



REVIEW

Fungal pollution of indoor environments and its management

A.A. Haleem Khan *, S. Mohan Karuppayil ¹

DST-FIST Sponsored School of Life Sciences, SRTM University, Nanded 431606, MS, India

Received 29 November 2011; revised 5 June 2012; accepted 6 June 2012
Available online 15 June 2012

KEYWORDS

Allergy;
Infections;
Toxicity;
Aspergillus;
Trichoderma;
Penicillium;
Mycotoxins;
HEPA filters;
Disinfectants

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.

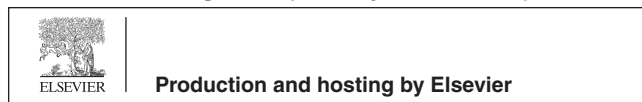
© 2012 King Saud University. Production and hosting by Elsevier B.V. All rights reserved.

Contents

1. Introduction	406
1.1. Fungal pollution of indoor environments	406
1.2. Health hazards of indoor fungi	414
1.3. Respiratory symptoms.	414
1.4. Hypersensitivity syndromes	414
1.5. Respiratory infections	414
1.6. Rheumatologic and other immune diseases	414
1.7. Allergy.	415
1.8. Neuro psychiatric problems	415
2. Fungal constituents of indoors	415
2.1. Volatile fungal metabolites (VFM)	415
2.2. (1–3)-β-D glucan	415

* Corresponding author. Mobile: 09848588901.
E-mail addresses: aahaleemkhan@yahoo.co.in (A.A. Haleem Khan),
prof.karuppayil@gmail.com (S. Mohan Karuppayil).
¹ Mobile: 09028528438.

Peer review under responsibility of King Saud University.



2.3. Ergosterol	415
2.4. Mycotoxins	415
3. Factors influencing fungal colonization	416
4. Quantitation of fungi	416
5. Sampling methods	416
6. Practices contributing to indoor biotic pollution	417
7. Control and precautions	417
Acknowledgements	418
References	418

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 Volatile 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 (Rosnagel, 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 Karuppaiyl, 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	<i>Cladosporium</i> spp. <i>Alternaria</i> spp. <i>Periconia</i> spp. <i>Curvularia</i> spp. <i>Stemphylium</i> spp. <i>Aspergillus</i> spp. <i>Penicillium</i> spp.	Diagnosis and treatment or preventive measures for allergy and asthmatic individuals	Hasnain et al. (2012)
Soybean and cotton mills, Giza	Egypt	<i>Aspergillus flavus</i> , <i>A. niger</i> , <i>A. parasiticus</i> , <i>Penicillium nigricans</i> , <i>Alternaria alternata</i> , <i>Cladosporium cladosporoides</i>	Inhalation of toxigenic fungi and production of mycotoxins in the lungs of workers	Abdel Hameed et al. (2012)
Green houses	Denmark	<i>Aspergillus fumigatus</i> <i>Beauveria</i> spp. <i>Trichoderma</i> spp. <i>Penicillium oslonii</i> <i>P. brevicompactum</i>	Exposure of vegetable growers to (1–3)- β -D-glucan, fungal spores and culturable fungi	Hansen et al. (2012)
Libraries and Archival settings	Portugal	<i>Stachybotrys</i> spp. <i>Aspergillus niger</i> , <i>A. fumigatus</i> <i>Fusarium</i> spp.	Indoor air quality in archives and libraries	Pinheiro et al. (2011)
Paper substrates, Genova	Italy	<i>Cladosporium sphaerospermum</i> , <i>Penicillium purpurogenum</i> , <i>Aspergillus melleus</i> , Filamentous fungi		Zotti et al. (2011)
Jasna Gora (Bright Hill) monastery library in Czestochowa	Poland	<i>Acremonium striatum</i> <i>Acremonium</i> spp. <i>Alternaria</i> spp. <i>Aspergillus flavus</i> <i>Aspergillus niger</i> <i>Aspergillus versicolor</i> <i>Chaetomium elongatum</i> <i>Chaetomium</i> spp. <i>Oidiodendron rhodogenum</i> <i>Oidiodendron truncatum</i> <i>Penicillium aurantiogriseum</i> <i>Penicillium verrucosum</i> <i>Penicillium</i> spp. <i>Ulocladium</i> spp. <i>Wallemia sebi</i> Yeasts <i>Candida famata</i> <i>Geotrichum candidum</i> <i>Rhodotorula glutinis</i>	FTIR-ATR analysis for identification of fungi 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	<i>Aspergillus versicolor</i> <i>Stachybotrys chartarum</i> <i>Penicillium</i> spp.	Analysis of fungal DNA in 69 hotel rooms in 20 countries of Asia & Europe	Norback and Cai (2011)

(continued on next page)

Table 1 (continued)

Location	Country	Predominant Fungi	Health concern	Reference	
Child day care centers, Uppsala	Sweden	<i>Aspergillus</i> spp. <i>Stachybotrys chartarum</i> <i>Penicillium</i> 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	<i>Aspergillus</i> spp. <i>Cladosporium</i> spp. <i>Penicillium</i> spp. <i>Acremonium</i> spp. <i>Botryodiplodia</i> spp. <i>Circinella</i> spp. <i>Myrothecium</i> spp. <i>Syncephalastrum</i> 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	<i>Aspergillus</i> spp. <i>Penicillium</i> spp. <i>Cladosporium</i> spp.	To determine possible correlations of bioaerosols (quantity of fungi)		Degobbi et al. (2011)
Poultry farmhouse, Burgundy	France	<i>Aspergillus</i> spp <i>Scopulariopsis</i> 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	<i>Aspergillus</i> spp. <i>Penicillium</i> spp. <i>Cladosporium</i> 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	<i>Aspergillus</i> spp. <i>Penicillium</i> spp. <i>Cladosporium</i> spp. Ascomycota	Fungal spores in Cave and seasonal behavior were studied		Docampo et al. (2011)
Bakery, Bucharest	Romania	<i>Aspergillus</i> spp. <i>Penicillium</i> spp. <i>Alternaria</i> spp. <i>Fusarium</i> spp. <i>Ulocladium</i> spp. <i>Neurospora</i> spp. <i>Trichoderma</i> spp.	Conventional and molecular methods were used to detect fungi		Cornea et al. (2011)
Building with wood decay, Plouzane	France	<i>Serpula lacrymans</i> <i>Coniophora puteana</i> , <i>Trametes versicolor</i> <i>Donkioporia expansa</i> <i>Phlebiopsis gigantea</i> <i>Scleroderma verrucosum</i>	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	<i>Trichoderma atroviride</i>	To elucidate relationship between <i>T. atroviride</i> & Sick Building Syndrome	To investigate relation with SBS, the mucosal irritation potency of compounds by <i>T. atroviride</i>	Polizzi et al. (2011)
Dairy plant, Attica	Greece	<i>Penicillium</i> spp. <i>Cladosporium</i> 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	<i>Aspergillus flavus</i> <i>Aspergillus niger</i> <i>Penicillium</i> spp.	To evaluate prevalent airborne fungi in the indoor environment of railway station		Ghosh et al. (2011)

House dust samples, Turubah, Taif	Saudi Arabia	<i>Aspergillus flavus Aspergillus fumigatus Aspergillus penicilloides Aspergillus repens Penicillium glabrum</i>	Xerophilic, yeast, thermophilic, thermotolerant, keratinophilic fungi were isolated	Fungi identified were toxigenic, opportunists, pathogenic and antigenic	Al-Humiany (2010)
Residential buildings, Lodz	Poland	<i>Stachybotrys chartarum Aspergillus versicolor Penicillium chrysogenum</i>	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	<i>Cladosporium cladosporoides Pseudeurotium desertorum Geomyces spp. Antarctomyces psychrotrophicus</i>	To confirm fungal presence in huts		Duncan et al. (2010)
Mogao Cave, Gansu province	China	<i>Penicillium spp. Cladosporium spp. Aspergillus spp. Alternaria spp.</i>	Temporal, spatial distributions of airborne fungi in caves		Wang et al. (2010a,b)
Railway stations, Tokyo	Japan	<i>Penicillium spp. Cladosporium spp. Aspergillus spp.</i>	Understand the distribution of airborne fungi		Kawasaki et al. (2010)
Wine cellars, Graz	Austria	<i>Penicillium spp. Cladosporium spp. Aspergillus spp.</i>	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	<i>Penicillium spp. Cladosporium spp.</i>	To evaluate the microbial prevalence inside buildings		Borrego et al. (2010)
Houses of asthmatic patients Sari city	Iran	<i>Aspergillus flavus A. fumigatus Cladosporium spp. Penicillium spp.</i>	To study the distribution of fungi in indoor and outdoor air of asthmatic patients houses		Hedayati et al. (2010)
Newly built dwellings, Okayama	Japan	<i>Alternaria spp Aspergillus spp. Aureobasidium spp. Cladosporium spp. Eurotium spp. Rhodotorula spp.</i>	To explore the cause of sick building syndrome		Takigawa et al. (2009)
Flood affected materials from homes, New Orleans	USA	<i>Arthrimum, Ganoderma, Polythrincium, Torula, Aspergillus, Penicillium, Cladosporium</i>	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	<i>Aspergillus, Penicillium, Cladosporium, Acremonium</i>	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	<i>Aspergillus, Penicillium, Geotrichum, Cladosporium</i>	Concentrations of culturable fungi were examined	Information provided was useful to determine etiology of wheeze and rhinitis	Zuraimi et al. (2009)

(continued on next page)

Table 1 (continued)

