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A survey of airborne algae and cyanobacteria within the indoor environment of an office building in Kuala Lumpur, Malaysia

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Abstract

This study investigates the occurrence of airborne algae and cyanobacteria (AAC) within the indoor environment of an office building in Kuala Lumpur, Malaysia. Samples of air, wall scrapings and soils of potted plants were collected from various sites within the building and surrounding areas. In addition, AAC were collected by exposing a culture medium to the indoor air. Based on the cultured material, 14 taxa of AAC consisting of cyanobacteria such as *Phormidium angustissima* and *Chroococcus minor* and chlorophytes such as *Chlorella vulgaris* and *Chlorococcum humicola* were recorded. The surrounding areas of the building recorded the highest occurrence (75%) of AAC. Within the building, the highest occurrence of AAC (45%) was recorded on the lower ground floor, an area exposed to the outdoor environment. Some of the AAC recorded were also detected in the wall scraping and soil samples. Areas with heavy human movement appeared to have high occurrence of AAC. Human movement appeared to be an important factor in affecting the dispersal of the AAC.

Keywords: *airborne algae, cyanobacteria, indoor environment, sick building syndrome, Phormidium, Kuala Lumpur*

Indoor air quality (IAQ) is an important factor that can affect the health of office building occupants. According to the World Health Organisation (WHO, 1983), up to 30% of new and remodelled buildings worldwide may be subjected to indoor air pollution. In association with IAQ is 'sick building syndrome' (SBS), which describes cases in which building occupants experience adverse health effects, linked to the time spent in a building (Appleby, 1996). The typical complaints from occupants of buildings associated with SBS include cough, mucosal membrane irritation, visual disturbances, headaches and chest tightness (Redlich et al., 1997). SBS has received much attention as it has an impact on productivity gains (Fisk, 2000). In the tropics, symptoms of SBS have been reported amongst office workers in Malaysia (Syazwan Aizat et al., 2009), Singapore (Ooi et al., 1998) and India (Gupta et al., 2007).

The biotic factors associated with indoor air pollution include bacteria, fungi, viruses, parasites and

mites. A one-year epidemiologic study in Boston, MA, found that upper respiratory symptoms of office building occupants were positively associated with total fungal concentrations recovered from chair dust (Chao et al., 2003). Dust-mite allergen levels and airborne fungi such as *Aspergillus* and *Rhodotorula* concentrations were found to be significantly related to SBS symptoms in newly built dwellings in Japan (Saijo et al., 2011). Fungi such as *Aspergillus* and *Penicillium* are also known to release volatile organic compounds and mycotoxins that may contribute to SBS (Strauss, 2009). In water-damaged buildings, overgrowth of the fungus *Stachybotrys* and the release of its spores containing toxins can be detrimental to health (Scheel et al., 2001). There is also a correlation in bacterial endotoxin and fungal β -glucan contents between the air and dust samples in office environments (Yao et al., 2009). In addition, *Acanthamoeba* was detected in dust samples collected from air-conditioners installed in a

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building in Kuala Lumpur, Malaysia (Chan et al., 2011).

In comparison with other organisms, algae and cyanobacteria may comprise a largely ignored group of microorganisms in indoor environments. In an early report, algae and cyanobacteria were detected in house dust collected during the indoor heating season in homes in the United States, where green algae (chlorophytes) such as *Chlorella*, *Chlorococcum*, *Chlamydomonas* and *Planktosphaeria*, and cyanobacteria such as *Anabaena* and *Schizothrix*, were found (Bernstein & Safferman, 1973). In another study in Sweden, dust samples from a healthcare centre, a recreational centre and several nursery schools contained viable green algae such as *Chlorococcum*, *Chlorella* and *Stichococcus*, and cyanobacteria such as *Nostoc*, *Phormidium* and *Anabaena* (Tiberg et al., 1983).

