

Incidence and remediation of fungi in a sick building in Malaysia: a case study

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Abstract Problems caused by indoor microbial, especially fungal growth, have been further exaggerated by the increased incidence of water intrusions, condensation from air-conditioning system, and other factors. While fungal contamination in a building can be one of the indicators of indoor air quality (IAQ), air quality assessment and remediation should be considered as important and should be carried out systematically. This study reports the incidence and remediation of an excessive fungal growth in a building in Universiti Sains Malaysia (USM), Pulau Pinang, Malaysia. Acting on an official report by the building owner and occupants, an immediate walk-through investigation was carried out between June and December 2009. A thorough sampling comprising swab and spore impactor techniques showed that the colony-forming unit per cubic meter of air (CFU/m³) levels were far above those in the guidelines of most developed countries. Thus, the building was declared a 'sick building' and closed to the publics. However, through immediate action with recommended methods to overcome the problem, the premise has been pronounced safe. This is a good example of successful teamwork that involved a continuous investigation by a team of experts along with comprehensive action

taken by the occupants and other authorities responsible for the building.

Keywords Indoor air quality · Sick building · Colony-forming unit · Remediation · Fungal growth · Air sampling

1 Practical implications

In this case study, the incidence and remediation of an excessive and extraordinary fungal growth in a very important building (University's Clinic for 30,000 students and 5,000 staff) in the Universiti Sains Malaysia (USM) main campus, Pulau Pinang, Malaysia, were reported. There are significant implications for the report of this case study as follows:

1. Giving a new idea on the incidence of fungal growth in a humid and warm region where Malaysia is not the only example.
2. Since reports of fungal occurrence in buildings in fast developing Asian countries are getting more frequent but are hardly reported or published, it would be of interest to report this study case.
3. As University's Clinic should be the safest and the most hygienic place, the comprehensive and immediate action carried out by the occupants and other authorities responsible for the building would be a good example/reference in overcoming similar cases in the future.

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2 Introduction

Air quality has been a concern for more than 100 years, started around 1850 during the hygienic revolution, followed by outdoor environmental issues (Spengler et al. 2000). Since the 1960s, this topic became one of the centers of intense discussion (Sundell 2004). While indoor pollutant levels in most cases are higher than those of outdoor levels (Montgomery and Kalman 1989), researches also found that most individuals spend 90% of their time indoors and inhale around 35 gallons of air each day. Since the air breathed in mostly comes from enclosed buildings, good indoor air quality (IAQ) is therefore very essential and critical to human health.

Environmental data in a building such as CO₂, relative humidity (RH), and temperature can be used as indicators of ventilation and overall environmental conditions (Spengler et al. 2000). Several studies showed that air-conditioning systems, mechanical ventilation, and sealed windows are among the best means for providing a healthy and comfortable environment (Niven et al. 2000). These factors can also decrease the prevalence of sick building syndrome (SBS) (Bourbeau et al. 1996). Indoor air contains varying matters with some being considered as pollutants. Lee and Chang (1999) listed particulate matter with diameter less than 10 µm, sulfur dioxide (SO₂), temperature, RH, carbon dioxide (CO₂), bacteria, formaldehyde (HCHO), nitric oxide (NO), and nitrogen dioxide (NO₂) as air pollutants and, at the same time, used as the parameters in air quality studies. Compared with cooler air, more moisture content can be found in warmer air. Thus, common recommendations suggested that indoor humidity should be maintained at 30–50% (Yang and Heinsohn 2007). A study by Platt et al. (1989) provides an example of association between damp and moldy buildings and health-related complaints from the occupants. However, the connection between indoor mold and health-related complaints is still very much in contention. Gots et al. (2003), for instance, have reported that a large range of fungal concentrations were measured even in non-complaint buildings.

Fungal spores along with bacteria and viruses are considered airborne particles also known as bioaerosols (Kalogerakis et al. 2005). The spores are fragile and easily spread by wind, water, or animals. Various studies showed that this kind of biological origin plays

a momentous role in IAQ problems (Spengler et al. 2000). Inefficient IAQ can be detected through a number of symptoms or signs of health problems such as headache, lethargy, dizziness, irritation of eyes, nose and throat, and running nose. These flu-like symptoms are some of the features of SBS (Burge 2004). In more serious cases, individuals with a weak immune system, particularly the elderly and the patients who are recovering from surgery operation or already suffer a disease, are prone to lung infection caused by the inhalation of fungal spores.

