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Indoor air quality during renovation actions: a case study

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A temporary renovation activity releases considerably high concentrations of particulate matter, viable and non-viable, into air. These pollutants are a potential contributor to unacceptable indoor air quality (IAQ). Particulate matter and its constituents lead, sulfate, nitrate, chloride, ammonium and fungi as well as fungal spores in air were evaluated in a building during renovation action. Suspended dust was recorded at a mean value of 6.1 mg m^{-3} which exceeded the Egyptian limit values for indoor air (0.15 mg m^{-3}) and occupational environments (5 mg m^{-3}). The highest particle frequency (23%) of aerodynamic diameter (dae) was 1.7 μm. Particulate sulfate (SO_4^{2-}), nitrate (NO_3^-), chloride (Cl^-), ammonium (NH_4^+) and lead components of suspended dust averaged 2960, 28, 1350, 100 and 13.3 μg m^{-3}, respectively. Viable fungi associated with suspended dust and that in air averaged 1.11×10^6 colony forming unit per gram (cfu g^{-1}) and 92 colony forming unit per plate per hour (cfu p^{-1} h^{-1}), respectively. *Cladosporium* (33%), *Aspergillus* (25.6%), *Alternaria* (11.2%) and *Penicillium* (6.6%) were the most frequent fungal genera in air, whereas *Aspergillus* (56.8%), *Penicillium* (10.3%) and *Eurotium* (10.3%) were the most common fungal genera associated with suspended dust. The detection of *Aureobasidium, Epicoccum, Exophiala, Paecilomyces, Scopulariopsis, Ulocladium* and *Trichoderma* is an indication of moisture-damaged building materials. *Alternaria*, *Aureobasidium*, *Cladosporium*, *Scopulariopsis* and *Nigrospora* have dae >5 μm whereas *Aspergillus*, *Penicillium* and *Verticillium* have dae <5 μm which are suited to penetrate deeply into lungs. Particulate matter from the working area infiltrates the occupied zones if precautionary measures are inadequate. This may cause deterioration of IAQ, discomfort and acute health problems. Renovation should be carefully designed and managed, in order to minimize degradation of the indoor and outdoor air quality.

Indoor air quality is the most commonly used term to represent the healthiness of the air we breathe inside buildings. The major reasons for poor IAQ in buildings are the presence of local sources, poorly designed, maintained or operated ventilation systems and occasional operations of construction and renovation.[1] Renovation and remodeling are routinely conducted in most buildings. Volatile and semi-volatile organic compounds, dusts, fibers, gases, bio-aerosols and physical agents are the major air pollutants generated by renovation actions.[2] Renovation actions introduce particulate matter into indoor environments, and in turn it may infiltrate to other parts of the building. Particulate matter may cause acute health effects including discomfort and respiratory symptoms in the occupants.[3]

The dust and chips from lead based paints are dangerous when swallowed or inhaled. Old lead based paint is considered the most significant source of lead exposure. Exposure to lead can occur when lead based paint is improperly removed from surfaces by sanding, dry scraping, flame burning and demolition.[4] Measurements of chemical composition of airborne particulate matter can provide valuable insights into atmospheric processes and the sources of particulate matter. SO_4^{2-}, NO_3^-, Cl^- and NH_4^+ are the main inorganic compounds found in suspended dust. SO_4^{2-} is mainly present in the atmosphere as ammonium sulfate or as a secondary pollutant formed from both sulfuric acid vapor and oxidation of SO_2 gas. Moreover, nitrate is found as sodium nitrate or may be formed from the oxidation of NO_2 gas. NH_4^+ is present mainly as ammonium nitrate and it may be derived from ammonia emissions.[5] Many such anions in suspended dust may damage respiratory system and decay nearby properties.