Direct sampling of the atmosphere has established that algae and cyanobacteria are a component of the naturally occurring aerial biota. The bulk of photosynthetic microorganisms in the atmosphere consist of mainly green algae, cyanobacteria, diatoms and trebouxiphytes (Sharma et al., 2007). The diversity and abundance of airborne algal particles are affected by climatic, topographical, geographical, diurnal and seasonal factors. In tropical regions, the diversity and abundance of airborne algae are generally higher than in other climatic regions due to the abundant soil and sub-aerial algae (Schlichting, 1974). Cyanobacteria are usually the dominant airborne photosynthetic microorganisms in tropical areas, while green algae are dominant in temperate regions (Sharma et al., 2006). Up to 12 coenobia of green algae per cubic metre air were recorded in Badajoz, Spain (Tormo et al., 2001). Algal propagules have also been detected in the air of the pristine environment of Antarctica (Marshall & Chalmers, 2006). There has been only one previous study on airborne algae and cyanobacteria (AAC) in Malaysia, conducted in the township of Bukit Jalil in Kuala Lumpur (Ng et al., 2011). The cyanobacteria *Phormidium* and *Nostoc* were the dominant airborne photosynthetic microorganisms of this township.

Several studies have shown that AAC may have adverse impacts on human health. The question of whether algae can be a cause of inhalant allergy was first raised by McElhenney et al. (1962). At least 38 AAC are known to induce allergy, skin irritation, hay fever, rhinitis, sclerosis and respiratory problems when aerosolised and inhaled (Genitsaris et al., 2011). AAC that are most frequently associated with health effects include *Chlorella*, *Scenedesmus*, *Klebsormidium* (*Hormidium*) and *Lyngbya*. Positive skin reactions to extracts from allergenic algae isolated from the atmosphere of Delhi, India, were

detected in patients suffering from naso-bronchial allergy (Mittal et al., 1979a). *Chlorella*-specific IgE has been detected in sera of atopic children sensitised to moulds (Tiberg et al., 1990). Intradermal test on mice followed by leucocyte count has also demonstrated that airborne cyanobacteria such as *Phormidium fragile* (Meneghini) Gomont and *Nostoc muscorum* Agardh ex Bornet et Flahaut could elicit allergenic reaction (Sharma & Rai, 2008). Bernstein and Safferman (1973) demonstrated that *Chlorella* from house dust could give rise to Type I hypersensitivity in humans. In another study, Holland et al. (1973) identified 40 viable algal taxa from house dust samples and correlated them with allergenic reactions in human.

The aim of this study was to investigate the occurrence of AAC within an office building in Kuala Lumpur, Malaysia. Soil and wall scraping samples from the indoor environment of the building were also examined to determine if they contained similar algae and cyanobacteria as those found in the air. In addition, air from the surrounding areas was sampled to determine if they were the source of the indoor AAC. The baseline data obtained will be most useful for further studies on the relationship between airborne algae and SBS.

Material and methods

Description of the study site

The study was conducted at a private institution of higher learning in Kuala Lumpur, Malaysia. The study site is a typical seven-storey modern office building comprising offices, lecture halls, study rooms, library, a canteen and lounges, with the lower ground floor and sub-basement as car parks. Major renovation work was carried out from 2006 to 2008 to construct a new wing linked to the main building via a sky-bridge. The total area of the building is about 36 000 m². As of 2008, the total building occupancy was approximately 2000 people and the occupants were mainly students and lecturers as well as administrative staff.

Sampling sites

Air samples were collected from the building for the survey between February and October 2008. The building was divided into seven levels, namely sub-basement (SB), lower ground floor (LGF), ground floor (GF), first floor (1F), second floor (2F), third floor (3F) and fourth floor (4F). In total, 140 sites were selected within the building for air sampling. On each level, there were 20 sampling sites, which were categorised according to the following criteria: busy versus quiet areas, new versus old areas and

open versus enclosed areas (see Appendix, Table AI). Busy areas were those places with high frequency of human movement. New areas refers to the places of the building that were built or renovated after January 2006. Areas within enclosed environment such as office rooms, lecture halls, laboratories and lounges are considered as enclosed areas, while open areas refers to other parts of the building. The LGF consisted of car parks and was exposed to the air from the outdoor environment. In addition to air samples, soil samples were collected from potted plants in the building at the following sites: C5, D7, D8, E10, E12, G5, G6, G11 and G16. As algae were seen growing on the walls of some areas on LGF and SB, samples of wall scrapings were collected from the sites (A7, B1, B10, B14 and B20). In addition, 12 air samples were collected from the immediate surroundings of the building (see Appendix, Table AII).