Studies carried out in temperate region, such as the United States, have shown that fungal occurrence in indoor environments was high during fall and summer seasons (Shelton et al. 2002), with environmental factors such as high temperature and relative humidity are among the factors contributed to the higher occurrences of indoor fungi.

Being in the tropical region, Malaysia's weather is hot and humid with day and night temperatures averaging 32 and 25°C, respectively. Nevertheless, in the last two decades, fast economic and physical developments and significant increase in both daily and night temperatures have prompted the construction of tighter, smaller, and more fully air-conditioned rooms in Malaysia. Pulau Pinang situated in the west coast of Peninsular Malaysia receives continuous rains from April to May and October to November. The year's average weather condition of Pulau Pinang (Table 1) shows that the yearly average temperature and RH vary from 23–32°C and 67–77%, respectively. This article reports an extraordinary fungal growth incident in a building in the tropical environment of Pulau Pinang and a series of remediation actions to solve the problem.

3 Materials and methods

3.1 Sampling location and technique

A physical inspection that leads to the finding of excessive fungal growth due to a water pipe leakage in one of the rooms on the second floor was reported by the owner and occupants of a double-storey building in the main campus of USM, Pulau Pinang. Seven enclosed rooms and two visibly clean rooms of the building were immediately selected and monitored every week by conducting fungal monitoring by air samplings and a swap technique. Three samplings were

Table 1 Year's average weather condition readings for Pulau Pinang, Malaysia

Month	Average sunlight (hours)	Temperature				Discomfort from heat and humidity	Relative humidity		Average precipitation (mm)	Wet days (+0.25 mm)
		Average		Record						
		Min	Max	Min	Max		am	pm		
Jan	8	23	32	19	37	High	75	68	94	8
Feb	8	23	33	19	36	High	74	64	79	7
March	8	23	33	19	37	High	75	64	142	11
April	8	24	33	19	37	High	79	66	188	14
May	7	23	32	19	36	High	78	66	272	16
June	7	23	32	20	36	High	77	67	196	12
July	7	23	32	21	35	High	77	67	191	12
Aug	6	23	32	21	36	High	78	67	295	15
Sept	5	23	31	20	37	High	80	69	401	18
Oct	5	23	32	19	34	High	81	70	429	21
Nov	6	23	31	18	35	High	79	71	302	19
Dec	7	23	32	19	35	High	76	68	147	11

Source: http://www.bbc.co.uk/weather/world/city_guides/results.shtml?tt=TT002620

carried out during June–December 2009 by using Anderson N-6 single-stage sampler and a swap technique with sterile cotton wool on visible fungal growth. Air sampling was done at the height of breathing zone (1.5 m above floor level) at an inflow rate of 16.45 l/min for 3 min and impacted onto malt extract agar (MEA) plate (Raper and Fennell 1965) as a medium for fungal growth and identification into species. The air samples were collected at three different places within the same room (Gou et al. 2004). At the same time, temperature (°C), relative humidity (%), and condition of the rooms were recorded.

3.2 Fungal analysis

The plates were incubated at room temperature for 48 h under the standard incubation conditions (Salleh and Sulaiman 1984). The number of colonies formed on the surface of the agar was counted and converted to colony-forming unit per m³ (CFU/m³). As Anderson N-6 single stage sampler was used, the counts were corrected with the positive holes correction table following Macher (1989).

3.3 Fungal identification

The fungi were identified to species levels using the references by Klich (2002), Raper and Thom (1949), Leslie and Summerell (2006), and Ellis (1971, 1976).

The fungi were identified through the observation of microscopic and macroscopic characteristics and the pigmentation of colonies on MEA and potato dextrose agar (PDA).

3.4 Health problem report

Oral interviewing session with randomly selected staff who worked in reported rooms was carried out after the first air samplings. Important questions such as health problems experienced and when the problems occurred, either before or after the incidence, were asked to the staffs. After the second and third air samplings, the same sets of staff were reinterviewed and all health complaints were recorded again. In all interviews, the staffs were asked to describe common health symptoms they faced during work and after work over the previous 1 month.

3.5 Reference guidelines

In this study, recommended level of fungal CFU (500 CFU/m³) from Singapore was followed.

4 Results

Physical inspections along with fungal air and swap samplings were carried out a week after the building

owner consulted our team in early June 2009. The staffs were instructed to take immediate action by removing the wet furniture and drying the wet areas in the upper floor where the leakages from water pipes occurred. However, within a month, fungal colonies were observed on the ceiling boards of the lower floor in several rooms and corridors. A serious fungal outbreak with a strong moldy smell was noticed in Rooms 51, 52, and 66 (Table 2). In the meantime, the furniture and cupboards were not removed yet.