Location	Country	Predominant Fungi	Health concern	Reference	
Hospitals, Zarqa	Jordan	<i>Aspergillus, Penicillium, Alternaria, Rhizopus</i>	To investigate air quality and microbial quantity	To assess level of airborne pathogens	Qudiesat et al. (2009)
Noodle factory, Nantou	Taiwan	<i>Aspergillus, Penicillium, Cladosporium,</i>	To evaluate the levels of microorganisms	To minimize the biological hazards	Tsai and Liu (2009)
Feedstuff-manufacturing factories, Seoul	Korea	<i>Aspergillus, Penicillium, Cladosporium,</i>	To investigate the distribution patterns of airborne fungi		Kim et al. (2009)
Indoors, Brisbane	Australia	<i>Aspergillus niger Penicillium, Cladosporium cladosporioides</i>	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	<i>Aspergillus fumigatus</i>	To study the particle size distribution of <i>Aspergilli</i> in compost operation	To evaluate potential health impacts	Deacon et al. (2009)
Dust samples, Kuopio	Finland	<i>Aspergillus, Penicillium, Paecilomyces</i>	To produce information of microbial concentrations using qPCR		Kaarakainen et al. (2009)
Maternity hospitals, Paris	France	<i>Aspergillus, Alternaria, Penicillium, Cladosporium,</i>	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	<i>Aspergillus flavus, Aspergillus niger, A. fumigatus, A. terreus, Penicillium chrysogenum, P. brevicompactum Fusarium solani Candida albicans</i>	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	<i>Aspergillus versicolor Penicillium expansum</i>	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	<i>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</i>	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	<i>Aspergillus orchraceus Aspergillus glaucus Stachybotrys chartarum</i>	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	<i>Aureobasidium</i> spp., <i>Trichoderma</i> spp., <i>Rhizopus</i> spp., <i>Cladosporium</i> spp., <i>Alternaria</i> spp., <i>Aspergillus</i> spp., <i>Penicillium</i> spp.,	To evaluate growth of indoor molds on fungal spores in the air		Haas et al. (2007)
Coir factory Kerala	India	<i>Aspergillus flavus</i> , <i>A. niger</i> <i>Cladosporium</i> , <i>Penicillium citrinum</i>	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	<i>Aspergillus</i> spp., <i>Penicillium</i> spp., <i>Cladosporium</i> spp.,	Characteristics of airborne fungi were surveyed with six-stage cascade impactor		Kim and Kim (2007)
Various working environments in hospitals, Genoa	Italy	<i>Aspergillus</i> spp., <i>Penicillium</i> 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	<i>Cladosporium</i> , <i>Penicillium</i> , <i>Aspergillus</i> , <i>Alternaria</i>	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	<i>Cladosporium</i> , <i>Penicillium</i> , <i>Aspergillus</i> , <i>Alternaria</i> , <i>Fusarium</i> , <i>Botrytis</i> , <i>Aureobasidium</i> , <i>Rhizopus</i> , <i>Epicoccum</i> , <i>Yeast</i> , <i>Nigrospora</i>	To investigate HEPA vacuuming of indoor particulates and fungi in residential environments		Cheong and Neumeister-Kemp (2005)
Pillows used for years in homes	UK	<i>Aspergillus fumigatus</i> <i>Aureobasidium pullulans</i> <i>Rhodotorula mucilaginosa</i>	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	<i>Aspergillus</i> , <i>Fusarium</i> <i>Penicillium</i> <i>Rhizopus</i>	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	<i>Basidiomycetes</i>	Seasonal and diurnal variations of airborne fungi		Hasnain et al. (2005)
Homes of children with allergy, Boston, Massachusetts	USA	<i>Aureobasidium</i> , <i>Aspergillus</i> , <i>Alternaria</i> , <i>Cladosporium</i> , <i>Penicillium</i>	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	<i>Alternaria</i> , <i>Ulocladium</i> , <i>Drechslera</i> <i>Cladosporium</i> ,	Data were analyzed in relation to their allergenic capability and spore calendars were designed to correlate the patients symptoms		Hasnain et al. (2005)

(continued on next page)

Table 1 (continued)

Location	Country	Predominant Fungi	Health concern	Reference	
Multi-storey hospital	USA	<i>Aspergillus flavus</i> , <i>Aspergillus fumigatus</i> , <i>Aspergillus niger</i> , <i>Aspergillus ochraceus</i> , <i>Aspergillus sydowii</i> , <i>Aspergillus ustus</i> , <i>Aspergillus versicolor</i> , <i>Eurotium (Asp.) spp</i>	Monitoring <i>Aspergillus</i> 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	<i>Cladosporium sphaerospermum</i> , <i>C. macrocarpum</i> , <i>C. cladosporioides</i> , <i>C. herbarum</i>	To evaluate allergenicity to <i>Cladosporium</i>		Hasnain et al. (2004)
Saw mill Palakkad, Kerala	India	<i>Aspergillus</i> , <i>Cladosporium</i> , <i>Penicillium</i> , <i>Nigrospora</i> , <i>Ganoderma</i>	Concentration of airborne fungal spores in indoor and outdoor environments		Jothish and Nayar (2004)
Residence with water leaks, California	USA	<i>Penicillium chrysogenum</i> , <i>P. crustosum</i> <i>P. aurantiogriseum</i>	Evaluation of water leak buildings for mold damage		Morey et al. (2003)
Water damaged and mold infested building materials, Lund	Sweden	<i>Aspergillus penicillioides</i> , <i>Stachybotrys chartarum</i> , <i>Chaetomium globosum</i>	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	<i>Cladosporium</i> , <i>Penicillium</i>	Fungal contamination in AC		Hamada and Fujita (2002)
Operating theaters and hematological units of hospital, Grenoble	Germany	<i>Cladosporium</i> , <i>Penicillium</i> , <i>Aspergillus fumigatus</i>	Surveillance of environmental fungal contamination in hospital		Faure et al. (2002)
House dust, Melbourne	Australia	<i>Cladosporium</i> , <i>Penicillium</i> ,	Assess the influence of indoor levels of fungi on sensitization and asthma in adults		Dharmage et al. (2001)
Water damaged Building, Cincinnati, Ohio	USA	<i>Penicillium</i> , <i>Aspergillus</i> , <i>Stachybotrys</i>	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	<i>Cladosporium</i> , <i>Penicillium</i> , <i>Aspergillus</i> , <i>Alternaria</i>	Concentrations of airborne fungal spores in market environment		Kakde et al. (2001)
Air samples from hospital, Taiwan	Republic of China	<i>Penicillium</i> , <i>Aspergillus</i> ,	Quantitative evaluation of fungal exposure		Wu et al. (2000)
Hematology ward, Lanarkshire	Scotland	<i>Aspergillus versicolor</i> , <i>A. fumigatus</i> , <i>A. niger</i> , <i>Candida albicans</i> , <i>C. glabrata</i> , <i>C. parapsilosis</i>	Air sampling and surveillance cultures for fungi were performed in a Scottish general hematology ward		Richardson et al. (2000)
House dust, Wageningen	The Netherlands	<i>Aspergillus</i> , <i>Penicillium</i>	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	<i>Alternaria, Aspergillus, Cladosporium, Helminthosporium Curvularia, Rhizopus</i>	To find out fungal flora and its impact	Jain (2000)
Indoor environments, Burdwan	India	<i>Alternaria, Aspergillus, Cladosporium, Drechslera, Curvularia, Fusarium</i>	Comparative survey of airborne fungal spores	Chakraborty et al. (2000)
Dust from carpet, Erfurt, Hamburg	Germany	<i>Alternaria, Aspergillus, Cladosporium, Penicillium</i>	To compare exposure to mold spores in two German cities	Koch et al. (2000)
Damp buildings, Lyngby	Denmark	<i>Penicillium, Aspergillus, Chaetomium, Ulocladium, Stachybotrys, Cladosporium</i>	To elucidate problems with fungal infestation in indoor environments	Gravesen et al. (1999)
Indoor environments	Uganda	<i>Mycosphaerella Yeasts, Fusarium, Penicillium, Aspergillus, Alternaria, Cochliobolus</i>	To identify and enumerate the different airborne fungi	Ismail et al. (1999)
Aerobiology, Riyadh	Saudi Arabia	<i>Cladosporium spp., Penicillium spp., Aspergillus spp., Alternaria spp., Ulocladium spp., Drechslera spp., Rhizopus spp.,</i>	To identify and quantify allergenic fungi and their seasonal fluctuations	Al-Suwaine et al. (1999)
Aerobiology, Riyadh	Saudi Arabia	<i>Alternaria, Aspergillus, Cladosporium, Penicillium, Ulocladium, Drechslera, Fusarium, Rhizopus, Stachybotrys</i>	To identify and quantify allergenic fungi	Al-Suwaine et al. (1999)
Indoor environments	Kuwait	<i>Aspergillus, Penicillium, Bipolaris, Cladosporium, Alternaria</i>	Study provides information on the prevalence of allergenic fungi in indoor environments of Kuwait	Khan et al. (1999)
Water damaged buildings	Denmark	<i>Stachybotrys chartarum, Aspergillus versicolor, Trichoderma spp.</i>	To verify the production of mycotoxins from <i>A. versicolor, S. chartarum, T. harzianum, T. longibrachiatum</i> and <i>T. atroviride</i> grown on artificially inoculated building materials	Nielsen et al. (1998)
Indoor atmosphere, Ismailia	Egypt	<i>Aspergillus flavus, Aureobasidium pullulans, Cladosporium cladosporioides</i>	Fungal spore population was studied	Wahid et al. (1996)
Saw mills, Lucknow	India	<i>Alternaria, Aspergillus, Curvularia, Drechslera, Epicoccum, Fusarium, Penicillium</i>	Fungi in different seasons in saw mill and their allergic potential were studied	Tewary and Mishra (1996)
Household environments, Riyadh	Saudi Arabia	<i>Alternaria, Aspergillus, Cercospora, Chaetomium, Cladosporium, Curvularia, Drechslera, Embellisia, Fusarium, Mucor, Penicillium, Rhizopus, Scytalidium, Trichoderma, Torula, Ulocladium</i>	Fungi inhabiting household environments in the West, East and Central localities of Riyadh city were screened	Bokhary and Parvez (1995)
Hospital New Delhi	India	<i>Aspergillus flavus, A. niger, A. versicolor, Cladosporium, Alternaria, Fusarium oxalicum, Penicillium citrinum</i>	Fungal airspora of hospital	Singh et al. (1994)

provide valuable information for the diagnosis and prophylaxis of allergic diseases

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/m³) 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 (Blackley, 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 (Savilanti 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 peg-board 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 μ g/g (Rylander and Holt, 1998; Rylander et al., 1998; Wan et al., 1999). The mean concentrations of 1.55–2.22 μ g/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 μ g/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
<i>Culture based</i>	
Air Sampling Impactor	Organisms are collected on culture medium
Liquid impinger	Organisms are collected in collection fluid
Air filtration	Organisms are collected on filter
<i>Non Culture based</i>	
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).

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 Karuppaiyil, 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 Karuppaiyil, 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 Karuppaiyil,

Table 3 Commonly used air sampling methods for indoor fungi.

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

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 air-borne 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 offensive 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 Karuppaiyl, 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 Karuppaiyl, 2010).

Acknowledgements

The authors thank Prof. Dr. Sarjerao Nimse, Hon. Vice chancellor of SRTM University for support.

