ABSTRACT
This review article is a synthesis of biodegraded indoor environments contain a complex mixture of live (viable) and dead (nonviable) microorganisms, fragments thereof, toxins, allergens, volatile microbial organic compounds and other chemicals. The indoor concentrations of some of these organisms and agents are known or suspected to be elevated in biodegraded indoor environments and may affect the health of people living or working there in. Asthma, asthmatic symptoms and allergic sensitization are linked with a number of indoor exposures, such as volatile organic compounds (VOCs), phthalates, tobacco smoke and biological agents. This review focuses solely on the biological exposures. Exposures to allergens, microbial agents and other biological particles are risk factors to these health effects, but the exact causal connections or the mechanisms underlying the symptoms are still not well understood. Among the open questions come the importance of genetic-environmental interactions in the development of allergy, pathophysiological mechanisms of the development of asthma and the role of various exposing agents as causal or adjuvant factors of these diseases.

Keywords: Bioaerosols, Biodegraded buildings, Indoor environment, Asthma, Allergic sensitization.

INTRODUCTION
The term bio-aerosol has been used for airborne particles that are living (bacteria, viruses and fungi) or has originated from living organisms. Bio-aerosols are ubiquitous, highly variable,
complex, natural or man-made in origin. The sampling and analysis of airborne microorganisms has received attention in recent years due to concerns with mould contamination in indoor environments the threat of bioterrorism and the occurrence of associated health effects, including infectious diseases, acute toxic effects, allergies and cancer. Bio-aerosols contribute to about 5-34% of indoor air pollution. In general, any bio-aerosols may be a potentially sensitizing agent but not all agents are equally important as the exposure agents of biodegraded building indoor environment. These exposure agents are known to bear major importance as indoor allergens.

It is obvious that bacterial cells and cellular fragments, fungal spores and by-products of microbial metabolism, present as particulate, liquid or volatile organic compounds may be components of bio-aerosols. Air contains significant number of microorganisms, acting as a medium for their transmission or dispersal. Though bio- aerosol particles are generally 0.3 to 100 um in diameter; but their respirable size fraction is regarding to be 1 to 10 um. Bio-aerosols ranging in size from 1.0 to 5.0 um generally remain in the air, whereas larger particles are deposited on surfaces [1].

Dust, mites, fungi, actinomycetes and bacteria produce allergens known to be associated with allergies and asthma. Many fungi, bacteria and actinomycetes are also known to produce toxins and irritants with suspected effects on respiratory health. It will be worthwhile to highlight that biodegraded indoor environments (particularly damp soil and wood) may also attract termites, fungi, actinomycetes and bacteria which can cause substantial damage to buildings, significantly compromising the integrity of the structure and therefore, is matter of deep concern to the health and safety of its occupants. Also, the presence of termites may indirectly affect the indoor environment by inducing the use and misuse of potentially hazardous pesticides. Although outbreaks of legionellosis are commonly associated with water sources in buildings, they are not typically associated with moist buildings.

Exposure to bio-aerosols unlike exposure to chemicals do not give threshold limits to assess health impact/ toxic effects, due to the complexity in their entity, variations in human response to their exposure and difficulties in recovering microorganisms that can pose hazard during routine sampling. Exposure agent of indoor environment that may have a role in the development of asthma and allergy. Microbial flora who produced infected indoor environment is listed as under:
Microbial agents of biodegraded building’s indoor environments-
- Toxins of Gram-positive and Gram-negative bacteria
- Fungal toxin
- Bacterial cells, spores and fragments
- Fungal spores and mycelia
- Microbial volatile organic compounds.

Allergens of the biodegraded building’s indoor environment-
- House dusts and mites
- Cockroaches, rodents and pests
- Pets: dog, cat, rabbit, mouse
- Fungal and bacterial allergens

Sources of Bio-aerosols in Indoor and Outdoor Environments
Bio-aerosols originate from any natural or man-made surface and each source gives rise to an entirely unique assemblage of bio-aerosols. Bioaerosols concentrations in air systems, indoor surfaces and damp room are highlighted in Table I. Deterioration of building materials, offensive odour and adverse human health effects are associated with microbial contamination of indoor environments.