Fungi can grow on almost all building materials, if there is enough moisture available.[6] Fungi require water activity (the viability of moisture) of at least 0.65 for growth and their activity increases as the water activity value approaches 1.[7] Demolition and renovation actions disturb the loci of fungal spores accumulated on buildings and release them with other particulates.[8] Airborne fungi or their mycotoxins in dust may cause inflammation, allergies and sick building syndrome.[9,10] Moreover, renovation and remediation can adversely impact indoor air quality and symptoms including headache, eye, throat and respiratory irritation and asthma are the most common complaints among occupants.[11]

The concentrations of suspended dust and airborne fungal spores were examined at the same building before renovation action.[12,13] It is essential to evaluate the concentration and composition of particulate matter during renovation actions. This study was carried out to evaluate concentrations of suspended dust and its components (lead, anions and fungi) as well as fungal spores in the air during renovation actions. In addition it aims to establish a rough picture of indoor airborne fungi that helps determine whether fungal types are toxic, infectious or allergenic; and also, to pay attention to such activities which have been carried out without any safety precautions.

Materials and methods

Sampling location

Air samples were collected from a seven storey building undergoing renovation. It is a scientific building containing many laboratories and offices. Technical investigation for moisture, mould damage and fibers was not made by engineers. The main renovation steps included demolishing, cutting, blowing, sand-blasting, supporting, epoxy painting, installing a new steel grid, the installation of sheets of concrete, cement or gypsum and finally painting. The building was not completely evacuated and there was no enclosure between renovation area and the occupied zones. Air samples were collected from

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different floors, in corridors, laboratories and offices, during various renovation steps. Air samples were collected between 10 am and 3 pm, at a height of 150 cm in the breathing zone above the floor during the renovation period (May to July, 2003).

Suspended dust

Suspended dust samples were collected using pre-weighed cellulose nitrate membrane filters (pore size 0.45 μm, diameter, 25 mm). Two consecutive air samples were obtained, every sampling day. Air was drawn at a flow rate of 6 l min^{-1}, for one hour. A total of 17 dust samples were collected from the working building. The filters were weighed under sterilized conditions, using a four figure balance (Precisa 80A–200M, Swiss Quality, with a resolution of 0.0001 g) and the results were calculated and expressed as mg m^{-3} of air.

Fungal spores associated with suspended dust

The sampled dust filters were washed in 100 ml sterilized distilled water, shaken vigorously for 60 min, and serial dilutions were prepared. Aliquots (0.5 ml) were plated onto the surface of Sabouraud dextrose agar medium (Difco, Detroit, MI). Petri Plates were incubated at 25 °C for 5–7 days, and checked periodically. The resultant colonies were calculated and expressed as colony forming unit per gram of suspended dust (cfu g^{-1}).

Airborne fungal spores

A sedimentation (open plate technique) method was used to collect airborne fungal spores. Six plates contained Sabouraud dextrose agar (Difco, Detroit, MI) were exposed to air for 15 min. Petri plates were incubated at 25 °C for 5–7 days and checked periodically. The resultant colonies were counted and expressed as colony forming unit per plate per hour (cfu p^{-1} h^{-1}).

Identification of fungi

Identification of fungi was performed mainly on the basis of the micro and macro-morphological features, reverse and surface coloration of colonies on Sabouraud dextrose agar, Czapex dox agar and Malt extract agar (Difco, Detroit, MI) media. Some cultivable isolates were identified to the genus level, whereas others were identified to species level using various literature references.[14–18]

Aerodynamic diameter measurement (dae)

Physical diameters of the sampled suspended dust filters (4 filters were cleared using immersion oil) as well as fungal spore were measured by an optical light microscopy (× 400) using calibrated circles of graduated size on an eye piece (reticule eye piece).[19] Aerodynamic diameter was computed from the physical diameter assuming a density of 1 g cm^{-3} and spherical shape.[20]

Sulfate, nitrate, chloride and ammonium associated with dust

SO_4^{2-}, NO_3^-, Cl^- and NH_4^+ components of suspended dust were measured in the remaining stock solution (washed water of membrane filters), 15 ml for each anion measurements.[21]

Lead analysis

The filter plus portion of stock solution (20 ml) were digested in acid solution (1 : 3 HCl : HNO_3). The final volume was adjusted to 25 ml and analyzed using an atomic absorption spectrophotometer (flame AAS 3300, Perkin-Elmer, Norwalk, CT, USA).[22]