References

- Asadi, E., Costa, J.J., da Silva, M.G., 2011. Indoor air quality audit implementation in a hotel building in Portugal. *Building and Environment* 46 (8), 1617–1623.
- Adgate, J.L., Ramachandran, G., Cho, S.J., Ryan, A.D., Grengs, J., 2008. Allergen levels in inner city homes: baseline concentrations and evaluation of intervention effectiveness. *Journal of Exposure Analysis and Environmental Epidemiology* 18, 430–440.
- Ahlen, C., Mandal, L.H., Iversen, O.J., 2003. An in-field demonstration of the true relationship between skin infections and their sources in occupational living systems in the North Sea. *Annals of Occupational Hygiene* 47, 227–233.
- Ahmad, I., Tansel, B., Mitrani, J.D., 2001. Effectiveness of HVAC Duct Cleaning Procedures in Improving Indoor Air Quality. *Environmental Monitoring and Assessment* 72 (3), 265–276.
- Airaksinen, M., Pasanen, P., Kurnitski, J., Seppanen, O., 2004. Microbial contamination of indoor air due to leakages from crawl space. A field study. *Indoor air* 4, 55–64.
- Alangaden, G.J., 2011. Nosocomial fungal infections: epidemiology, infection control, and prevention. *Infectious Disease Clinics of North America* 25 (1), 201–225.
- Asan, A., Okten, S.S., Sen, B., 2010. Airborne and soilborne microfungi in the vicinity Hamitabat Thermic Power Plant in Kırklareli City (Turkey), their seasonal distributions and relations with climatological factors. *Environmental Monitoring and Assessment* 164 (1–4), 221–231.

- Ayoko, G.A., Morawska, L., Kokot, S., Gilbert, D., 2004. Application of multicriteria decision making methods to air quality in the microenvironments of residential houses in Brisbane, Australia. *Environmental Science Technology* 38, 2609–2616.
- Aydogdu, H., Asan, A., Otkun, M.T., 2010. Indoor and outdoor airborne bacteria in child day-care centers in Edirne City (Turkey), seasonal distribution and influence of meteorological factors. *Environmental Monitoring and Assessment* 164 (1–4), 53–66.
- Aydogdu, H., Asan, A., 2008. Airborne fungi in child day care centers in Edirne City, Turkey. *Environmental Monitoring and Assessment* 147 (1–3), 423–444.
- Al-Suwaine, A.S., Bahkali, A.H., Hasnain, S.M., 1999a. Seasonal incidence of airborne fungal allergens in Riyadh, Saudi Arabia. *Mycopathologia* 145 (1), 15–22.
- Al-Suwaine, A.S., Hasnain, S.M., Bahkali, A.H., 1999b. Vaible airborne fungi in Riyadh, Saudi Arabia. *Aerobiologia* 15 (2), 121–130.
- Abdel Hameed, A.A., Ayesh, A.M., Abdel Razik Mohamed, M., Adel Malwa, H.F., 2012. Fungi and some mycotoxins producing species in the air of soybean and cotton mills: a case study. *Atmospheric Pollution Research* 3, 126–131.
- Alwakeel, S.S., Nasser, L.A., 2011. Indoor terrestrial fungi in household dust samples in Riyadh, Saudi Arabia. *Microbiology Journal* 1 (1), 17–24.
- Al-Humiani, A.A., 2010. Opportunistic pathogenic fungi of the house dust in Turuban. Kingdom of Saudi Arabia 4 (2), 122–126.
- Adhikari, A., Jung, J., Reponen, T., Lewis, J.S., DeGrasse, E.C., Faye Grimsley, L., Chew, G.L., Grinshpun, S.A., 2009. Aerosolization of fungi, (1–3)- β -glucan and endotoxin from flood-affected materials collected in New Orleans homes. *Environmental Research* 109, 215–224.
- Benhorst, D., Muller, A., Bock, K., Manuwald, O., Herbarth, O., von Bergen, M., 2008. Identification of spore allergens from the indoor mould *Aspergillus versicolor*. *Allergy* 63, 454–460.
- Bogomolova, E., Kirtsideli, I., 2009. Airborne fungi in four stations of the St. Petersburg Underground railway system. *International Biodeterioration & Biodegradation* 63, 156–160.
- Borrego, S., Guiamet, P., de Saravia, S.G., Batistini, P., Garcia, M., Lavin, P., Perdomo, I., 2010. The quality of air at archives and the biodeterioration of photographs. *International Biodeterioration & Biodegradation* 64, 139–145.
- Beletsotiis, E., Ghikas, D., Kalantzi, K., 2011. Incorporation of microbiological and molecular methods in HACCP monitoring scheme of molds and yeasts in a Greek dairy plant: a case study. *Procedia Food Science* 1, 1051–1059.
- Bokhary, H.A., Parvez, S., 1995. Fungi inhabiting household environments in Riyadh, Saudi Arabia. *Mycopathologia* 130, 79–87.
- Bakke, J.V., Norbäck, D., Wieslander, G., Hollund, B.E., Florvaag, E., Haugen, E.N., Moen, B.E., 2008. Symptoms, complaints, ocular and nasal physiological signs in university staff in relation to indoor environment – temperature and gender interactions. *Indoor Air* 18, 131–143.
- Barnes, C.S., Dowling, P., Van Osdol, T., Portnoy, J., 2007. Comparison of indoor fungal spore levels before and after professional home remediation. *Annals of Allergy, Asthma Immunology* 98, 262–268.
- Bartlett, K.H., Kennedy, S.M., Brauer, M., Van Netten, C., Dill, B., 2004. Evaluation and a predictive model of airborne fungal concentrations in school classrooms. *Annals of Occupational Hygiene* 48, 547–554.
- Baxter, C.G., Jones, A.M., Webb, K., Denning, D.W., 2011. Homogenisation of cystic fibrosis sputum by sonication – An essential step for *Aspergillus* PCR. *Journal of Microbiological Methods* 85 (1), 75–81.
- Bholah, R., Subratty, A.H., 2002. Indoor biological contaminants and symptoms of sick building syndrome in office buildings in Mauritius. *International Journal of Environmental Health Research* 12, 93–98.
- Bhetariya, P.J., Madan, T., Basir, S.F., Varma, A., Usha, S.P., 2011. Allergens/Antigens, Toxins and Polyketides of Important *Aspergillus* Species. *Indian Journal of Clinical Biochemistry* 26 (2), 104–119.
- Beezhold, D.H., Green, B.J., Blachere, F.M., Schmechel, D., Weissman, D.N., Velickoff, D., Hogan, M.B., Wilson, N.W., 2008. Prevalence of allergic sensitization to indoor fungi in 70 West Virginia. *Allergy and Asthma Proceedings* 29, 29–34.
- Blackely, C.H., 1873. Hay fever. Experimental research on the causes, treatment of Catarrhus Aestivus. Baillere Tindall Cox, London.
- Bornehag, C.G., Sundell, J., Sigsgaard, T., 2005. Dampness in buildings and health (DBH): Report from an epidemiological investigation on the association between indoor environmental factors and health effects among children in Sweden. *Indoor Air* 14, 59–66.
- Bonetta, S., Bonetta, S., Mosso, S., Sampo, S., Carraro, E., 2010. Assessment of microbiological indoor air quality in an Italian office building equipped with an HVAC system. *Environmental Monitoring and Assessment* 161 (1–4), 473–483.
- Boyacioglu, H., Haliki, A., Ates, M., Guvensen, A., Abaci, O., 2007. The statistical investigation on airborne fungi and pollen grains of atmosphere in Izmir-Turkey. *Environmental Monitoring and Assessment* 135 (1–3), 327–334.
- Beijer, L., Thorn, J., Rylander, R., 2002. Effects after inhalation of (1–3)- β -D-Glucan and relation to mould exposure in the home. *Mediators of Inflammation* 11, 149–153.
- Breda, L., Nozzi, M., De Sanctis, S., Chiarelli, F., 2010. Laboratory tests in the diagnosis and follow-up of pediatric rheumatic diseases: an update. *Seminars in Arthritis and Rheumatism* 40 (1), 53–72.
- Breum, N.O., Nielsen, B.H., Lyngbye, M., Midtgard, U., 1999. Dustiness of chopped straw as affected by lignosulfonate as a dust suppressant. *Annals of Agricultural and Environmental Medicine* 6, 133–140.
- Britton, L.A., 2003. Microbiological threats to health in the home. *Clinical Lab Science* 16, 10–15.
- Bazaka, K., Jacob, M.V., Crawford, R.J., Ivanova, E.P., 2011. Plasma-assisted surface modification of organic biopolymers to prevent bacterial attachment. *Acta Biomaterialia* 7 (5), 2015–2028.
- Buckmaster, P., 2008. Successful mold growth remediation in HVAC systems. *Occupational Health Safety* 77, 28–30.
- Buemi, M., Floccari, F., Netto, M., Allegra, A., Grasso, F., Mondio, G., Perillo, P., 2000. Environmental air pollution in an intensive care unit for nephrology and dialysis. *Journal of Nephrology* 13, 433–436.
- Burge, H.A., Rogers, C.A., 2000. Outdoor allergens. *Environmental Health Perspectives* 108, 653–659.
- Bush, R.K., 2008. Indoor allergens, environmental avoidance, and allergic respiratory disease. *Allergy and Asthma Proceedings* 29 (6), 575–579.
- Burton, N.C., Adhikari, A., Iossifova, Y., Grinshpun, S.A., Reponen, T., 2008. Effect of gaseous chlorine dioxide on indoor microbial contaminants. *Journal of the Air Waste Management Association* 58, 647–656.
- Burt, S.A., 2004. Essential oils: their antibacterial properties and potential applications in foods: a review. *International Journal of Food Microbiology* 94, 223–253.
- Burr, M.L., Matthews, I.P., Arthur, R.A., Watson, H.L., Gregory, C.J., Dunstan, F.D., Palmer, S.R., 2007. Effects on patients with asthma of eradicating visible indoor mould: a randomised controlled trial. *Thorax* 62, 767–772.
- Cabral, J.P.S., 2010. Can we use indoor fungi as bioindicators of indoor air quality? Historical perspectives and open questions. *Science of the total environment* 408 (20), 4285–4295.
- Cook, A., Derbyshire, E., Plumlee, G., 2011. Impact of natural dusts on human health. *Encyclopedia of Environmental Health*, 178–186.