Buildings: The presence of undesirable bio-aerosols is often associated with sick building syndrome (SBS) and building related illnesses (BRI). Sources include furnishings and building materials; fungal contamination within wall, ceiling, and floor cavities by movement of cells, spores and cell fragments via wall openings and gaps at structural joints. Lack of fresh air due to increased insulation of buildings, poorly maintained or operated ventilation systems, poorly regulated temperature and relative humidity levels contribute to the presence and multiplication of bio-aerosols. In developing countries, inadequacies in the buildings, design and improper ventilation may contribute to poor indoor air quality.

Healthcare Facilities: The microbial load in dental indoor air is highly influenced by the number of occupants, their activity and the ventilation. Occupants are a potential source of microorganisms as they shed the microorganisms from the skin squames and the respiratory. Ventilation causes dilution thus reducing the microbial load. Sinks, wash-basins and drains, nebulisers, humidifiers, and cooling towers are the potential sources of gram negative bacilli, which colonise on the moist surfaces. Dressings and bedding also can be the sources of
airborne microorganisms. Sweeping of floors and changing of bed linens also can cause suspension of bio-aerosols in air. Fungal spores gain entry into the hospital buildings through ventilation ducts with inadequate filtration. Since exposure levels are high, this may be an issue in the immune-compromised patients.

**Prevalence of dampness and bio-aerosols exposure**

The magnitude of the public health impact of dampness and bio-aerosols also depends on the prevalence of dampness and bio-aerosols. The American Housing Survey of the U.S. Census for 2003 reports that 10.4% of U.S. homes had water damage from exterior leakage, while 8% had water damage from interior leakage. However, the survey did not cover dampness or bio-aerosols. There is otherwise no national database on the prevalence of dampness and bio-aerosols in the biodegraded indoor environment. However, there is considerable variation in the prevalence estimates for each of the indicated moisture categories. For the “any dampness or microbes category”, four of the studies report the prevalence to be 50% or more, while three report prevalence values below 50%. The largest study reports prevalence of dampness and bio-aerosols in 50% of the homes \(^2\). Excluding the Freeman study because it only included bathrooms, the population weighted average prevalence of dampness or bio-aerosols from these studies are 47% in the U.S. This suggests that approximately half or almost half of residents of housing units in the United States have a substantially higher risk of experiencing adverse respiratory related health effects because of their exposure to dampness and/or bio-aerosols in their buildings. Moisture and bio-aerosols problems in buildings are known to cause health effects, but the causal agents of the exposure and the mechanisms of the health effects are obscure. To understand this phenomenon it is important to know how the indoor environment. So we have needed to develop such data base under Indian condition.

**Indoor environmental bio-aerosols and health**

Indoor air complaints are one of the most common environmental health problems. A great many complaints are connected with moisture problems and microbial growth in buildings, a phenomenon having several names depending on its appearance and severity, such as dampness, damp, damp or moisture patches, water damage, moisture damage, condensation, visible mould, mould growth or fungal growth. The association between health and various moisture problem indicators has been studied extensively, in more than 100 studies as reviewed by Verhoeff and Burge, Peat *et al.*, and Bornehag *et al.*,\[^3,4,5\]. The adverse health effects associated with dampness and mould appear mainly as respiratory symptoms (cough,
wheeze and asthma), but also as unspecific symptoms like tiredness and headaches [6]. The health findings are quite similar in various climatic areas and among both children and adults. Irritative symptoms in the eyes, respiratory tract and skin have been observed in the occupants of mouldy buildings, and in some cases, exposed people even develop outright allergies [7,8,9,10]. In addition, the prevalence of respiratory infections has been abnormally high in occupants of mouldy buildings [7,11,12]. Alveolitis, organic dust toxic syndrome (ODTS) and other chronic pulmonary diseases may also develop, although they are usually associated with high exposure in occupational environments such as agriculture [8,10,13]. The association between health effects and building-related moisture and mould is well demonstrated, but the causative agents and mechanisms that lead to the symptoms remain poorly known [5]. Sensitization to mite allergens can explain only part of the adverse health effects encountered in mouldy buildings [5]. Even though the mechanisms and causal factors are still obscure, extensive moisture damage and fungal growth in buildings are unacceptable and should be removed and prevented [14,15,16]. One important challenge in this research field is to reveal the causal relationships behind the complex phenomenon.