During the observation, the ceilings boards were already repainted. However, the moldy odor was still present, and the fungal colonies can be detected on the cupboards frame, boxes, and wall surfaces. The staffs also complaint about flu-like symptoms since the incident happened.

4.1 Density and diversity of aerial fungi

Concentrations of indoor air fungi in all sampling locations involved were between 855 and 22,474 CFU/m³ during the first air sampling. However, the concentrations gradually decreased to 353–2,804 CFU/m³ and 101–288 CFU/m³ during the second and third air samplings, respectively. Overall, the total CFU/m³ levels in all measured areas were getting lower after a series of antifungal treatments and comprehensive remediation had been carried out. At the same time, the range between the highest and the lowest readings of temperature and RH in the building were decreasing from the first through the third sampling as shown in Table 3.

Isolates of fungi from each location monitored were identified to the genus and species levels (Tables 4 and 5). In Table 4, the percentage of fungal genera present during indoor air monitoring showed that the most isolated and dominant fungi were from the genus *Aspergillus*, *Penicillium*, and *Cladosporium* while *Fusarium* was the least fungal colony found in the building. Table 5 presents the specific species in fungal genera found from the air and swab samplings.

4.2 Health symptoms

All interviewed staff complained of having flu-like symptoms that they faced a few days after the incident of water pipe leakage until the first air sampling. Among the common symptoms revealed were cough, running nose, sore throat, dizziness, headache, and

aching eyes, which occurred during works and resolve quickly after works. Cough and sore throat were the most prevalent while aching eyes were the least prevalent. Unpleasant odors were also reported mainly in Rooms 153, 51, and 47. There were cases where at least five staff who asked for 1–3 days medical leaves due to the health problems they faced in the first week of the incidence. During second and third air sampling sessions, the prevalence of the reported symptoms among the same set of staff was less prevalence.

4.3 Remediation

A series of fungal treatments and other remediation steps were carried out to improve conditions that were favorable for the establishment and growth of the fungi. The infected areas were treated with biological fungicide after the first air monitoring. The fungal treatment was carried out once every 2 weeks until the last air monitoring on December 2009. Salleh (1988) proposed this action and biological fungicide be used as it is environment-friendly and more biodegradable. During the treatment, special clothing with rubber gloves and mask was used to protect the skin and eyes. Besides, high-efficiency particulate air (HEPA) respirators (N95) were used during the fungal treatment. The effectiveness of the treatment was proven by the decreasing numbers of CFUs during secondary air sampling as shown in Table 3. The actions taken for remediation purposes are summarized in Table 2.

4.4 Recommendation

Since the decreasing fungal concentrations were still over, the recommend levels in Singapore by Anonymous (1996) except for Room 153 during the second air sampling, comprehensive prevention steps were taken along with treatment for the fungal infections. First, any sources of visible fungal growth especially wet cellulose-based type materials such as wood products and ceiling tiles were removed and taken out of the building. Then, the materials were burned to prevent the recurrence of the fungal growth. The staffs were also reminded not to bring food and drink or eat in the suspected room as fungal spores can be ingested by food or drink after being contaminated by airborne fungal spores. Besides that, any spots or stains of fungal growth on walls and carpets were removed immediately with a small amount of water with 5% detergent.

Table 2 Chronological records of findings and actions taken in a 'sick building' in USM, Pulau Pinang

Date	Findings	Actions
27 April 2009	Half of the premise was flooded with water leaking from first floor	The main water supply was turned off and the pipes were repaired after a complaint was made to the contractors
21 May 2009	The water leakage had continued for a week with water dripping down from some flaws in the first floor Room 51 was found to be heavily overgrown with dark and brown fungi at ceiling and wall	The insulating layer for air conditioning ducting in Room 51 was left to drip dry The ceiling and wall was immediately repainting with antifungal paint
26 May 2009	Damp and mouldy smell was noticed in the room Black moldy things grew at the raw untreated edge of wood cabinets in Room 51 and Room 66	Materials that cannot be cleaned were moved out Suppliers were called into repaint the wooden edge
28 May 2009	Moulds growth found at the walls of Room 44 and Room 45	Walls were repainted with antifungal paint
8 June 2009		Building owner consulted research team for air quality assessment in the building
15 June 2009		First air sampling was conducted at various sites by research team
24 June 2009	Yellowish fungi growth was found at the plywood shelving in Room 52	
10 July 2009	Findings and recommendations presented by the research team	Recommendations: Using high-efficiency particulate air (HEPA) respirators (N95) to filter out fungus spores Prohibition of food in suspected room Turning on the air conditioning system 24 h for de-humidifying purposes Using blower as another source of de-humidifier in order to reduce the relative humidity (RH) especially in Room 52 and Room 66 Removing or burn any sources of visible fungi growth Treating the infected area with fungicide (s) Removing or discard the infected ceiling tiles Improving air filtration system
13 July 2009	Removal of cellulose media overgrown with mould and fungi	All storage items from Room 51, Room 52 and Room 66 were shifted out
14 July 2009	Fungal air-treatment started	All wooden cabinets and wooden shelving were removed
24 July 2009		Treatment for heavily infested rooms was done every 2 weeks starting on 14th July. Biological fungicide was used throughout the treatment
25 Sept 2009		Second air sampling was conducted at various sites by research team Inspection by the architect and development office Removal of air-conducting in Room 47 Scraping of fungal infected ceiling and repainting of cement slab