Results and discussion

There is a lack of data regarding concentrations of air pollutants released during renovation action. Renovation activity generates particulate matter (viable and non-viable) into air in which it may be a potential contributor to poor IAQ. In this study, suspended dust ranged from 0.95 to 51.1 mg m^{-3} with a mean value of 6.1 mg m^{-3} (Table 1). The highest dust level (51.1 mg m^{-3}) was detected during dry sanding tasks. Eighty microscopic fields were randomly counted in 4 chosen filters and a total of 2108 particles were sized. The sampled dust particles differed in size. The highest particle frequency (23%) of dae was 1.7 μm; however the median particle dae was 4.95 μm. Generally, particles <5 μm in diameter constituted ~80% whereas particles >5 μm constituted ~20%. Therefore most of the airborne particles may remain suspended for longer periods of time. This gives the opportunity for particles to disperse from the working site to the occupied zones (the building was not completely evacuated). In the present study, the level of particulate matter exceeded the Egyptian limit values of indoor air (150 μg m^{-3}) and occupational settings (5000 μg m^{-3}).[23] Moreover, our findings greatly exceeded the mean value (584 μg m^{-3}) of suspended dust detected in the same building during normal housekeeping activities[12] and the maximum dust level (313 μg m^{-3}) for indoor air in office environments.[24]

Particulate sulfate (SO_4^{2-}), nitrate (NO_3^-), chloride (Cl^-) and ammonium (NH_4^+) levels were detected at mean values of 2960, 28, 1350 and 100 μg m^{-3}, respectively (Table 1). Sulfate constituted the major portion (2960 μg m^{-3}) of suspended dust components. For all components our results exceeded the levels (64.9, 7.95, 13.9 and 12.25 μg m^{-3}) recorded by Kamal[24] in indoor air of office environments. This is due to SO_4^{2-}, Cl^-, NH_4^+ and NO_3^- salts which are originally contained in the dust released from building materials. Anionic compounds may be produced from scientific laboratories and in turn may settle onto surfaces. Also, chemical conversion of infiltrated gases may play a role in SO_4^{2-}, Cl^-, NH_4^+ and NO_3^- formation. Hansen[1] reported that the exposure to chemical contaminants vary according to the building's characteristics such as its age, type of materials used in its construction, and type of equipment and supplies used by building occupants, and this corresponds to our discussion.

Table 1 The range, mean and standard deviation (SD) of the indoor air viable and non-viable pollutants during renovation action

Pollutant	Range	Mean	±SD
Suspended dust/mg m^{-3}	0.96–51.1	6.1	12.1
Anionic components/μg m^{-3}			
SO_4^{2-}	1260–6900	2960	1810
Cl^-	480–3900	1350	1170
NO_3^-	12–43	28	8
NH_4^+	34–270	100	75
Lead/μg m^{-3}	2–45	13.3	9.1
Fungi associate with dust/cfu g^{-1}	2×10^5–1.33×10^6	1.11×10^6	1.28×10^6
Airborne fungi/cfu p^{-1} h^{-1}	18–204	92	61

[a] cfu g^{-1}: colony forming unit per gram, cfu p^{-1} h^{-1}: colony forming unit per plate per hour.

Pinto *et al.*[25] reported that PM10 and PM2.5 pose a greater health risk, as tiny particles can penetrate the human respiratory system, damage the respiratory tract, and increase asthma and lung diseases. Sawyer[26] stated that the dust generated by renovation activities would not result in any significant adverse health effects at typical levels, but generating large quantities of dust in an enclosed area can create short term respiratory problems. However, epidemiological studies suggested that morbidity and mortality rates are associated with fine particles, sulfates, hydrogen ion or acid mist concentrations.[27] Acid aerosols can impair mucociliary clearance and exposure of animal models to H_2SO_4 and SO_2 caused chronic bronchitis.[28] Moreover, Dolske[29] concluded that anionic compounds may cause decay of building surfaces.