### Table I. Bio-aerosols concentrations in air system, indoor surface and damp room

<table>
<thead>
<tr>
<th>Category</th>
<th>Activity type</th>
<th>Bacteria (cfu/m³)</th>
<th>Fungi (cfu/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Air systems</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HVAC</td>
<td></td>
<td>10²-10⁵</td>
<td>10³-10⁴</td>
</tr>
<tr>
<td>Cooler</td>
<td></td>
<td>10²-10⁷</td>
<td>10³-10⁴</td>
</tr>
<tr>
<td><strong>Indoor surfaces</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ceiling and walls</td>
<td></td>
<td>10²-10⁷</td>
<td>10³-10⁸</td>
</tr>
<tr>
<td>Carpet</td>
<td></td>
<td>10²-10⁶</td>
<td>10³-10⁶</td>
</tr>
<tr>
<td>House plants</td>
<td></td>
<td>10³-10⁴</td>
<td>10³-10⁴</td>
</tr>
<tr>
<td>Operating room</td>
<td></td>
<td>10²-10³</td>
<td>10³-10⁴</td>
</tr>
<tr>
<td><strong>Damp rooms</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bathroom</td>
<td></td>
<td>10³-10⁷</td>
<td>10²-10⁷</td>
</tr>
<tr>
<td>Aeration tank</td>
<td></td>
<td>10²-10⁷</td>
<td>10³-10⁶</td>
</tr>
</tbody>
</table>

### Factors affecting microbial growth

The most important factors that affect microbial growth on building materials are moisture, nutrients, and temperature. In principle, water availability, usually discussed in terms of water activity (a_w), is the most critical factor for microbial growth. Moisture demands depend on fungal genus or species [17], but, in general, most mesophilic moulds can grow at a_w of 0.95-0.99, while the range for xerophilic moulds and for yeasts are 0.65-0.90 and 0.88-0.99,
respectively [18]. On building materials with limited nutrients, the minimal aw is higher as is the case with lower than optimum temperatures [17,19]. Fungal growth can start rapidly when moisture conditions are optimal in the material [20]. Rapid drying of a material decreases the viability of the spores [21], even though some fungi (e.g. Penicillium) can tolerate fluctuating moisture conditions [20,22]. Relative humidity (RH) of air has no direct influence on fungal growth, because fungi can grow at very low air humidities if there is enough moisture on the surface [18]. Condensation on cold surfaces, however, is possible and the humidity of air can influence the moisture content of material; an RH value of 70% is often considered to be critical [17]. No colonization of fibber glass insulation was seen at RH below 50% [23]. Fungi and bacteria need external sources of nutrition: carbon, nitrogen, phosphorous, and potassium [24] which is usually provided by most building materials. Trace amounts of nutrient occurs even in house dust and water and therefore, the availability of nutrients does not generally limit the microbial growth. Fungi can indeed grow on materials such as fibber glass and on galvanized steel which has an accumulated dust layer or a residue of lubricant oil [25,26]. The temperature in buildings, typically 20-25°C, promotes mainly mesophilic microbes, that have their optimal growth temperature 20-<45°C [27,28]. However, microbes may grow slowly at temperatures well below their optimal [27]. In addition, thermophilic microbes growing at 35-90°C are occasionally found in buildings. Most of the fungi grow best in rather neutral circumstances, optimally in the pH range 5-6.5 [27], which is also the pH range of most building materials. Because there is usually also enough light and oxygen available in the buildings, the availability of water remains the critical factor regulating the possible growth of microbes in indoor environments.