Sample collection

An impaction culture plate sampler (air IDEAL3P, bioMerieux, France) was used to collect 500 l of air at the speed of 100 ml/min for 5 min at each sampling site. The instrument is based on the principle, in which air is aspirated through a grid perforated with a pattern of 286 calibrated holes. The air stream containing the microbial particles was directed onto the surface of Bold's Basal Medium (BBM) agar (Nichols, 1973) in a sterile petri dish (90 mm in diameter) attached to the air sampler. Before use, the air sampler was cleaned thoroughly with alcohol swap. After completion of air sampling, the petri dishes were removed and sealed immediately with parafilm. The petri dishes were labelled and kept in an incubator for the growth of algae. Soil and wall scraping samples were collected with a spatula that was wiped with alcohol before use. The samples were kept in sealed plastic bags before being transferred into 100 ml liquid BBM. All algae samples were grown in an illuminated incubator set at 28 °C with irradiance of 42 µmol/m²/s on a 12:12 h light-dark cycle. Visible algal growth was usually seen after 20 to 30 days of incubation.

As another sampling method, liquid BBM was exposed to the indoor air to trap any algal and cyanobacterial propagules that might exist in the indoor environment. Plastic containers filled with 120 ml BBM were placed at ten sampling sites on 4F (G1–G5, G7, G8, G12, G14 and G18) and another four sampling sites on LGF (B4, B12, B14 and B19) of the building. The liquid medium was left exposed to the environment for 45 days. Sterile water was added to the medium throughout the exposure period to maintain the original volume of the medium. On day 45, all the samples were

collected back and immediately sealed with parafilm. The samples were then incubated until day 78 before the examination of the algae and cyanobacteria.

Identification and isolation of algae and cyanobacteria

The algae and cyanobacteria were examined under a light microscope (Nikon Eclipse 80i, Tokyo, Japan) and micrographs were taken. Cell dimensions of the algae and cyanobacteria in terms of length, width and diameter were measured. The algae and cyanobacteria were identified based on the taxonomic keys in Anagnostidis and Komarek (1988), Desikachary (1959), Prescott (1962) and Whitford and Schumacher (1973). A checklist of the identified algae and cyanobacteria was compiled. The algae and cyanobacteria were also isolated into axenic or unialgal cultures by repeated streak-plating technique.

Measurement of physical parameters

The light intensity, temperature and relative humidity were measured at selected sampling sites in the building during the study period. The measurements were taken at 9:00, 12:00, 15:00 and 18:00. Light intensity was measured with a light meter (Tenmars TM-202, Taipei, Taiwan), while the temperature and relative humidity were measured simultaneously with a hygrometer (Conmark N8006, Norwich, UK). The physical parameters were measured at five randomly selected sites at each level of the building for five days.

Data analysis

The percentage occurrence of AAC on each floor of the building was calculated using the following formula:

Percentage occurrence of airborne algae

$$= \frac{\text{[Total number of plates that yielded algae]}}{\text{Total number of plates with air samples}} \times 100$$

To assess the heterogeneity of algae and cyanobacteria found in the air, soil and wall scraping samples, the Sorensen's Quotient of Similarity (*S*) was calculated using the following formula:

$$S = \frac{2j}{(A + B)} \times 100\%$$

where *j* is the number of taxa occurring in both types of samples, *A* the total number of taxa found in type A samples and *B* the total number of taxa found in type B samples.