In the present study, lead concentrations ranged from 2 to 45 μg m^{-3} with a mean value of 13.3 μg m^{-3} (Table 1). The highest lead level, 45 μg m^{-3}, was found during dry sanding tasks. This is attributed to renovation dust which may contain high levels of lead-based paints. Lead compounds have been widely used as pigments in paints. Our findings are in agreement with Piacitelli and Sussell[30] who found lead in the range of "not detected" to 660 μg m^{-3} with a mean value of 22 μg m^{-3} where the highest lead level (660 μg m^{-3}) was detected during dry manual sanding. People are exposed to airborne lead either directly by inhalation or indirectly by ingestion of leaded dust. Once lead is adsorbed it is distributed to the soft tissue and skeleton.[31] Lead can produce many toxic effects in the body. The main symptoms of lead poisoning include anemia, abdominal cramps, and renal damage. Therefore paints that are distributed during renovation pose a significant long term health hazard.[31]

Table 1 shows the concentration of fungal spores associated with suspended dust. It varied from 2×10^5 to 1.33×10^6 cfu g^{-1} with a mean value of 1.11×10^6 cfu g^{-1} which exceeded the OSHA[32] limit value of 10^6 cfu g^{-1}. This finding indicates that fungi proliferate on moisture-damaged building materials. A building may contain much biodegradable material which supports microbial growth, which in its turn may emit aeroallergens. The predominant fungal types associated with suspended dust are shown in Table 2. *Aspergillus* spp. (56.9%), *Penicillium* spp. (10.3%), *Eurotium* (10.3%), and *Paecilomyces* (3.4%) were the most frequent fungal genera associated with suspended dust. Moreover, *Absidia*, *Helminthosporium*, *Trichoderma*, *Basidiomycetes*, *Chlamydomyces* and yeasts reached relative frequencies of 1.7 or 3.4%. The high counts of *Aspergillus* detected may be interpreted according to Krasinski *et al.*[33] who stated that renovation and construction can disperse *Aspergillus*-contaminated dust and bursts of airborne fungal spore clusters. *Aspergillus* species have been reported to be allergenic and their presence is associated with many health problems.[34]

Airborne fungi ranged from 18 to 204 cfu p^{-1} h^{-1} with a mean value of 92 cfu p^{-1} h^{-1} (Table 1). A sedimentation method was used to isolate airborne fungi because of its practicality and low cost.[35] On the other hand it gives only a rough approximation of the types and numbers of airborne organisms.[36] Table 3 shows the type, count, percentage and aerodynamic diameter of the isolated airborne fungi. A total of 242 fungal isolates belonging to 23 genera were identified. *Aspergillus* (10 spp., 25.4%), *Cladosporium* (33%), *Alternaria* (11.2%) and *Penicillium* (5 spp., 6.6%) were the most dominant genera. *Epicoccum* (0.83%), *Ulocladium* (0.4%), *Aureobasidium* (1.65%), *Scopulariopsis* (1.24%), *Nigrospora* (1.65%), *Geotrichum* (1.24%), *Trichophyton* (0.4%), *Verticillium* (0.4%), *Fusarium* (0.83%), *Basidiomycetes* (0.4%), *Mucor* (0.4%), *Biospora* (0.4%), *Chalara* (0.4%), yeasts (3.7%), sterile hyphae (6.2%) and unknown spp. (2.1%) were also found during renovation. Many of these fungal genera indicate signs of moisture problems and water-damaged building materials. At the same building before renovation Abdel Hameed[13] found airborne fungi in the range of 25–48 cfu p^{-1} h^{-1}, in which *Aspergillus*, *Penicillium, Alternaria, Trichoderma*, *Cladosporium* and yeasts only were detected.

The difference between fungal types and their frequencies before and during renovation is shown in Fig. 1. It is clear that

Table 2 Identification of fungal spores associated with suspended dust

Genera and species	Count	%
***Aspergillus* link**	**33**	**56.8**
Aspergillus flavus	3	5.2
Aspergillus fumigatus	2	3.4
Aspergillus glaucus	1	1.7
Aspergillus niger	8	13.7
Aspergillus sydowii	1	1.7
Aspergillus versicolor	13	22.4
Aspergillus species	5	8.6
Absidia	1	1.7
Basidiomycetes	2	3.4
Chlamydomyces	1	1.7
Eurotium	6	10.3
Helminthosporium	2	3.4
***Penicillium* link**	**6**	**10.3**
Penicillium atramentosum	4	6.9
Penicillium corylophium	2	3.4
Paecilomyces	2	3.4
Trichoderma	2	3.4
Yeasts	1	1.7
Sterile hyphae	2	3.4
Total isolates	**58**	