Table 2 continued

Date	Findings	Actions
26 Sept -15 Oct 2009		Removing old air-conducting in Room 51 Installing new air-conducting and heater with RH controller in Room 51 and Room 47
24 Oct 2009		Scraping of fungal infected ceiling and re-painting in stages completed
8 Dec 2009		Walls of the rooms re-painted with antifungal paint
11 Dec 2009		Installation of metal cabinets to Room 51 and Room 66
29 Dec 2009		Last air sampling was conducted at various sites by research team
6 Jan 2010	Final findings and results was presented by the research team while contractors, architect and Development Office presented their working progress	

Subsequently, dehumidification strategies were implemented by the Development Office by turning on the air-conditioning system throughout 24 h and using air blowers as another source of dehumidifier to reduce the relative humidity, especially in rooms where CFU/m³ was higher than 3,000, e.g., in Rooms 52 and 66. Temperature and RH detectors were strategically placed in the rooms where regular checking and recording were carried out by the staff. The remediation and improvement of indoor environmental conditions were completed at the end of November 2009. The fungal indoor contaminants have been significantly reduced as shown by CFUs and by the absence of the musty smell in all rooms during the last air sampling in December 2009 as stated in Table 3.

5 Discussion

Based on the CFU/m³ levels from first air sampling, the premise was declared as a 'sick building'. Therefore, it was closed to the public as the CFU in most of the enclosed rooms had reached alarmingly high levels as proposed by Singapore and several other guidelines being practiced in developed countries. Currently, there is no standard universal regulation for an acceptable level of indoor fungi. Thus, the IAQ guidelines with recommended levels of fungal CFU are varied between countries, i.e., Institute of Environmental Epidemiology, Singapore—500 CFU/m³ for air-conditioned office premises (Anonymous 1996), The Government of the Hong Kong Special Administrative Region—500 CFU/m³ (Anonymous 2003), National Institute of Occupational Safety and Health (NIOSH), and American Conference of Governmental Industrial Hygienists (ACGIH)—1,000 CFUs/m³ for bioaerosol particle (Kalogerakis et al. 2005). Malaysia does not have its own standard as we only have Indoor Air Quality Code of Practice, issued by the Occupational Safety and Health Department (OSHD) in August 2005 (Anonymous 2005). As both Singapore and Malaysia are close neighbors with similar tropical climate, recommended level of Singapore was followed in this study.

It was difficult to achieve RH level as recommend by Yang and Heinsohn (2007) since Pulau Pinang was surrounded by the sea and the normal RH is always in the higher range of 70–90%. So, it was recommended to the contractors to maintain the RH levels lower than

Table 3 Summary of indoor air monitoring results showed temperature (°C), relative humidity (%), and life fungal spore density (CFU/m³) in a 'sick building' in USM, Pulau Pinang

Monitored location	Temp. (°C)			RH (%)			CFU/m ³		
	1 ^a	2 ^b	3 ^c	1	2	3	1	2	3
Room 153	23.1	26.0	24.0	63.5	62.5	64	1,129	353	122
Outside Room 153	25.0	26.2	24.4	57.6	55.1	63.3	969	900	101
Room 51	23.8	25.9	22.3	75.4	57.0	49.0	2,197	632	122
Outside Room 51	23.5	24.2	22.3	70.1	59.6	57.7	875	610	288
Room 47	23.6	21.4	23.4	68.2	64.8	59.8	1,293	721	144
Room 52	26.1	25.5	22.6	79.0	65.5	58.1	6,983	2,804	205
Room 66	23.4	21.0	22.9	64.6	66.5	49.3	22,474	610	247
Room 44	23.2	22.0	24.5	65.0	67	53.5	1,412	1,246	205
Room 45	21.7	22.0	24.0	65.2	69	59.8	855	786	128