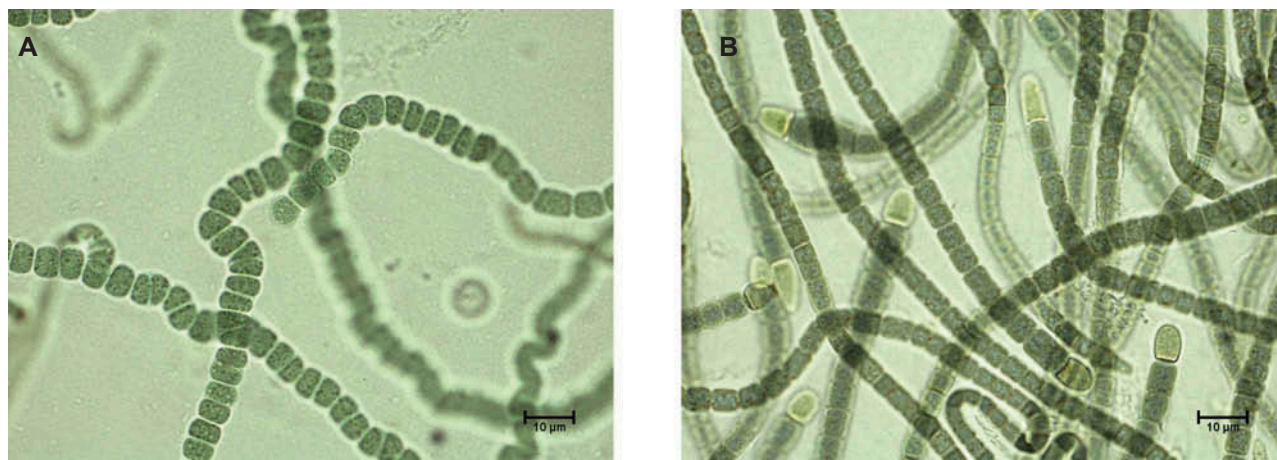


Figure 1. Two of the airborne cyanobacteria recorded from the air samples collected from the indoor environment of the office building in this study. **A.** Unidentified filamentous cyanobacterium. **B.** *Cylandrospermum* sp. Scale bars – 10 µm.

Results

Checklist of algae and cyanobacteria

In total, 26 taxa of algae and cyanobacteria were recorded in this study including one unidentified filamentous cyanobacterium (Figure 1A, Table I). The highest number of taxa were cyanobacteria (12 taxa) followed by Chlorophyta (nine taxa) and Bacillariophyta (five taxa). Both unicellular and filamentous algae and cyanobacteria were found in this study. All cyanobacteria are filamentous except for *Chroococcus minor* (Kutzing) Nageli and *Synechococcus elongatus* Nageli. In comparison, all green algae were unicellular except for *Ulothrix subtilissima* Rabenhorst and their shapes ranged from coccoid, ovoid to lunate. In terms of size, the coccoid algae ranged from 3–23 µm in diameter, while the cell length and width of the filamentous cyanobacteria ranged from 1.6–10 µm and 0.8–13 µm, respectively.

Of the 26 taxa of algae recorded, 14 originated from the air samples, 17 from soils and ten from wall scrapings. The AAC recorded include those collected through direct sampling as well as through the exposure of the culture medium to the environment. The heterogeneity of the algae from air, soil and wall samples was very similar based on the following Sorensen's Quotient of Similarity (*S*) values: air versus soil (45%), air versus wall (50%) and soil versus wall (50%). The airborne photosynthetic microorganisms were mainly cyanobacteria (nine taxa) and green algae (eight taxa), while the diatoms (bacillariophytes) were found mainly in the soil samples. The following algae and cyanobacteria were found in all the three types of samples: *Chlorococcum humicola* (Nageli) Rabenhorst, *Chlorella vulgaris* Beijerinck, *Scenedesmus bijuga* (Turp.) Lagerhim, *Stichococcus*

bacillaris Nageli and *Phormidium angustissima* West et West. Most of the cyanobacteria found in the air samples including *Cylandrospermum* sp. (Figure 1B) and *Phormidium retzii* (Agardh) Gomont were not detected in the soil or wall scraping samples. The exceptions were *Phormidium angustissima*, which was found in the three types of samples, and the unidentified filamentous cyanobacterium, which also occurred in the soil samples. In comparison, most of the green algae recorded were found in all three types of samples.

AAC occurrence in the building and surrounding areas

Most of the AAC recorded in the building were from 4F (nine taxa) and LGF (seven taxa) (Table II). The AAC collected from 4F originated from both air and soil samples, while those from LGF were mainly from wall scrapings. On LGF, *Chlorococcum humicola* and *Chlorella vulgaris* were found in both air samples and wall scrapings, while on 4F, these two species occurred in both air and soil samples. Most of the AAC from GF, 1F and 2F were also found in the soil samples. Very low occurrence of AAC was recorded from SB, GF and 3F. A total of nine taxa of AAC were recorded from the outdoor samples. The dominant airborne cyanobacterium was *Phormidium angustissima*, which was found on all levels of the building except for GF. This cyanobacterium was also recorded in air samples from outdoors. The algae recorded from the exposed culture medium were mainly green algae, especially *Chlorella vulgaris* and *Chlorococcum humicola*.