Table 3 Type, count, percent and aerodynamic diameter (dae) of airborne fungal spores

Genera and species	Count	%	Dae/μm
Alternaria	27	11.2	5–10 × 14–20[a]
***Aspergillus* link**	**62**	**25.62**	
Aspergillus aegypticus	1	0.4	2.5–4
Aspergillus flavus	10	4.1	3.8–4
Aspergillus fumigatus	2	0.8	2
Aspergillus niger	28	11.6	3.7
Aspergillus luchuensis	1	0.4	4
Aspergillus oryzae	1	0.4	5.7
Aspergillus sydowii	5	2.1	2
Aspergillus terreus	3	1.24	2
Aspergillus versicolor	3	1.24	2.5
Aspergillus species	8	3.3	2.5–4
Aureobasidium	4	1.65	5
Basidiomycetes	1	0.4	–
Blastomyces	1	0.4	3
Biospora	1	0.4	–
Chalara	1	0.4	–
Cladosporium	80	33	2.4–4 × 4.9–14[a]
Epicoccum	2	0.83	17.2
Exophiala	2	0.83	1.6
***Fusarium* link**	**2**	**0.83**	
Fusarium proliferatum	1	0.4	1.7–2.4 × 10[a]
Fusarium solani	1	0.4	2.2–3 × 10–11[a]
Geotrichum	3	1.24	4–7.5
Mucor	1	0.4	5.5
Nigrospora	4	1.65	8.5
***Penicillium* link**	**16**	**6.6**	
Penicillium atramentosum	7	2.9	2.1 × 3[a]
Penicillium chrysogenum	2	0.8	2.8
Penicillium citrogenium	3	1.24	3.3
Penicillium citrinium	3	1.24	2.1
Penicillium corylophilum	2	0.83	2.4
Scopulariopsis	3	1.24	5.7
Trichophyton	1	0.4	–
Ulocladium	1	0.4	14
Verticillium	1	0.4	3.1
Yeasts	9	3.7	5 × 13.7[a]
Sterile hyphae	15	6.2	–
Unknown	3	2.1	–
Total	**242**		

[a] Long axis; —: not measured.

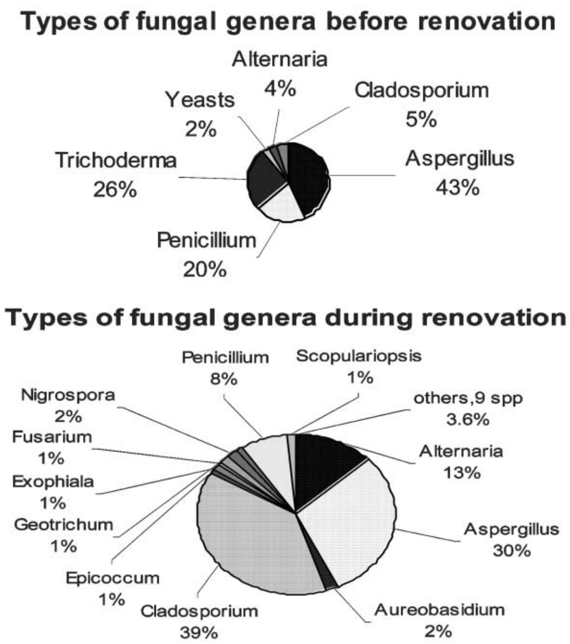

Fig. 1 Types of fungal genera before and during renovation.