^a First air sampling 15 June 2009^b Second air sampling 24 July 2009^c Third air sampling 29 December 2009**Table 4** Percentage of recovery of fungal genera present during indoor air monitoring in a 'sick building' in USM, Pulau Pinang

Monitored location	Fungal genera								
	<i>Aspergillus</i>	<i>Penicillium</i>	<i>Cladosporium</i>	<i>Alternaria</i>	<i>Rhizopus</i>	<i>Curvularia</i>	<i>Trichoderma</i>	<i>Botrytis</i>	<i>Fusarium</i>
Room 153	(55)	(37)	(7)	–	(1)	–	–	–	–
Outside Room 153	(53)	(24)	(7)	(11)	–	–	–	(5)	–
Room 51	(47)	(37)	(7)	(5)	(2)	–	(2)	–	–
Outside Room 51	(29)	(43)	(20)	–	–	(8)	–	–	–
Room 47	(58)	(25)	(3)	–	–	(4)	(6)	(4)	–
Room 52	(47)	(36)	(3)	(3)	(7)	–	(1)	–	(3)
Room 66	(50)	(45)	(1)	(1)	(1)	(1)	–	(1)	–
Room 44	(29)	(44)	(5)	(6)	(6)	(7)	(3)	–	–
Room 45	(36)	(39)	(18)	(7)	–	–	–	–	–

(), percentage of fungi present

–, fungi absent

55% while the temperature was maintained at 23–26°C by using a dehumidifier at least in the first month. In order to overcome the critical problem of closing the premise, prevention and remediation of fungal growth were applied to decrease CFU readings.

The dominance of *Aspergillus*, *Penicillium*, and *Cladosporium* in all monitored locations was in agreement with Shelton et al. (2002), who reported that these were the dominant culturable airborne fungi in indoor buildings in United States and elsewhere. There were also reports that *Aspergillus* can be used as

an indicator for fungal contamination in buildings (Hicks et al. 2005). Murry et al. (1988) had proved that the appearance of *Aspergillus* spores has a direct correlation with the incidence of aspergillosis among immunosuppressed patients while some of the species (*A. niger*, *A. flavus*, and *A. fumigatus*) have been reported to be associated with human allergies. According to Steyn (1995), Salleh (1998), and Nielsen (2003), *Aspergillus*, *Penicillium*, *Fusarium*, *Alternaria*, *Claviceps*, and *Trichoderma* are the most frequently found fungal genera indoor and some

Table 5 Specific species in fungal genera recovered from the air and swab samplings

Fungal genera	Species
<i>Aspergillus</i>	<i>niger</i> ^a , <i>fumigatus</i> , <i>flavus</i> , <i>ochraceus</i> ^a , <i>japonicus</i>
<i>Penicillium</i>	<i>chrysogenum</i> ^a , <i>citrinum</i> , <i>lanosum</i>
<i>Cladosporium</i>	<i>herbarum</i> , <i>cladosporioides</i>
<i>Alternaria</i>	<i>alternate</i>
<i>Rhizopus</i>	<i>stolonifer</i>
<i>Curvularia</i>	<i>lunata</i> , <i>ellisii</i>
<i>Trichoderma</i>	<i>viride</i>
<i>Botrytis</i>	<i>cinerea</i>
<i>Fusarium</i>	<i>solani</i>

^a Fungal species isolated from swab samplings

species of these genera are main mycotoxin producers that can cause mycotoxicoses. This toxic response sometime leads to deterioration of liver or kidney functions if ingested by humans through food (Henry et al. 1999; Pitt 2000; Marasas et al. 2001).

6 Conclusion

From this study, data from IAQ assessment and measurement have proven to be valuable information in establishing a significant fungal level in a building. Due to the concerns for the health of occupants, a collective evaluated IAQ data were put forth in place. The data, along with the actions taken, were very useful in preventing a high-repair bill or time wasted caused by the remediation and antifungal treatments. This is a good example of teamwork where the contractors, Development Office, owner of the premise, occupants, scientist, and students worked together for achieving the same goal, i.e., to tackle IAQ data and subsequently apply feasible remediation techniques to eliminate or reduce fungal air contamination and visible growth in an already declared sick building in tropical conditions.

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