design phase of a new building, but it will be difficult in an existing building (Lange et al., 2004). The selection of building materials, finishes, furnishings and construction techniques are effective approaches to reduce the sources within a building (Menetrez et al., 2008).

To ensure clean air in the indoors - heating, ventilation and air conditioning system must drive out stale air and replenish it within a building (Gosden et al., 1998). Varying climatic regions demand different thermal performance and conditioning within a building (Buckmaster, 2008). Diffusers and grills should be placed at opposite ends of buildings and be free from any obstructions that may result in the block of air flow into the building (Foarde and Menetrez, 2002). Effective air filtration ensures clean indoor air (Ahmad et al., 2001). Impingement, electronic and adsorption techniques are the three common air filtration technologies designed to get clean air (Escombe et al., 2009). Particulates are removed from the air by impingement and electronic air filters. Adsorptive type of filters eliminate unwanted gases present in the air (Garrison et al., 1993). Dry panel filters, Extended surface (dry) filters, High efficiency particulate air filters (HEPA), Bag filters and Charged media filters are different types of impingement and electronic filters (Hahn et al., 2002).

Regular cleaning prevents the accumulation of debris and particulate matter. Sometimes the cleaning products may also cause indoor air pollution, especially when the products are chemicals or solvent based (Myatt et al., 2008). Hence the use of non toxic cleaning solutions is recommended (Williams, 2004). The cleaning schedule should be during weekends or during periods when the building is not occupied. The maintenance of the HVAC system is very important, as poorly maintained HVAC systems may cause occupant discomfort and illnesses (Manuel, 2004; Gorny et al., 2007). In humidification systems, water drains and drip pans should not become stagnant to avoid air contamination.

Portable vacuum systems can be potential sources of airborne particulate matter (Oren et al., 2001). The smaller, more harmful particles may pass through them and be suspended in the air. Hence central vacuum systems which expel particulate matter to the exterior are the best alternatives (Buemi et al., 2000). A person may get sensitized to fungal spores while cleaning hence well fitted particulate mask with 1 μm particle retention should be used (Gage-White, 1998). Use of mask can avoid fungal allergy during the handling of compost, vacuuming and cleaning (Warsco and Lindsey, 2003; Rengasamy et al., 2004).

There is a renewed interest in the use of germicidal treatment or irradiation to disinfect indoor environments for the control of infectious diseases in hospitals, other health care facilities and the public sector (Cardenas et al., 2008). It has been known for many years that UV light has various effects on fungi (Levetin et al., 2001). Only a few studies have specifically focused on the effects of germicidal UV light. Currently various manufacturers are marketing germicidal UV lamps for controlling contamination, including fungal contamination in indoor environments, as well as Air Handling Units (AHU's) and ducts (Menzies et al., 1999; Alangaden, 2011).

Control of fungi in the indoor environments has traditionally focused on identifying the source of contamination control, use of filters, cleaning etc. Generally glutaraldehyde, formaldehyde and phenol derivatives such as cresol are used as disinfectants of the floors (Robertson et al., 1942; Weber et al., 1999). Glutaraldehyde shows high toxicity and its vapors irritate eyes, nose and throat (Samimi and Ross, 2003). Formaldehyde stimulates irritation of mucosa and is also reported as a carcinogen. Cresol is less toxic but extensive use may be harmful (Menetrez et al., 2007).

High toxicity and offensible odor of common disinfectants make their use restricted; there is a need for disinfectants which are harmless. There is considerable interest in plant extracts and molecules of natural origin (Khan and Karuppayil, 2010). Biologically active components from plants are reported to eliminate pathogenic microorganisms. A study on antimicrobial activity of vapors of aroma compounds was done to evaluate the practical applications in the indoor environment to reduce microbial count in air. Cinnamaldehyde vapors were reported as strong antimicrobials against air borne microbes (Sato et al., 2006). Essential oils and components of plants are good candidates for the inhibition of growth of environmental isolates. Plant extracts are generally assumed to be more acceptable and less hazardous than the synthetic disinfectants which have similar action (Burt, 2004; Khan and Karuppayil, 2010).

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