The percentage occurrence of AAC was much higher in the outdoor environment (75%) compared to the indoor air (5–45%) (Figure 2). The

Table I. Checklist of algae and cyanobacteria collected from the indoor environment of the building and its surrounding areas.

Taxon	Cell dimension	Morphology	Occurrence		
			Air ^a	Soil	Wall
BACILLARIOPHYTA					
Naviculaceae					
<i>Navicula</i> sp. 1	Length: 7–24 μm; Width: 2–4 μm	Unicellular, solitary		x	
<i>Navicula</i> sp. 2	Length: 9–15 μm; Width: 4–8 μm	Unicellular, solitary		x	x
<i>Navicula</i> sp. 3	Length: 16–18 μm; Width: 3–5 μm	Unicellular, solitary		x	
<i>Navicula</i> sp. 4	Length: 5–12 μm; Width: 3–4 μm	Unicellular, solitary		x	
Nitzschiaceae					
<i>Nitzschia</i> sp.	Length: 17–24 μm; Width: 4–5 μm	Unicellular, solitary			x
CHLOROPHYTA					
Chlamydomonadaceae					
<i>Chlamydomonas</i> sp.	Length: 5–10 μm; Width: 2.5–7 μm	Unicellular, flagellate, formed aplanospores	x	x	
Chlorococcaceae					
<i>Chlorococcum humicola</i> (Nageli) Rabenhorst	Diameter: 3–12 μm	Unicellular, coccoid, Formed aplanospores	x	x	x
<i>Neochloris alveolaris</i> Bold	Diameter: 4–23 μm	Unicellular, coccoid, formed aplanospores		x	
Tribouxiophyceae					
<i>Chlorella ellipsoidea</i> Gerneck	Length: 4–8 μm; Width: 2–5 μm	Unicellular, ovoid	x		x
<i>Chlorella vulgaris</i> Beijerinck	Diameter: 5–13 μm	Unicellular, coccoid	x	x	x
<i>Pseudococcomyxa simplex</i> (Mainx) Fott	Length: 10–19 μm; Width: 3–5 μm	Unicellular, lunate		x	
Scenedesmaceae					
<i>Scenedesmus bijuga</i> (Turp.) Lagerhelm	Length: 5–8 μm; Width: 4–7 μm	Unicellular, coenobial (2–4 cells)	x	x	x
Ulotrichaceae					
<i>Stichococcus bacillaris</i> Nageli	Length: 7–15 μm; Width: 4–6 μm	Short filaments of 2–4 cells, usually fragmented into unicells	x	x	x
<i>Ulothrix subtilissima</i> Rabenhorst	Diameter: 4–5 μm	Filamentous		x	x
CYANOBACTERIA					
Chroococcaceae					
<i>Chroococcus minor</i> (Kutzing) Nageli	Diameter: 3–8 μm	Unicellular, colonial (2–4 cells)	x		
<i>Synechococcus elongatus</i> Nageli	Length: 3–5 μm; Width: 1.5–2 μm	Unicellular, rod-shaped		x	
Nostocaceae					
<i>Anabaena conferoides</i> Reinsch	Length: 2.5–4 μm; Width: 3–4 μm	Filamentous	x		
<i>Cylindrospermum</i> sp.	Length: 5–10 μm; Width: 4–7.5 μm	Filamentous	x		
Oscillatoriaceae					
<i>Lyngbya polysiphoniae</i> Frey	Length: 2–1.2 μm; Width: 0.8–4 μm	Filamentous			x
<i>Lyngbya putealis</i> Mont.	Length: 8–16 μm; Width: 8–13 μm	Filamentous		x	
<i>Oscillatoria pseudogeminata</i> G. Schmid	Length: 2–4 μm; Width: 1.6–4 μm	Filamentous	x		
<i>Symploca muscorum</i> (Agardh) Gomont	Length: 3–7.5 μm; Width: 2.5–3.5 μm	Filamentous		x	
Phormidiaceae					
<i>Phormidium angustissima</i> West et West	Length: 2.5–3.5 μm; Width: 1–3 μm	Filamentous	x	x	x
<i>Phormidium retzii</i> (Agardh) Gomont	Length: 7.5–13.5 μm; Width: 3–6 μm	Filamentous	x		
Pseudanabaceae					
<i>Pseudanabaena</i> sp.	Length: 1.6–3.2 μm; Width: 0.8–2.5 μm	Filamentous	x		
Unidentified filamentous cyanobacterium	Length: 3–9 μm; Width: 1–3.5 μm	Filamentous	x	x	

^aInclude airborne algae collected from the exposed medium.