- Cardenas, M.X., Cortes, J.A., Parra, C.M., 2008. *Aspergillus* spp. in risk areas of transplant patients in a university hospital. *Revista Iberoamericana de Micologia* 25, 232–236.
- Chao, H.J., Schwartz, J., Milton, D.K., Burge, H.A., 2003. The work environment and workers health in four large office buildings. *Environmental Health Perspectives* 111, 1242–1248.
- Cai, G., Malarstig, B., Kumlin, A., Johansson, I., Janson, C., Norback, D., 2011. Fungal DNA and pet allergen levels in Swedish day care centers and associations with building characteristics. *Journal of Environmental Monitoring* 13, 2018–2024.
- Cheong, C.D., Neumeister-Kemp, H.G., 2005. Reducing airborne indoor fungi and fine particulates in carpeted Australian homes using intensive, high efficiency HEPA vacuuming. *Journal of Environmental Health Research* 4 (1), 3–16.
- Chakraborty, S., Sen, S.K., Bhattacharya, K., 2000. Indoor and outdoor aeromycological survey in Burdwan, West Bengal, India. *Aerobiologia* 16 (2), 211–219.
- Cleri, D.J., Ricketti, A.J., Vernaleo, J.R., 2007. Fever of Unknown Origin Due to Zoonoses. *Infectious Disease Clinics of North America* 21 (4), 963–996.
- Cole, E.C., Cook, C.E., 1998. Characterization of infectious aerosols in health care facilities: an aid to effective engineering controls and preventive strategies. *American Journal of Infection Control* 26, 453–464.
- Cone, J.E., 1998. Indoor environmental quality. *The Western Journal of Medicine* 169, 373–374.
- Cornea, C.P., Ciuca, M., Voaides, C., Gagi, V., Pop, A., 2011. Incidence of fungal contamination in a Romanian bakery: a molecular approach. *Romanian Biotechnological Letters* 16 (1), 5863–5871.
- Cunningham, M.J., Roos, C., Gu, L., Spolek, G., 2004. Predicting psychrometric conditions in biocontaminant microenvironments with a microclimate heat and moisture transfer model description and field comparison. *Indoor Air* 14, 235–242.
- Curtis, L., Cali, S., Conroy, L., Baker, K., Ou, C.H., Hershov, R., Norlock-Cruz, F., Scheff, P., 2005. *Aspergillus* surveillance project at a large tertiary-care hospital. *Journal of Hospital Infection* 59, 188–196.
- Curtis, L., Allan, L., Stark, M., Rea, W., Vetter, M., 2004. Adverse health effects of Indoor Molds. *Journal of Nutritional Environmental Medicine* 14, 261–274.
- Drappatz, J., Schiff, D., Kesari, S., Norden, A.D., Wen, P.Y., 2007. Medical Management of Brain Tumor Patients. *Neurologic Clinics* 25 (4), 1035–1071.
- Dean, T.R., Roop, B., Betancourt, D., Menetrez, M.Y., 2005. A simple multiplex polymerase chain reaction assay for the identification of four environmentally relevant fungal contaminants. *Journal of Microbiological Methods* 61, 9–16.
- de Blay, F., Casel, S., Colas, F., Spirlet, F., Pauli, G., 2000. Elimination of airborne allergens from the household environment. *Revue des maladies respiratoires* 17, 29–39.
- Downs, S.H., Mitakakis, T.Z., Marks, G.B., Car, N.G., Belousova, E.G., Leuppi, J.D., Xuan, W., Downie, S.R., Tobias, A., Peat, J.K., 2001. Clinical importance of *Alternaria* exposure in children. *American Journal of Respiratory and Critical Care Medicine* 164, 455–459.
- Doherty, W.O.S., Mousaviou, P., Fellows, C.M., 2011. Value-adding to cellulosic ethanol: Lignin polymers. *Industrial Crops and products* 33 (2), 259–276.
- Douwes, J., 2003. (1–3)- β -D-glucans and respiratory health: a of the scientific evidence. *Indoor Air* 15, 160–169.
- Dharmage, S., Bailey, M., Raven, J., Mitakakis, T., Cheng, A., Guest, D., Rolland, J., Forbes, A., Thien, F., Abramson, M., Walters, E.H., 2001. Current indoor allergen levels of fungi and cats, but not house dust mites, influence allergy and asthma in adults with high dust mite exposure. *Am J Respir Crit Care Med* 164, 65–71.
- Dassonville, C., Demattei, C., Detaint, B., Barral, S., Bex-Capelle, V., Momas, I., 2008. Assessment and predictors determination of indoor airborne fungal concentrations in Paris newborn babies homes. *Environmental Research* 108, 80–85.
- Deacon, L.J., Pankhurst, L.J., Drew, G.H., Hayes, E.T., Jackson, S., Longhurst, P.J., Longhurst, J.W.S., Liu, J., Pollard, S.J.T., Tyrrel, S.F., 2009. Particle size distribution of airborne *Aspergillus fumigatus* spores emitted from compost using membrane filtration. *Atmospheric Environment* 43, 5698–5701.
- Duncan, S.M., Farrell, R.L., Jordan, N., Jurgens, J.A., Blanchette, R.A., 2010. Monitoring and identification of airborne fungi at historic locations on Ross Island, Antarctica. *Polar Science* 4, 275–283.
- Docampo, S., Trigo, M.M., Recio, M., Melgar, M., Garcia-Sanchez, J., Cabezudo, B. Fungal spore content of the atmosphere of the Cave of Nerja (southern Spain): Diversity and origin. *Science of the Total Environment*, 409, pp.835–843.
- Degobbi, C., Lopes, F.D.T.Q.S., Carvalho-Oliveira, R., Munoz, J.E., Saldiva, P.H.N., 2011. Correlation of fungi and endotoxin with Pm2.5 and meteorological parameters in atmosphere of Sao Paulo, Brazil. *Atmospheric Environment* 45, 2277–2283.
- de Ana, S.G., Torres-Rodriguez, J.M., Ramirez, E.A., Garcia, S.M., Belmonte-Soler, J., 2006. Seasonal distribution of *Alternaria*, *Aspergillus*, *Cladosporium* and *Penicillium* species isolated in homes of fungal allergic patients. *Journal of Investigational Allergology and Clinical Immunology* 16 (6), 357–363.
- Dutkiewicz, J., Skorska, C., Krysinska-Traczyk, E., Cholewa, G., Sitkowska, J., Milanowski, J., Gora, A., 2002. Precipitin response of potato processing workers to work-related microbial allergens. *Annals of Agricultural and Environmental Medicine* 9, 237–242.
- Ebbehoj, N.E., Hansen, M.O., Sigsgaard, T., Larsen, L., 2002. Building-related symptoms and molds: a two-step intervention study. *Indoor Air* 12, 273–277.
- Engelhart, S., Glasmacher, A., Simon, A., Exner, M., 2007. Air sampling of *Aspergillus fumigatus* and other thermotolerant fungi: Comparative performance of the Sartorius MD8 airport and the Merck MAS-100 portable bioaerosol sampler. *International Journal of Hygiene and Environmental Health* 210 (6), 733–739.
- Erkara, I.P., Asan, A., Yilmaz, V., Pehlivan, S., Okten, S.S., 2008. Airborne *Alternaria* and *Cladosporium* species and relationship with meteorological conditions in Eskisehir City, Turkey. *Environmental Monitoring and Assessment* 144 (1–3), 31–41.
- Escombe, A.R., Moore, D.A., Gilman, R.H., Navincopa, M., Ticona, E., Mitchell, B., Noakes, C., Martinez, C., Sheen, P., Ramirez, R., Quino, W., Gonzalez, A., Friedland, J.S., Evans, C.A., 2009. Upper-room ultraviolet light and negative air ionization to prevent tuberculosis transmission. *PLoS Medicine* 6, e43.
- Etzel, R.A., 2001. Indoor air pollutants in homes and schools. *Pediatric Clinics of North America* 48, 1153–1165.
- Ewers, L., Clark, S., Menrath, W., Succop, P., Borschein, I.L., 1994. Clean up of lead in house hold carpet and floor dust. *American Industrial Hygiene Association Journal* 55, 650–657.
- Fogelmark, B., Thorn, J., Rylander, R., 2001. Inhalation of (1–3)- β -D-Glucan causes airway eosinophilia. *Mediators of Inflammation* 10, 13–19.
- Foarde, K.K., Menetrez, M.Y., 2002. Evaluating the potential efficacy of three antifungal sealants of duct liner and galvanized steel as used in HVAC systems. *Journal of Industrial Microbiology and Biotechnology* 29, 38–43.
- Faure, O., Fricker-Hidalgo, H., Lebeau, B., Mallaret, M.R., Ambroise-Thomas, P., Grillot, R., 2002. Eight-year surveillance of environmental fungal contamination in hospital operating rooms and haematological units. *Journal of Hospital Infection* 50, 155–160.
- Ferguson, A., Bursac, Z., Coleman, S., Johnson, W., 2009. Comparisons of computercontrolled chamber measurements for soil–skin