Aspergillus, *Penicillium* and *Cladosporium* were the most common fungal genera in the air before and during renovation. Moreover, renovation adds more fungal types into the air. *Penicillium* and *Aspergillus* species were common indoors because they originate from indoor sources.[37] Ledford[38] reported that *Penicillium, Aspergillus* and *Cladosporium* are the most dominant indoor molds in non-damaged indoor environments, but when a building is damaged by moisture or water leakage, the aforementioned common molds are replaced by molds requiring higher water activity. Moreover, Flannigan[39] reported that dust reflects the microbial flora of the building and the viable counts are higher in dust than in the air. *Acremonium*, *Alternaria*, *Aspergillus*, *Aureobasidium*, *Chaetomium*, *Eurotium*, *Exophiala*, *Paecilomyces*, *Phoma*, *Phialophora*, *Scopulariopsis*, *Trichoderma* and *Wallemia* are indicators of moisture-damaged buildings.[40,41] Many of these fungal types were detected in the present study. However, the presence or absence of any fungal genus is related to the amount of moisture available inside buildings, because the moisture level dictates what fungal types proliferate to problematic levels.[42]

There are no established guidelines for indoor airborne fungi. However, some fungal types are unacceptable in indoor air (*Aspergillus fumigatus* and *Stachybotrys chartarum*).[43] Hansen[1] reported that absolute number may be misleading, "*i.e.* the concentration may be low but the predominant species may be dangerous". Reponen[44] reported that number of fungal genera or species needed to cause a certain symptom or disease is not known. OSHA[32] adds that levels in excess of the limit value do not necessarily imply that the conditions are unsafe or hazardous, but the type and concentration of the microorganism will determine the hazard to the employee. Inhalation of fungal spores or airborne mycotoxins can cause a variety of well characterized problems including hypersensitivity, pneumonia and allergies.[1] Our results confirmed that the concentration and composition of pollutants may raise the opportunity of infection and acute health problems among occupants and workers, in particular individuals at risk.

The aerodynamic diameter of isolated airborne fungi is shown in Table 3. Variation in spore size, however, by genus was observed. *Alternaria*, *Aspergillus oryzae*, *Cladosporium* L. ax, *Aureobasidium*, *Scopulariopsis*, yeast, *Nigrospora* and *Mucor* have dae ranging from 5 to 10 μm which may be deposited in the upper respiratory system causing allergic rhinitis. However, *Aspergillus* spp, *Blastomyces*, *Exophiala*, *Penicillium* and *Verticillium* have dae <5 μm which may pass deep into the lungs causing allergic alveolitis.[45] Aerodynamic diameter affects the landing site of an organism. Infectivity of a deposited particle is affected by many factors such as biological properties, chemical components, dose and landing site of their deposition in the human respiratory tract,[46] in addition to the person's immunity and the virulence of the organism.[47] It should be mentioned that aerodynamic diameter depends on effective diameter, degree of hydration, relative humidity and internal direction of non-spherical particles.[48] Therefore in the present study calculation of dae without an aerodynamic particle sizer is difficult and does not reflect reality.

In this case study renovation was conducted without taking any particular precautions in order to minimize dust emission and occupant exposure to viable and non-viable particulates. There was no walk through and visual inspection to identify gross loci of fungi or to determine the presence of fibers (asbestos). Uncontrolled disturbance of air pollutants could spread potentially toxic, allergenic and infectious agents to the occupied zones. It is recommended that a number of safety precautions must be taken to avoid either excess exposure to hazardous pollutants or to improve IAQ during future proposed projects. SMANCA[49] lists many of procedures in order to control and improve IAQ during renovation. Some of them are to schedule tasks which produce large levels of dust during periods when the building is completely evacuated, to use local exhaust ventilation, effectively to isolate the working area from the occupied zones and to intensify housekeeping. Moreover, dry sanding and dry scraping to remove paints should be avoided.

Conclusion

Renovation produces and distributes problematic pollutants into indoor air. Particulate matter is released at considerably high levels. Its constituents, particularly lead and *Aspergillus* spp., have been identified as health problem agents during renovation. *Aspergillus* was the most common fungal genus associated with dust whereas *Cladosporium* followed by *Aspergillus* were the common fungal genera detected in air. Renovation adds diverse fungal types into air. Many of them are an indication of water incursion and moisture-damaged building materials. Technical actions should be taken into consideration in order to minimize the spread of pollutants from the working area to the occupied zones and to improve IAQ. From this point of view our results are important in hospital, daycare facility and school renovations because of the high risk of viable and non-viable particles being released and infiltrated into the occupied zones.

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