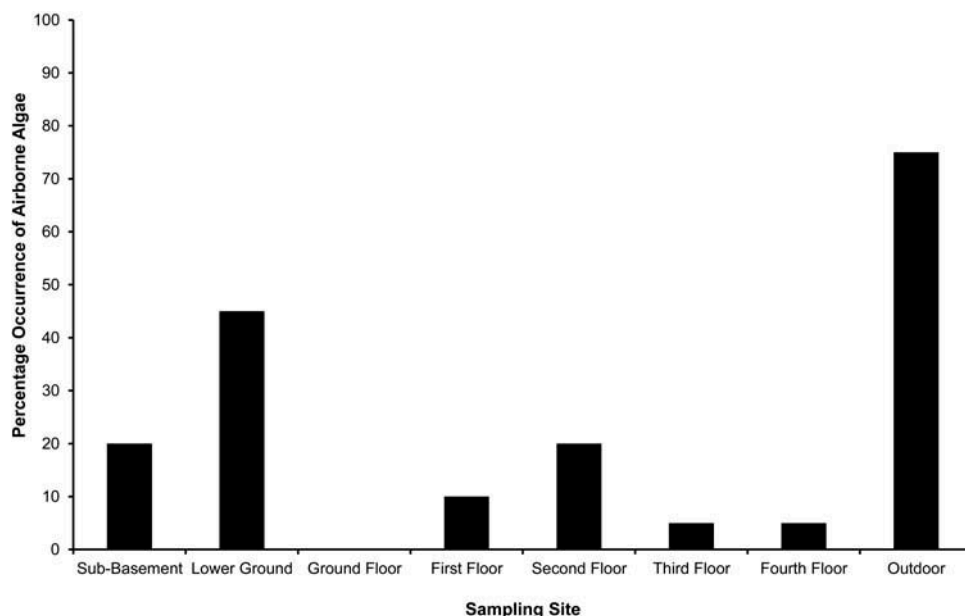


Figure 2. Percentage occurrence of airborne algae and cyanobacteria on each level of the building and its surrounding areas in the outdoor environment.

LGF showed the highest percentage occurrence of AAC (45%), while very low occurrence of AAC was recorded from 1F, 3F and 4F. No AAC were detected at GF.

In general, high occurrence of AAC was recorded from sites with busy movement, especially at 1F and 2F (Table III). On 2F, higher percentage occurrence of AAC was recorded from the new sites compared to the old sites. Open areas, especially at 1F and 2F, showed higher percentage occurrence of AAC than closed areas. However, on 3F, AAC were only detected in enclosed areas.

Physical parameters

In general, the relative humidity (68–70%) and temperature (26–28 °C) of SB and LGF were higher than that of other levels of the building (56–61% and 24–25 °C, respectively). The relative humidity and temperature stayed relatively constant from 9:00 to 18:00. The light intensity was highest on 4F (787–1196 lux), as it was exposed to the light from the external environment, which passed through the transparent roof, especially at noon. In contrast, very low light intensity was recorded on SB (70–75 lux) and LGF (74–137 lux), where parking lots with very dim light were located.

Discussion

Most studies on AAC were conducted in outdoor environments, especially in urban areas including Varanasi, India (Sharma et al., 2006), Cairo, Egypt (El-Gamal, 2008) and Thallasoniki, Greece

(Genitsaris et al., 2011). In Malaysia, a recent survey on AAC was conducted in the township of Bukit Jalil, Kuala Lumpur (Ng et al., 2011). To our knowledge, the present study is the first documentation on the occurrence of AAC within the indoor environment in the tropics.