- adherence from aluminum and carpet surfaces. *Environmental Research* 109 (3), 207–214.
- Farley, R.D., Franklin, D.H., 1992. Development of a humidifier for patient ventilation using a semi-permeable tube to minimize system condensate. *Journal of Biomedical Engineering* 14 (5), 426–430.
- Frazier, L.N., 1998. One stop mycology. *Mycological Research* 102 (1), 103–128.
- Franks, T.J., Galvin, J.R., 2010. Hypersensitivity pneumonitis: essential radiologic and pathologic findings. *Surgical Pathology Clinics* 3 (1), 187–198.
- Fung, F., Hughson, W.G., 2003. Health effects of indoor fungal bioaerosol exposure. *Applied Occupational and Environmental Hygiene* 18, 535–544.
- Gabrio, T., Dill, I., Fischer, G., Grun, L., Rabe, R., Samson, R., Seidl, H.P., Szewzyk, R., Trautmann, C., Warscheid, T., 2003. Strategies and targets for establishing a multicenter trial: Identification of indoor relevant moulds. *Mycoses* 46, 32–36.
- Gage-White, L., 1998. Practical environmental modifications for the inhalant allergy patient. *Otolaryngologic Clinics of North America* 31, 83–90.
- Gaffin, J.M., Phipatanakul, W., 2009. The role of indoor allergens in the development of asthma. *Current Opinion in Allergy and Clinical Immunology* 9, 128–135.
- Garrison, R.A., Robertson, L.D., Koehn, R.D., Wynn, S.R., 1993. Effect of heating/ventilation-air conditioning system sanitation on airborne fungal populations in residential environments. *Annals of Allergy, Asthma and Immunology* 71, 546–556.
- Guieysse, B., Hort, C., Platel, V., Munoz, R., Ondarts, M., Revah, S., 2008. Biological treatment of indoor air for VOC removal: Potential and challenges. *Biotechnology Advances* 26 (5), 398–410.
- Ghosh, D., Dhar, P., Das, A.K., Uddin, N., 2011. Identification and distribution of aeromycoflora in the indoor environment of Shyam bazaar metro-railway station, Kolkata, India. *African Journal of Microbiology Research* 5 (31), 5569–5574.
- Gutarowska, B., Sulyok, M., Krska, R., 2010. A study of the toxicity of moulds isolated from dwellings. *Indoor and Built Environment* 19 (6), 668–675.
- Gravesen, S., Nielsen, P.A., Iversen, R., Nielsen, K.F., 1999. Microfungal contamination of damp buildings—examples of risk constructions and risk materials. *Environmental Health Perspectives* 107 (3), 505–508.
- Gralton, J., Tovey, E., McLaws, M.L., Rawlinson, W.D., 2011. The role of particle size in aerosolised pathogen transmission: a review. *Journal of Infection* 62 (1), 1–13.
- Guo, H., 2011. Source apportionment of Volatile organic compounds in Hong Kong homes. *Building and Environment* 46 (11), 2280–2286.
- Giulio, M.D., Grande, R., Campi, E.D., Bartolomeo, S.D., Luigina Cellini, L., 2010. Indoor air quality in university environments. *Environmental Monitoring and Assessment* 170 (1–4), 509–517.
- Gottschalk, C., Bauer, J., Meyer, K., 2008. Detection of satratoxin g and h in indoor air from water-damaged building. *Mycopathologia* 166 (2), 103–107.
- Gosden, P.E., MacGowan, A.P., Bannister, G.C., 1998. Importance of air quality and related factors in the prevention of infection in orthopaedic implant surgery. *Journal of Hospital Infection* 39, 173–180.
- Gorny, R.L., Mainelis, G., Wlazlo, A., Niesler, A., Lis, D.O., Marzec, S., Siwinska, E., Ludzen-Izbinska, B., Harkawy, A., Kasznia-Kocot, J., 2007. Viability of fungal and actinomycetal spores after microwave radiation of building materials. *Annals of Agricultural and Environmental Medicine* 14, 313–324.
- Hagmolen, W., van den Berg, N.J., van der Palen, J., van Aalderen, W.M., Bindels, P.J., 2007. Residential exposure to mould and dampness is associated with adverse respiratory health. *Clinical Experimental Allergy* 37, 1827–1832.
- Hahn, T., Cummings, K., Michalek, A.M., Lipman, B., Segel, B., McCarthy, P., 2002. Efficacy of High efficiency particulate air filtration in preventing aspergillosis in immunocompromised patients with hematologic malignancies. *Infection Control and Hospital Epidemiology* 23, 525–531.
- Haas, D., Habib, J., Galler, H., Buzina, W., Schlacher, R., Marth, E., Reinthaler, F.F., 2007. Assessment of indoor air in Austrian apartments with and without visible mold growth. *Atmospheric Environment* 41 (25), 5192–5201.
- Hibbett, D.S., Ohman, A., Glotzer, D., Nuhn, M., Kirk, P., Nilsson, R.H., 2011. Progress in molecular and morphological taxon discovery in *Fungi* and options for formal classification of environmental sequences. *Fungal Biology Reviews* 25 (1), 38–47.
- Hsu, N.Y., Chen, P.Y., Chang, H.W., Su, H.J., 2011. Changes in profiles of airborne fungi in flooded homes in southern Taiwan after Typhoon Morakot. *Science of the Total Environment* 409 (9), 1677–1682.
- Hatfield, M.L., Hartz, K.E.H., 2011. Secondary organic aerosol from biogenic Volatile organic compounds mixtures. *Atmospheric Environment* 45 (13), 2211–2219.
- Hoang, C.P., Kinney, K.A., Corsi, R.L., Szaniszló, P.J., 2010. Resistance of green building materials to fungal growth. *International Biodeterioration Biodegradation* 64 (2), 104–113.
- Heinrich, J., 2011. Influence of indoor factors in dwellings on the development of childhood asthma. *International Journal of Hygiene and Environmental Health* 214 (1), 1–25.
- Herbarth, O., Schlink, U., Müller, A., Richter, M., 2003. Spatiotemporal distribution of airborne mould spores in apartments. *Mycological Research* 107, 1361–1371.
- Hasnain, S.M., Fatima, K., Al-Frayh, A., Al-Sedairy, S.T., 2005a. One year pollen and spore calendars of Saudi Arabia Al-Khobar, Abha and Hofuf. *Aerobiologia* 23 (3–4), 241–247.
- Hasnain, S.M., Fatima, K., Al-Frayh, A.S., Al-Sedairy, S.T., 2005b. Prevalence of airborne basidiospores in three coastal cities of Saudi Arabia. *Aerobiologia* 21 (2), 139–145.
- Hasnain, S.M., Al-Frayh, A.S., Al-Suwaine, A., Gad-El-Rab, M.O., Fatima, K., Al-Sedairy, S.T., 2004. *Cladosporium* and respiratory allergy: Diagnostic implications in Saudi Arabia. *Mycopathologia* 157 (2), 171–179.
- Hamada, N., Fujita, T., 2002. Effect of air-conditioner on fungal contamination. *Atmospheric Environment* 36, 5443–5448.
- Haas, D., Galler, H., Habib, J., Melkes, A., Schlacher, R., Buzina, W., Friedl, H., Marth, E., Reinthaler, F.F., 2010. Concentrations of viable airborne fungal spores and trichloroanisole in wine cellars. *International Journal of Food Microbiology* 144, 126–132.
- Harkawy, A., Gorny, R.L., Ogierman, L., Wlazlo, A., Lawniczek-Walczyk, A., Niesler, A., 2011. Bioaerosol assessment in naturally ventilated historically library building with restricted personnel access. *Annals of Agricultural and Environmental Medicine* 18 (2), 323–329.
- Hasnain, S.M., Akhter, T., Waqar, M.A., 2012. Airborne and allergenic fungal spores of the Karachi environment and their correlation with meteorological factors. *Journal of Environmental Monitoring* 14, 1006–1013.
- Hansen, V.M., Meyling, N.V., Winding, A., Eilenberg, J., Madsen, A.M., 2012. Factors affecting vegetable growers exposure to fungal bioaerosols and airborne dust. *The Annals of Occupational Hygiene* 56 (2), 170–181.
- Hedayati, M.T., Mayahi, S., Denning, D.W., 2010. A study on *Aspergillus* species in houses of asthmatic patients from Sari City, Iran and a brief review of the health effects of exposure to indoor *Aspergillus*. *Environmental Monitoring and Assessment* 168 (1–4), 481–487.
- Halios, C.H., Helmis, C.G., 2010. Temporal evolution of the main processes that control indoor pollution in an office microenvironment: a case study. *Environmental Monitoring and Assessment* 167, 199–217.
- Hiipakka, D.W., Buffington, J.R., 2000. Resolution of sick building syndrome in a highsecurity facility. *Applied Occupational and Environmental Hygiene* 15, 635–643.

- Hintikka, E.L., 2004. The role of *Stachybotrys* in the phenomenon known as sick building syndrome. *Advances in Applied Microbiology* 55, 155–173.
- Horner, W.E., 2003. Assessment of the indoor environment: evaluation of mold growth indoors. *Immunology and Allergy Clinics of North America* 23, 519–531.
- Husman, T., 1996. Health effects of indoor-air microorganisms. *Scandinavian Journal of Work, Environment Health* 22, 5–13.
- Hyvarinen, A., Sebastian, A., Pekkanen, J., Larsson, L., Korppi, M., Putus, T., Nevalainen, A., 2006. Characterizing microbial exposure with ergosterol, 3-hydroxy fatty acids, and viable microbes in house dust: determinants and association with childhood asthma. *Archives of Environmental and Occupational Health* 61, 149–157.
- Ismail, M.A., Chebon, S.K., Hakamya, R., 1999. Preliminary surveys of outdoor and indoor aeromycobiota in Uganda. *Aerobiologia* 148 (1), 41–51.
- Jaakkola, M.S., Laitinen, S., Piipari, R., Uitti, J., Nordman, H., Haapala, A.M., Jaakkola, J.J., 2002. Immunoglobulin G antibodies against indoor dampness-related microbes and adult-onset asthma: a population-based incident case-control study. *Clinical and Experimental Immunology* 129, 107–112.
- Jo, W.K., 2011. Bioaerosols in Apartment Buildings. *Encyclopedia of Environmental Health*, 323–330.
- Jung, J.H., Lee, J.E., Bae, G.N., 2011. Real-time measurement of UV-inactivated *Escherichia coli* bacterial particles by electrospray-assisted UVAPS spectrometry. *Science of the Total Environment* 409 (17), 3249–3255.
- Jacobs, R.L., Andrews, C.P., 2003. Hypersensitivity pneumonia-nonspecific interstitial pneumonia/fibrosis histopathologic presentation: a study in diagnosis and long-term management. *Annals of Allergy, Asthma Immunology* 90, 265–270.
- Jothish, P.S., Nayar, T.S., 2004. Airborne fungal spores in a saw mill environment in Palakkad District, Kerala, India. *Aerobiologia* 20 (1), 75–81.
- Jain, A.K., 2000. Survey of bioaerosol in different indoor working environments in central India. *Aerobiologia* 16 (2), 221–225.
- Jain, S., nag, V., Marak, R.S.K., prasad, N., Dhole, T., 2010. Incidence of mycobacteria and fungi in clinically suspected urinary tract infection of immunocompromised patients – A tertiary care hospital study. *International Journal of Infectious Diseases* 14 (1), e206–e207.
- Jovanovic, S., Felder-Kennel, A., Gabrio, T., Kouros, B., Link, B., Maisner, V., Piechotowski, I., Schick, K.H., Schrimpf, M., Weidner, U., Zollner, I., Schwenk, M., 2004. Indoor fungi levels in homes of children with and without allergy history. *International Journal of Hygiene and Environmental Health* 207, 369–378.
- Kawasaki, T., Kyotani, T., Ushioji, T., Izumi, Y., Lee, H., Hayakawa, T., 2010. Distribution and Identification of airborne fungi in railway stations in Tokyo, Japan. *Journal of Occupation Health* 52, 186–193.
- Kanaani, H., Hargeeaves, M., Ritovski, Z., Morawska, L., 2009. Fungal spore fragmentation as a function of airflow rates and fungal generation methods. *Atmospheric Environment* 43, 3725–3735.
- Kim, K., Kim, H., Kim, D., Nakajima, J., Higuchi, T., 2009. Distribution characteristics of airborne bacteria and fungi in the feedstuff-manufacturing factories. *Journal of Hazardous Materials* 169, 1054–1060.
- Kaarakainen, P., Rintala, H., Vesalainen, A., Hyvarinen, A., Nevalainen, A., Meklin, T., 2009. Microbial content of house dust samples determined with qPCR. *Science of the Total Environment* 407, 4673–4680.
- Kim, K.Y., Kim, C.N., 2007. Airborne microbiological characteristics in public buildings of Korea. *Building and Environment* 45 (2), 2188–2196.
- Kelkar, U., Bal, A.M., Kulkarni, S., 2005. Fungal contamination of air conditioning units in operating theatres in India. *Journal of Hospital Infection* 60, 81–84.
- Koch, A., Heilemann, K.J., Bishof, Heinrich, J., Wichmann, H.E., 2000. Indoor viable mold spores—a comparison between two cities, Erfurt (eastern Germany) and Hamburg (western Germany). *Allergy* 55, 176–180.
- Khan, Z.U., Khan, M.A.Y., Chandy, R., Sharma, P.N., 1999. *Aspergilli* and other moulds in the air of Kuwait. *Mycopathologia* 146 (1), 25–32.
- Kakde, D.B., Kakde, H.U., Saoji, A.A., 2001. Seasonal variation of fungal propagules in a fruit market environment, Nagpur (India). *Aerobiologia* 17 (2), 177–182.
- Kalyoncu, F., 2010. Relationship between airborne fungal allergens and meteorological factors in Manisa City, Turkey. *Environmental Monitoring and Assessment* 165 (1–4), 553–558.
- Karunasena, E., Larranaga, M.D., Simoni, J.S., Douglas, D.R., Straus, D.C., 2010. Building-associated neurological damage modeled in human cells: a mechanism of neurotoxic effects by exposure to mycotoxins in the indoor environment. *Mycopathologia* 170 (6), 377–390.
- Katz, Y., Verleger, H., Barr, J., Rachmiel, M., Kiviti, S., Kuttin, E.S., 1999. Indoor survey of moulds and prevalence of mould atopy in Israel. *Clinical and Experimental Allergy* 29, 186–192.
- Kawel, N., Schorer, G., Desbiolles, L., Seifert, B., Marincek, B., Boehm, T., 2011. Discrimination between invasive pulmonary aspergillosis and pulmonary lymphoma using CT. *European Journal of Radiology* 77 (3), 417–425.
- Kuo, N.W., Chiang, H.S., Chiang, C.M., 2008. Development and application of an integrated indoor air quality audit to an international hotel building in Taiwan. *Environmental Monitoring and Assessment* 147 (1–3), 139–147.
- Khan, A.A.H., Karuppaiyl, S.M., Chary, M., Kunwar, I.K., Wagh-ray, S., 2009. Isolation, identification and testing of allergenicity of fungi from air-conditioned indoor environments. *Aerobiologia* 25, 119–123.
- Khan, A.A.H., 2009. Studies on Indoor Fungi and Their Control (Thesis), Department of Biotechnology, School of Life Sciences, Swami Ramanand Teerth Marathwada University, Nanded.
- Khan, A.A.H., Karuppaiyl, S.M., 2010. Potential natural disinfectants for indoor environments. *International Journal of Clinical Aromatherapy* 7, 1–5.
- Khan, A.A.H., Karuppaiyl, S.M., 2011. Practices contributing to biotic pollution in Airconditioned indoor environments. *Aerobiologia* 27, 85–89.
- Kennedy, S.M., Copes, R., Bartlett, K.H., Brauer, M., 2004. Point-of-sale glass bottle recycling: indoor airborne exposures and symptoms among employees. *Occupational and Environmental Medicine* 61, 628–635.
- Kilburn, K.H., 2004. Role of molds and mycotoxins in being sick in buildings: neurobehavioral and pulmonary impairment. *Advances in Applied Microbiology* 55, 339–359.
- Krause, J.D., Hammad, Y.Y., Ball, L.B., 2003. Application of a fluorometric method for the detection of mold in indoor environments. *Applied Occupational and Environmental Hygiene* 18, 499–503.
- Kreja, L., Seidel, H.J., 2002. Evaluation of the genotoxic potential of some microbial volatile organic compounds (MVOC) with the comet assay, the micronucleus assay and the HPRT gene mutation assay. *Mutation Research* 513, 143–150.
- Lander, F., Meyer, H.W., Norn, S., 2001. Serum IgE specific to indoor moulds, measured by basophil histamine release, is associated with building-related symptoms in damp buildings. *Inflammation Research* 50, 227–231.
- Lange, J.H., Thomulka, K.W., Mastrangelo, G., Fedeli, U., Quezada, N.V., 2004. Airborne mold concentrations during remediation of an apartment building. *Bulletin of Environmental Contamination and Toxicology* 73, 487–489.
- Levetin, E., Shaughnessy, R., Rogers, C.A., Scheir, R., 2001. Effectiveness of germicidal UV radiation for reducing fungal contamination within air-handling units. *Applied and Environmental Microbiology* 67, 3712–3715.