The main causes of bio-aerosols

• Water leaks from windows, roof, downspouts, guttering, internal plumbing and flooding.
  • Penetrating damp through walls
• Rising damp – usually caused by non-existent or defective damp proof courses.
• Wet or damp basements or crawl spaces
• Condensation from high relative humidity in air
• Too much water vapour or steam being generated through cooking, washing, bathing, showering and clothes drying which is allowed to travel throughout the house.
• Inadequate ventilation
• Inadequate heating
• Inadequate cleaning and drying after major water leaks and bursts or floods.
Where does micro flora typically appear from water leaks, penetrating and rising damp?

**In the house**
- Walls under the bottom corners of windows
- Floors around toilets and under dishwashers
- Walls around un-insulated cold-water pipes
- Around the chimney in the attic
- Near damaged or blocked downspouts.
- Basement - Bottom of walls, corners and floors
- Bottoms of walls - bridged or earth covered damp proof courses.

**In the crawl space**
- Exposed soil
- Standing water
- Mould growth on the joists or sub-floor
- Wood debris on ground

**In the basement**
- Damp walls or floors
- Under boxes or carpets
- Cracks and holes
- Efflorescence (A mineral deposit which is a sign of moisture entering the home)

Where do bio-aerosols appear from condensation?

**In bathrooms**
- Evidence of mould growth? How long does it take for moisture to disappear of cold surfaces after baths and showers?
- Is there an extractor fan and is it used?
- On ceilings over the bath or shower
- Window glass, sills and frames
- Under or behind the toilet and tank
- Exterior walls and tiled surfaces

**Bedrooms**
- Windows, in the bottom corners, sides or on the glass
• Behind dressers and wardrobes on exterior walls
• Particularly on the top corners of the bedroom walls which are the furthest from any heating source.

**Basement**

• On dry wall attached to exterior walls

**Crawl space**

• Bottom of un-insulated wood floors
• Inside of foundation walls or skirting

**Behavior of microbes in indoor environments**

Different fungal and bacterial genera have different capacities to release spores, and propagules which partly explains the fungal and bacterial composition of indoor air. For example, dry spores of *Aspergillus* and *Penicillium* are more easily released into air than *Cladosporium* spores under the same indoor air conditions \(^{[21]}\). *Penicillium commune* more easily releases spores than *Aspergillus versicolor* or *Paecilomyces variotii* \(^{[29]}\). This may partly explain the frequent occurrence of *Penicillium* in indoor air \(^{[30,31]}\). Fungi producing spores in slime, such as *Stachybotrys* and *Acremonium*, or those producing spores in closed fruiting bodies, such as *Chaetomium*, are not able to release spores easily \(^{[32]}\), thus the finding of their spores in air is less probable.

The release of spores of fungi and also sporulating bacteria such as actinobacteria are affected by external factors such as air humidity \(^{[33,34]}\) and air velocity \(^{[35,36]}\), as well as the texture of the surface and vibration of contaminated material \(^{[37]}\). More spores were released at a higher air velocity and at lower air humidity, while air turbulence increased the release from a rough surface \(^{[37]}\). A mechanical disturbance of mold growth, such as dismantling, increased the airborne concentration of spores \(^{[30]}\). Actinobacteria growing in the insulation layer of an external wall were observed to infiltrate to the indoor air, while fungal contamination originating from the envelope of precast concrete panel buildings was rare \(^{[3]}\). The behavior of airborne microbes, like particles in general, is strongly affected by the size of the spore or the cell \(^{[38]}\). All mechanisms for settling, resuspension and removal of microbes are at least partly influenced by the size of the particle. The smaller particles stay airborne longer, whereas the larger particles settle faster. Spores and cells are removed from indoor air by gravitational settling or by air movements due to ventilation. Even though lower
concentrations of fungi have been reported in buildings with mechanical ventilation \[39\], the operation of the mechanical ventilation does not always correlate with the airborne concentrations of viable fungi and bacteria \[40\]. Settled spores can be resuspended into the air by human activity.