The surrounding outdoor air could be a major source of AAC found in the building, as six of the nine AAC species found indoors were also present in the surrounding areas. The algal and cyanobacterial propagules could be brought into the building through human movement. Such bioparticles might also be drawn into the indoor environment through air-conditioners. Microorganisms such as *Acanthamoeba* have been isolated from dust samples collected from air-conditioners within a building in Kuala Lumpur (Chan et al., 2011). It was suggested that algae could be one of the food sources for this parasite.

In outdoor environments, soil could be a major source of AAC. For instance, 53% of the AAC in the atmosphere of Varanasi, India, are of soil origin (Sharma et al., 2006). In indoor environments, potted plants could be a major source of soil borne algae and cyanobacteria. Soil particles with algae may be dislodged into the air and the soil algae may remain viable in the air as they are known to be able to withstand desiccation. For instance, Gupta and Agrawal (2006) demonstrated that soil algae are able to survive even after being stored in a desiccator for 0.5–1.5 months. In this study, AAC such as *Phormidium angustissima*, *Chlorococcum humicola*, *Chlorella vulgaris*, *Scenedesmus bijuga* and *Stichococcus bacillaris* were also detected in the soil samples,

indicating that they might originate from the soil of the potted plants. It has been suggested that the soil of potted plants could be the source of fungal contamination in indoor environments and this may be a risk factor for the health of building occupants (Khan & Karuppayil, 2011). However, the possible health risk of algae from the soil of potted plants is yet to be investigated.

Algae and cyanobacteria are known to grow on painted buildings and they are one of the major groups of biofouling organisms on such structures. Dominant algae and cyanobacteria found on painted buildings include *Synechococcus*-like cyanobacteria

and *Chlorella*, as reported in a study conducted in Latin America (Gaylarde & Gaylarde, 2000). In another study in Singapore, the green filamentous alga *Trentepohlia odorata* (F.G. Wiggers) Wittrock was found to be one of the major species growing on surfaces of buildings (Wee, 1988). However, these previous studies focused mainly on the exterior walls of buildings. In comparison, the samples in the present study were collected from the interior parts of the building, where a different consortium of algae was found, consisting of mainly green algae such as *Chlorococcum humicola*, *Chlorella vulgaris*, *Scenedesmus bijuga* and *Stichococcus bacillaris*. Such species were

Table II. Occurrence of algae and cyanobacteria in the indoor environment of the building and its surrounding areas.^a

Taxon	Sampling sites							
	Sub-basement	Lower Ground	Ground Floor	First Floor	Second Floor	Third Floor	Fourth Floor	Outdoors
BACILLARIOPHYTA								
Naviculaceae								
<i>Navicula</i> sp. 1							S	
<i>Navicula</i> sp. 2		W	S	S			S	
<i>Navicula</i> sp. 3							S	
<i>Navicula</i> sp. 4					S		S	
Nitzschiaceae								
<i>Nitzschia</i> sp.		W						
CHLOROPHYTA								
Chlamydomonadaceae								
<i>Chlamydomonas</i> sp.		A		S	S		A	
Chlorococcaceae								
<i>Chlorococcum humicola</i> (Nageli)		A, W			S		A, S	A
Rabenhorst								
<i>Neochloris alveolaris</i> Bold				S				
Tribouxiophyceae								
<i>Chlorella ellipsoidea</i> Gerneck	W							A
<i>Chlorella vulgaris</i> Beijerinck	A	A, W		S	S		A, S	A
<i>Pseudococcomyxa simplex</i> (Mainx) Fott					S			
Scenedesmaceae								
<i>Scenedesmus bijuga</i> (Turp.) Lagerhelm		W	S				A	
Ulotrichaceae								
<i>Stichococcus bacillaris</i> Nageli		W	S		S		A, S	
<i>Ulothrix subtilissima</i> Rabenhorst		W		S	S			
CYANOBACTERIA								
Chroococcaceae								
<i>Chroococcus minor</i> (Kutzing) Nageli					A		A	
<i>Synechococcus elongatus</i> Nageli							S	
Nostocaceae								
<i>Anabaena confervoides</i> Reinsch							A	
<i>Cylindrospermum</i> sp.								A
Oscillatoriaceae								
<i>Lyngbya polysiphoniae</i> Frey		W						
<i>Lyngbya putealis</i> Mont.							S	
<i>Oscillatoria pseudogeminata</i> G. Schmid								A
<i>Symploca muscorum</i> (Agardh) Gomont						S		
Phormidiaceae								
<i>Phormidium angustissima</i> West & West	A	A, W		A	A	A	A, S	A
<i>Phormidium retzii</i> (Agardh) Gomont		A					A	A
Pseudanabaceae								
<i>Pseudanabaena</i> sp.		A						A
Unidentified filamentous cyanobacterium		A					S	A

^aA, air (include airborne algae collected from the exposed medium); W, wall scraping; S, soil.

also recorded from the air samples, suggesting that algae growing on painted walls could be another origin of the indoor airborne algae.