- Leong, S.L., Pettersson, O.V., Rice, T., Hocking, A.D., Schnurer, J., 2011. The extreme xerophilic mould *Xeromyces bisporus* –Growth and competition at various water activities. *International Journal of Food Microbiology* 145 (1), 57–63.
- Lanier, C., Richard, E., Heutte, N., Picquet, R., Bouchart, V., Garon, D., 2010. Airborne molds and mycotoxins associated with handling of corn silage and oilseed cakes in agricultural environment. *Atmospheric Environment* 44 (16), 1980–1986.
- Li, D.W., Yang, C.S., 2004. Fungal contamination as a major contributor to sick building syndrome. *Advances in Applied Microbiology* 55, 31–112.
- Li, A., Liu, Z., Zhu, X., Liu, Y., Wang, Q., 2010. The effect of air-conditioning parameters and deposition dust on microbial growth in supply air ducts. *Energy and Buildings* 42, 449–454.
- Lugauskas, A., Levinskaite, L., Peculyte, D., 2003. Micromycetes as deterioration agents of polymeric materials. *International Biodeterioration Biodegradation* 52 (4), 233–242.
- Manuel, J., 2004. HVAC officemate. *Environmental Health Perspectives* 112, A346.
- Marcoux, D., Jafarian, F., Joncas, V., Buteau, C., Victor Kokta, V., Albert Moghrabi, A., 2009. Deep cutaneous fungal infections in immunocompromised children. *Journal of the American Academy of Dermatology* 61 (5), 857–864.
- Molhave, L., 2011. Sick building syndrome. *Encyclopedia of Environmental Health*, 61–67.
- McDonnell, G., Burke, P., 2011. Disinfection: is it time to reconsider Spaulding? *Journal of Hospital Infection* 78 (3), 163–170.
- Moulatrat, S., Hulin, M., Robine, E., Annesi-Maesano, I., Caillaud, D., 2011. Airborne fungal volatile organic compounds in rural and urban dwellings: detection of mould contamination in 94 homes determined by visual inspection and airborne fungal volatile organic compounds method. *Science of the Total Environment* 409 (11), 2005–2009.
- Muilenberg, M.L., 2003. Sampling devices. *Immunology and Allergy Clinics of North America* 23 (3), 337–355.
- Moulatrat, S., Robine, E., 2006. Mesure des mycotoxines aeroportees. *Revue Française d'Allergologie et d'Immunologie Clinique* 46 (3), 180–183.
- Menzies, D., Pasztor, J., Rand, T., Bourbeau, J., 1999. Germicidal ultraviolet irradiation in air conditioning systems: effect on office worker health and wellbeing: a pilot study. *Occupational and Environmental Medicine* 56, 397–402.
- Menetrez, M.Y., Foarde, K.K., Webber, T.D., Dean, T.R., Betancourt, D.A., 2007. Testing antimicrobial cleaner efficacy on gypsum wallboard contaminated with *Stachybotrys chartarum*. *Environmental science and pollution research international* 14, 523–528.
- Menetrez, M.Y., Foarde, K.K., Webber, T.D., Dean, T.R., Betancourt, D.A., 2008. Testing antimicrobial paint efficacy on gypsum wallboard contaminated with *Stachybotrys chartarum*. *Journal of Occupational and Environmental Hygiene* 5, 63–66.
- Moulatrat, S., Robine, E., Ramalho, O., Oturan, M.A., 2008. Detection of fungal development in closed spaces through the determination of specific chemical targets. *Chemosphere* 72, 224–232.
- Mc Grath, J.J., Wong, W.C., Cooley, J.D., Straus, D.C., 1999. Continually measured fungal profiles in sick building syndrome. *Current Microbiology* 38, 33–36.
- Mc Kernan, L.T., Wallingford, K.M., Hein, M.J., Burge, H., Rogers, C.A., Herrick, R., 2008. Monitoring microbial populations on wide-body commercial passenger aircraft. *Annals of Occupational Hygiene* 52, 139–149.
- Mitchell, C.S., Zhang, J., Sigsgaard, T., Jantunen, M., Liyo, P.J., Samson, R., Karol, M.H., 2007. Current state of the science. Health effects and indoor environmental quality. *Environmental Health Perspectives* 115, 958–964.
- Maurice, S., Floch, G.L., Bras-Quere, M.L., Barbier, G., 2011. Improved molecular methods to characterize *Serpula lacymans* and other Basidiomycetes involved in wood decay. *Journal of Microbiological Methods* 84, 208–215.
- Morey, P.R., Hull, M.C., Andrew, M. El Nino water leaks identify rooms with concealed mould growth and degraded indoor air quality. *International Biodeterioration & Biodegradation*, 52, pp. 197–202.
- Morrison, J., Yang, C., Lin, K.T., Haugland, R.A., Neely, A.N., Vesper, S.J., 2004. Monitoring *Aspergillus* species by quantitative PCR during construction of a multi-storey hospital building. *Journal of Hospital Infection* 57, 85–87.
- Mork, L., 2002. Breaking the mold. *Occupational Health Safety* 71, 80.
- Muise, B., Seo, D.C., Blair, E.E., Applegate, T., 2010. Mold spore penetration through wall service outlets: a pilot study. *Environmental Monitoring and Assessment* 163 (1–4), 95–104.
- Myatt, T.A., Minegishi, T., Allen, J.G., Macintosh, D.L., 2008. Control of asthma triggers in indoor air with air cleaners: a modeling analysis. *Environmental health* 7, 43.
- Nakayama, K., Morimoto, K., 2007. Relationship between, lifestyle, mold and sick building syndromes in newly built dwellings in Japan. *International Journal of Immunopathology Pharmacology* 20, 35–43.
- Nayar, T.S., Mohan, T.K., Jothish, P.S., 2007. Status of airborne spores and pollen in a coir factory in Kerala, India. *Aerobiologia* 23 (2), 131–143.
- Nielsen, K.F., Thrane, U., Larsen, T.O., Nielsen, P.A., Gravesen, S., 1998. Production of mycotoxins on artificially inoculated building materials. *International Biodeterioration & Biodegradation* 42, 9–16.
- Nieguitsila, A., Arne, P., Durand, B., Deville, M., Benoit-Valiergue, H., Chermette, R., Cottenot-Latouche, S., Guillot, J., 2011. Relative efficiencies of two air sampling methods and three culture conditions for the assessment of airborne culturable fungi in a poultry farmhouse in France. *Environmental Research* 11, 248–253.
- Norback, D., Cai, G., 2011. Fungal DNA in hotel rooms in Europe and Asia-associations with latiyude, precipitation, building data, room characteristics and hotel ranking. *Journal of Environmental Monitoring* 13, 2903–2895.
- Nevalainen, A., Seuri, M., 2005. Of microbes and men. *Indoor Air* 15, 58–64.
- Nilsson, A., Kihlstrom, E., Lagesson, V., Wessen, B., Szponar, B., Larsson, L., Tagesson, C., 2004. Microorganisms and volatile organic compounds in airborne dust from damp residences. *Indoor Air* 14, 74–82.
- Noris, F., Siegel, J.A., Kinney, K.A., 2011. Evaluation of HVAC filters as a sampling mechanism for indoor microbial communities. *Atmospheric Environment* 45 (2), 338–346.
- O'Neill, T.B., 1988. Succession and interrelationships of microorganisms on painted surfaces. *International Biodeterioration* 24 (4–5), 373–379.
- Olsen, J.H., Dragsted, L., Autrup, H., 1988. Cancer risk and occupational exposure to aflatoxins in Denmark. *British Journal of Cancer* 58, 392–396.
- O'Meara, T., Tovey, E., 2000. Monitoring personal allergen exposure. *Clinical Reviews in Allergy and Immunology* 18, 341–395.
- Oren, I., Haddad, N., Finkelstein, R., Rowe, J.M., 2001. Invasive pulmonary aspergillosis in neutropenic patients during hospital construction: before and after chemoprophylaxis and institution of HEPA filters. *American Journal of Hematology* 66, 257–262.
- Otto, D., Molhave, L., Rose, G., Hundell, H.K., House, D., 1990. Neurobehavioral and sensory irritant effects of controlled exposure to a complex mixture of volatile organic compounds. *Neurotoxicology and Teratology* 12, 649–652.
- Park, J.H., Cox-Ganser, J.M., Kreiss, K., White, S.K., Rao, C.Y., 2008. Hydrophilic fungi and ergosterol associated with respiratory illness in a water-damaged building. *Environmental Health Perspectives* 116, 45–50.
- Pedro-Botet, M.L., Sanchez, I., Sabria, M., Sopena, N., Mateu, L., Garcia-Nunez, M., Rey-Joly, C., 2007. Impact of copper and silver