Normal walking on a carpet can significantly increase spore counts \[41\]. In addition, the higher airborne fungal levels found in schools with carpeted floors than in respective offices were suggested to be due to the higher activity levels in schools \[42\]. Human activity is also known to cause the phenomenon called the “personal cloud” by being close to sources, such as cooking and vacuuming, and by resuspension of coarse particles \[43\]. The concentrations of viable fungi in indoor air are suggested to have large temporal and spatial variations \[30\]. The temporal variation is partly due to the seasonal variation in the fungal concentrations of the outdoor air \[31,44\] and partly due to the activity of the occupants; the highest concentrations are seen during the most intense activity \[15\]. The spatial variation of total spores within the same building can be remarkable \[45\] but there are also studies reporting no or little spatial variation between the different rooms of the same building \[44,46\]. Higher concentrations of fungal spores in the living room have been explained by higher activity there than in other rooms, but also by the influence of outdoor air, because the difference was seen in the concentrations of *Alternaria* and *Cladosporium* \[45\]. Spatial variation may also be caused by differences in fungal sources, as the variation seems to be greatest in damp residences, and between living areas and basement \[44\]. Li and Kendrich said that the largest fungal diversity found in the kitchens is thought to reflect the release of spores during food preparation and cooking \[46\].

**Control Measures for Reducing Bio-aerosols**

In order to reduce bio-aerosol loads in indoor environments, certain control measures can be followed. These include, proper identification and elimination of the microbial source in occupational and house-hold settings, maintenance of equipment, humidity control, natural ventilation, use of filters in ventilation, and air cleaning by the use of disinfectants and biocides. Periodical use of disinfectants and biocides is one of the methods to ensure controlled bio-aerosol concentrations. Air in the operating rooms and other critical areas like isolations rooms can be disinfected by fumigation using various microbicidal agents. Bacillocid is the most commonly used commercially available surface and environment disinfectant that has very good cleansing property along with bactericidal, eridical, sporicidal and fungicidal activity. It is either sprayed or mopped liberally allowing as contact time of 30
minutes and provides complete asepsis within 30 – 60 minutes. It does not require cleaning with detergent or carbolic acid or formalin fumigation. It does not require shutdown of the disinfected areas such as operating rooms for 24 hours.

CONCLUSION
How can be a potential source of bio-aerosols? In the context of healthcare settings, bio-aerosols can cause occupational hazards and nosocomial infection. It is likely that among individuals who are genetically susceptible to asthma and allergy, many environmental factors influence the development of such diseases. Current evidence suggests that exposure to indoor allergen is important in causing sensitization to these allergens. Sensitization to one or more of the common indoor allergens has been consistently associated with asthma and allergy among children and adults. That allergen provocation and low-dose repeated exposure can induce many of the features of asthma strongly suggests a causal relationship between allergen exposure in the home and asthma. Evidence for the direct link between exposure to indoor allergens and the development of asthma is available but not conclusive. It is likely that allergen exposure has its maximum effect during the postnatal period. What remains to be resolved is the dose of allergen causing sensitization versus tolerance, which might depend on the type of allergen, the effect of concomitant exposures (pollutant, viral infection, diet), and the differential effect observed in those with specific genetic susceptibility. Previous observational studies did not take into account the underlying genetic susceptibility, which is critical in the gene–environment interaction outcomes. As our understanding of genetic susceptibility increases, we should get better at resolving the mystery of the effect of indoor allergens and other environmental factors on the causation of asthma and allergy. In the developing country, there is a need for increased awareness for targeted surveillance for allergy and asthma infection control.

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