- ionization on fungal colonization of the water supply in health care centers: implications for immunocompromised patients. *Clinical Infectious Diseases* 45, 84–86.
- Pieckova, E., Wilkins, K., 2004. Airway toxicity of house dust and its fungal composition. *Annals of Agricultural and Environmental Medicine* 11, 67–73.
- Pinheiro, A.C., Macedo, M.F., Jurado, Saiz-Jimenez, C., Viegas, C., Brandao, J., Rosado, L., 2011. Mould and yeast identification in archival settings: Preliminary results on the use of traditional methods and molecular biology options in Portuguese archives. *International Biodeterioration & Biodegradation* 65 (4), 619–627.
- Perdelli, F., Cristina, M.L., Sartini, M., Spagnolo, A.M., Dallera, M., Ottria, G., Lombardi, R., Orlando, P., 2006. Fungal contamination in hospital environments. *Infection Control and Hospital Epidemiology* 27 (1), 44–47.
- Phipatanakul, W., 2003. Environmental indoor allergens. *Pediatric Annals* 32, 40–48.
- Polizzi, V., Adams, A., Picco, A.M., Adriaens, E., Lenoir, J., Van Peteghem, C., De Saeger, De Kimpe, N., 2011. Influence of environmental conditions on production of volatiles by *Trichoderma atroviride* in relation with sick building syndrome. *Building and Environment* 46, 945–954.
- Portnoy, J.M., 2003. Evaluation of indoor mold exposure is what allergists do best. *Annals of Allergy, Asthma Immunology* 90, 175.
- Qudiesat, K., Abu-Elteen, K., Elkarmi, A., Hamad, M., Abussaud, M., 2009. Assessment of airborne pathogens in healthcare settings. *African Journal of Microbiology* 3 (2), 066–076.
- Reijula, K., 2004. Moisture-problem buildings with molds causing work-related diseases. *Advances in Applied Microbiology* 55, 175–189.
- Rene, E., Montes, M., Veiga, M.C., Kennes, C., 2010. Biotreatment of gas-phase VOC mixtures from fiberglass and composite manufacturing industry. *Journal of Biotechnology* 150 (1), 218–219.
- Ruping, M.J.G.T., Gerlach, S., Fischer, G., Lass-Flörl, C., Hellmich, M., Vehreschild, J.J., Cornely, O.A., 2011. Environmental and clinical epidemiology of *Aspergillus terreus*: data from a prospective surveillance study. *Journal of Hospital Infection* 78 (3), 226–230.
- Rajasekar, A., Balasubramanian, R., 2011. Assessment of airborne bacteria and fungi in food courts. *Building and Environment* 46 (10), 2081–2087.
- Reponen, T., 2011. Methodologies for Assessing Bioaerosol Exposures. *Encyclopedia of Environmental Health*, 722–730.
- Rengasamy, A., Zhuang, Z., BerryAnn, R., 2004. Respiratory protection against bioaerosols: literature review and research needs. *American Journal of Infection Control* 32 (6), 345–354.
- Reynolds, S.J., Black, D.W., Borin, S.S., Breuer, G., Burmeister, L.F., Fuortes, L.J., Smith, T.F., Stein, M.A., Subramanian, P., Thorne, P.S., Whitten, P., 2001. Indoor environmental quality in six commercial office buildings in the Midwest United States. *Applied Occupational and Environmental Hygiene* 16, 1065–1077.
- Robertson, O.H., Bigg, E., Puck, T.T., Miller, B.F., 1942. The bactericidal action of propylene glycol vapor on microorganisms suspended in air. *Journal of Experimental Medicine* 75 (6), 593–610.
- Roussel, S., Reboux, G., Bellanger, A.P., Sornin, S., Grenouillet, F., Dalphin, J.C., Piarroux, R., Millon, L., 2008. Characteristics of dwellings contaminated by moulds. *Journal of Environmental Monitoring* 10, 724–729.
- Rossnagel, B., 2000. IAQ priorities for mold, yeast, bacteria spores. *Occupational Health Safety* 69, 58–60.
- Richardson, M.D., Rennie, S., Marshall, I., Morgan, M.G., Murphy, J.A., Shankland, G.S., Watson, W.H., Soutar, R.L., 2000. Fungal surveillance of an open haematology ward. *Journal of Hospital Infection* 45, 288–292.
- Reponen, T., Singh, U., Schaffer, C., Vesper, S., Johansson, E., Adhikari, A., Grinshpun, S.A., Indugula, R., Ryan, P., Levin, L., LeMasters, G., 2010. Visually observed mold and moldy odor versus quantitatively measured microbial exposure in homes. *Science of the Total Environment* 408, 5565–5574.
- Rylander, R., Lin, R.-H., 2000. (1–3)- β -D-Glucan – relationship to indoor air-related symptoms, allergy and asthma. *Toxicology* 152, 47–52.
- Rylander, R., 2004. Microbial cell wall agents and sick building syndrome. *Advances in Applied Microbiology* 55, 139–154.
- Rylander, R., Holt, P.G., 1998. (1 \rightarrow 3)- β -D-Glucan and endotoxins modulate immune response to inhaled allergen. *Mediators of Inflammation* 7, 105–110.
- Rylander, R., Norrhall, M., Engdahl, U., Tunser, A., Holt, P.G., 1998. Airways inflammation, atopy, and (1 \rightarrow 3)- β -D-Glucan exposures in two schools. *American Journal of Respiratory and Critical Care Medicine* 158, 1685–1687.
- Rylander, R., 2010. Organic dust induced pulmonary disease – the role of mould derived β -glucan. *Annals of Agricultural and Environmental Medicine* 17, 9–13.
- Rylander, R., Reeslev, M., Hulander, T., 2010. Airborne enzyme measurements to detect indoor mould exposure. *Journal of Environmental Monitoring* 12, 2161–2164.
- Robbins, C.A., Swenson, L.J., Nealley, M.L., Gots, R.E., Kelman, B.J., 1999. Health effects of mycotoxins in indoor air: a critical. *Applied Occupational and Environmental Hygiene* 15, 773–784.
- Sailer, M.F., van Nieuwenhuijzen, E.J., Knol, W., 2010. Forming of a functional biofilm on wood surfaces. *Ecological Engineering* 36 (2), 163–167.
- Samet, J.M., Spengler, J.D., 2003. Indoor environments and health: Moving into the 21st century. *American Journal of Public Health* 93 (9), 1489–1493.
- Santilli, J., Rockwell, W., 2003. Fungal contamination of elementary schools: a new environmental hazard. *Annals of Allergy, Asthma Immunology* 90 (2), 203–208.
- Sato, K., Krist, S., Buchbauer, G., 2006. Antibacterial effect of trans-Cinnamaldehyde, (-)- perillaldehyde, (-)-citronellal, Citral, Eugenol and Carvacrol on Air borne microbes using an air washer. *Biological Pharmaceutical Bulletin* 29, 2292–2294.
- Savilahti, E., Kolho, K. L., Westerholm-Ormio, M., M Verkasalo, M., 2010. Clinics of coeliac disease in children in the 2000s *Acta Paediatrica/Acta Paediatrica*, 99, pp. 1026–1030.
- Shinoj, S., Visvanathan, R., Panigrahi, S., Kochubabu, M., 2011. Oil palm fiber (OPF) and its composites: a review. *Industrial Crops and Products* 33 (1), 7–22.
- Samimi, B.S., Ross, K., 2003. Extent of fungal growth on fiberglass duct liners with and without biocides under challenging environmental conditions. *Applied Occupational and Environmental Hygiene* 18, 193–199.
- Shirakawa, M.A., Loh, K., John, V.M., Silva, M.E.S., Gaylarde, C.C., 2011. Biodeterioration of painted mortar surfaces in tropical urban and coastal situations: comparison of four paint formulations. *International Biodeterioration Biodegradation* 65 (5), 669–674.
- Shirakawa, M.A., Gaylarde, C.C., Gaylarde, P.M., John, V., Gambale, W., 2002. Fungal colonization and succession on newly painted buildings and the effect of biocide. *FEMS Microbiology Ecology* 39 (2), 165–173.
- Sykes, P., Morris, R.H.K., Allen, J.A., Wildsmith, J.D., Jones, K.P., 2011. Workers' exposure to dust, endotoxin and b-(1–3) glucan at four large-scale composting facilities. *Waste Management* 31, 423–430.
- Simoes, S.A., Junior, D.P.L., Hahn, R.C., 2011. Fungal microbiota in air-conditioning installed in both adult and neonatal intensive treatment units and their impact in two university hospitals of the central western region, Mato Grosso, Brazil. *Mycopathologia* 172, 109–116.
- Salonen, H., Lappalainen, S., Lindroos, O., Harju, R., Reijula, K., 2007. Fungi and bacteria in mould-damaged and non-damaged office environments in subarctic climate. *Atmospheric Environment* 41, 6797–6807.

- Stark, P.C., Celedon, J.C., Chew, G.L., Ryan, L.M., Burge, H.A., Muilenberg, M.L., Gold, D.R., 2005. Fungal levels in the home and allergic rhinitis by 5 years of age. *Environmental Health Perspectives* 113 (10), 1405–1409.
- Singh, A., Gangal, S.V., Singh, A.E., 1994. Airborne fungal spores in the hospitals of metropolitan Delhi. *Aerobiologia* 10 (1), 11–21.
- Sen, B., Asan, A., 2009. Fungal flora in indoor and outdoor air of different residential houses in Tekirdag City (Turkey): seasonal distribution and relationship with climatic factors. *Environmental Monitoring and Assessment* 151 (1–4), 209–219.
- Soroka, P.M., Cyprowski, M., Stanczyk, I.S., 2008. Occupational exposure to mycotoxins in various branches of industry. *Medycyna pracy* 59, 333–345.
- Srikanth, P., Sudharsanam, S., Steinberg, R., 2008. Bio-aerosols in indoor environment: composition, health effects and analysis. *Indian Journal of Medical Microbiology* 26, 302–312.
- Thacker, P.D., 2004. Airborne mycotoxins discovered in moldy buildings. *Environmental Science Technology* 38 (15), 282A.
- Tilak, S.T., 1986. *Aerobiological investigations*. Department of Ocean Development technical publication No. 3, pp. 175–177.
- Tercelj, M., Salobir, B., Harlander, M., Rylander, R., 2011. Fungal exposure in homes of patients with sarcoidosis - an environmental exposure study. *Environmental Health* 10 (8), 1–5.
- Tewary, R., Mishra, J.K., 1996. Allergic potential of some *Aspergilli* on saw mill workers in Lucknow, India. *Aerobiologia* 12 (4), 229–232.
- Trout, D., Bernstein, J., Martinez, K., Biagini, R., Wallingford, K., 2001. Bioaerosol lung damage in a worker with repeated exposure to fungi in a water-damaged building. *Environmental Health Perspectives* 109, 641–644.
- Tsai, M., Liu, H., 2009. Exposure to culturable airborne bioaerosols during noodle manufacturing in central Taiwan. *Science of the Total Environment* 407, 1536–1546.
- Takigawa, T., Wang, B., Sakano, N., Wang, D., Ogino, K., Kishi, R., 2009. A longitudinal study of environmental risk factors for subjective symptoms associated with sick building syndrome in new dwellings. *Science of the Total Environment* 407, 5223–5228.
- Uztan, A.H., Ates, M., Abaci, O., Gulbahar, O., Erdem, N., Ciftci, O., Boyacioglu, H., 2010. Determination of potential allergenic fungal flora and its clinical reflection in suburban elementary schools in Izmir. *Environmental Monitoring and Assessment* 168 (1–4), 691–702.
- Vacher, S., Hernandez, C., Bartschi, C., Poussereau, N., 2010. Impact of paint and wall-paper on mould growth on plasterboards and aluminum. *Building and Environment* 45 (4), 916–921.
- Vesper, S.J., Wong, W., Kuo, C.M., Pierson, D.L., 2008. Mold species in dust from the International space station identified and quantified by mold-specific quantitative PCR. *Research in Microbiology* 159, 432–435.
- Voisey, C.R., 2010. Intercalary growth in hyphae of filamentous fungi. *Fungal Biology Reviews* 24 (3–4), 123–131.
- Varani, S., Stanzani, M., Paolucci, M., Melchionda, F., Castellani, G., Nardi, L., Landini, M.P., Baccarani, M., Pession, A., Sambri, V., 2009. Diagnosis of bloodstream infections in immunocompromised patients by real-time PCR. *Journal of Infection* 58 (5), 346–351.
- Vojdani, A., Kashanian, A., Vojdani, E., Campbell, A.W., 2003a. Saliva secretory IgA antibodies against molds and mycotoxins in patients exposed to toxigenic fungi. *Immunopharmacology and Immunotoxicology* 25, 595–614.
- Vojdani, A., Campbell, A.W., Kashanian, A., Vojdani, E., 2003b. Antibodies against molds and mycotoxins following exposure to toxigenic fungi in a water-damaged building. *Archives of Environmental Health* 58, 324–336.
- Wan, G.H., Li, C.S., 1999. Indoor endotoxin and glucan in association with airway inflammation and systemic symptoms. *Archives of Environmental Health* 54, 172–179.
- Wan, G.H., Li, C.S., Guo, S.P., Rylander, R., Lin, R.H., 1999. An airborne mold-derived product, (1–3)- β -D-Glucan, potentiates airway allergic responses. *European Journal of Immunology* 29, 2491–2497.
- Wang, C.C., Fang, G.C., Kuo, C.H., 2010a. Bioaerosols as contributors to poor air quality in Taichung City, Taiwan. *Environmental Monitoring and Assessment* 166 (1–4), 1–9.
- Wang, W., Ma, X., Ma, Y., Mao, L., Wu, F., Ma, X., An, L., Feng, H., 2010b. Seasonal dynamics of airborne fungi in different caves of the Mogao Grottoes, Dunhuang, China. *International Biodeterioration & Biodegradation* 64, 461–466.
- Woodcock, A.A., Steel, N., Moore, C.B., Howard, S.J., Custovic, A., Denning, D.W., 2006. Fungal contamination of bedding. *Allergy* 61 (1), 140–142.
- Wu, P., Su, H.J., Ho, H., 2000. A comparison of sampling media for environmental viable fungi collected in hospital environment. *Environmental Research Section A* 82, 253–257.
- Wady, L., Bunte, A., Pehrson, C., Larsson, L., 2003. Use of gas chromatography-mass spectrometry/solid phase microextraction for the identification of MVOCs from moldy building materials. *Journal of Microbiological Methods* 52, 325–332.
- Wouters, I.M., Douwes, J., Doekes, G., Thorne, P.S., Brunekreef, B., Heederik, D.J.J., 2000. Increased levels of markers of microbial exposure in homes with indoor storage of organic household waste. *Applied and Environmental Microbiology* 66 (2), 627–631.
- Wahid, O.A.A., Moustafa, A.W.F., Moustafa, A.M., 1996. Fungal population in the atmosphere of Ismailia City. *Aerobiologia* 12 (4), 249–255.
- Walinder, R., Norback, D., Wessen, B., Venge, P., 2001. Nasal lavage biomarkers: effects of water damage and microbial growth in an office building. *Archives of Environmental Health* 56, 30–36.
- Warsco, K., Lindsey, P.F., 2003. Proactive approaches for mold-free interior environments. *Archives of Environmental Health* 58 (8), 512–522.
- Weinhold, B., 2007. A spreading concern: inhalational health effects of mold. *Environmental Health Perspectives* 115, A300–A305.
- Weir, E., 2000. Indoor moulds and human health. *Canadian Medical Association Journal* 162, 1469.
- Weber, D.J., Barbee, S.L., Sobsey, M.D., Rutala, W.A., 1999. The effect of blood on the antiviral activity of sodium hypochlorite, a phenolic, and a quaternary ammonium compound. *Infection Control and Hospital Epidemiology* 20 (12), 821–827.
- Wilkins, K., Nielsen, K.F., Din, S.U., 2003. Patterns of volatile metabolites and nonvolatile trichothecenes produced by isolates of *Stachybotrys*, *Fusarium*, *Trichoderma*, *Trichothecium* and *Memnoniella*. *Environmental science and pollution research international* 10 (3), 162–166.
- Williams, D., 2004. An IAQ overview. Increasing ventilation is a fundamental method to reduce concentrations of several substances of concern. *Occupational Health Safety* 73, 66–96.
- Wilson, S.C., Straus, D.C., 2002. The presence of fungi associated with sick building syndrome in North American zoological institutions. *Journal of Zoo and Wildlife* 33, 322–327.
- Yates, A., Gray, F.B., Misiaszek, J.I., Wolman, W., 1986. Air ions: Past problems and future directions. *Environment International* 12 (1–4), 99–108.
- Yazicioglu, M., Asan, A., Ones, U., Vatansver, U., Sen, B., Ture, M., Bostancioglu, M., Pala, O., 2004. Indoor airborne fungal spores and home characteristics in asthmatic children from Edirne region of Turkey. *Allergologia et immunopathologia* 32, 197–203.
- Yike, I., 2011. Fungal Proteases and Their Pathophysiological Effects. *Mycopathologia* 171 (5), 299–323.
- Yamamoto, N., Schmechel, D., Chen, B.T., Lindsley, W.G., Peccia, J., 2011. Comparison of quantitative airborne fungi measurements by active and passive sampling methods. *Journal of Aerosol Science* 42 (8), 499–507.
- Yau, Y.H., Chandrasegaran, D., Badarudin, A., 2011. The ventilation of multiple-bed hospital wards in the tropics: a review. *Building and Environment* 46 (5), 1125–1132.
- Yamashita, K., Nishiyama, T., Yokoyama, T., Abe, H., Manabe, M., 2005. A comparison of the rate of bacterial contamination for

- prefilled disposable and reusable oxygen humidifiers. *Journal of Critical Care* 20 (2), 172–175.
- Yau, Y.H., Ng, W.K., 2011. A comparison study on energy savings and fungus growth control using heat recovery devices in a modern tropical operating theatre. *Energy Conversion and Management* 52 (4), 1850–1860.
- Zadrazil, F., Galletti, G.C., Piccaglia, R., Chiavari, G., Francioso, O., 1991. Influence of oxygen and carbon dioxide on cell wall degradation by white-rot fungi. *Animal Feed Science and Technology* 32 (1–3), 137–142.
- Zeliger, H.I., 2003. Toxic effects of chemical mixtures. *Archives of Environmental Health: An International Journal* 58 (1), 23–29.
- Zhen, S., Li, K., Yin, L., Yao, M., Zhang, H., Chen, L., Zhou, M., Chen, X., 2009. A comparison of the efficiencies of a portable BioStage impactor and a Reuter centrifugal sampler (RCS) High Flow for measuring airborne bacteria and fungi concentrations. *Journal of Aerosol Science* 40 (6), 503–513.
- Zain, M.E., 2011. Impact of mycotoxins on humans and animals. *Journal of Saudi Chemical Society* 15 (2), 129–144.
- Zotti, M., Ferroni, A., Calvini, P., 2011. Mycological and FTIR analysis of biotic foxing on paper substrates. *International Biodegradation & Biodegradation* 65 (4), 569–578.
- Zuraimi, M.S., Fang, L., Tan, T.K., Chew, F.T., Tham, K.W., 2009. Airborne fungi in low and high allergic prevalence child care centers. *Atmospheric Environment* 43, 2391–2400.