The dampness of the walls at the collection sites could have triggered the growth of algae and cyanobacteria. Such habitats would be colonised by biofilms consisting of algae, cyanobacteria, protozoa, fungi, slime molds, actinomycetes and other bacterial group, as reported to be found on painted buildings (Gaylarde & Gaylarde, 2000). Some of those microorganisms, especially moulds such as *Stachybotrys* spp. and *Aspergillus versicolor* (Vuillemin) Tiraboschi are a potential source of mycotoxins (Tuomi et al., 2000). This could be detrimental to the building occupants' health and a contributing factor to SBS. In addition, spores of fungi such as *Penicillium* and *Aspergillus* originating from water-damaged walls are known to be associated with respiratory allergic symptoms (Fischer & Dott, 2003). However, it is not known whether algae and cyanobacteria that grow on painted walls in a building pose a health risk to its occupants. Despite that, they could be a source of AAC within the building as indicated in the present study.

The wide occurrence of cyanobacteria in indoor air was similar to that observed in outdoor environments. For instance, cyanobacteria were the dominant airborne photosynthetic microorganisms recorded in Delhi (Mittal et al., 1979b) and Bukit Jalil (Ng et al., 2011). Such dominance could be attributed to the resistance of cyanobacteria to unfavourable conditions. The presence of sheath and mucilage protects the cells against desiccation, as they contain extracellular polymeric substances (EPS) incorporating large amounts of water (Gupta & Agrawal, 2008; Macedo et al., 2009). Almost all of the cyanobacteria found in this study were of the filamentous type. Such filamentous cyanobacteria are known to form clumps and produce mucilage,

which enable them to adhere to humans or other objects for dispersal. Amongst the cyanobacteria, *Phormidium angustissima* appeared to occur most widely in the building. *Phormidium* is a common genus of airborne cyanobacteria, as reported in studies conducted in Varanasi, India, and Cairo, Egypt (Sharma et al., 2006; El-Gamal, 2008).

The aim of exposing the culture medium to the environment was to trap algal propagules that might exist in the air. There were indeed algal propagules in the indoor air; however, it took a long time before the algae could be detected in the exposed medium. Visible algal growth in the medium was only detected after incubating the samples for more than 20 days under illuminated conditions. In a study conducted in Greece, wind-dispersed phytoplankton from a reservoir was found to colonise the experimental water containers placed near the study site only after ten weeks (Chrisostoumou et al., 2009).

The algae found in the exposed medium were mainly unicellular green algae rather than filamentous cyanobacteria as detected through direct air sampling. The green algae were mainly *Chlorella vulgaris* and *Chlorococcum humicola*, which are coccoid-shaped cells that may be heavier than filamentous cyanobacteria. Such cells could be easily dislodged into the air but could easily settle. Thus, direct sampling might not capture those cells but the liquid medium might capture such algal propagules if it is exposed for a long period of time.

Factors affecting the occurrence of the indoor AAC

The occurrence of AAC within the building appeared to be higher at sites with heavy human movement. A similar trend was observed by Ng et al. (2011), who reported the high occurrence of AAC at a Light Railway Train (LRT) station with heavy human movement in Kuala Lumpur. As humans are highly mobile, they can be an important agent in the passive dispersal of algae and cyanobacteria into the air. Algae and cyanobacteria from external sources may be dispersed into the indoor environment through this manner. Humans have also been shown to be an important source of other airborne microorganisms such as bacteria even in the extreme environment of Antarctica (Pearce et al., 2010).

Higher occurrence of AAC was generally found in open areas compared to enclosed areas, especially on 1F, 2F and 4F. The dispersal of algae and cyanobacteria might be more efficient in open areas compared to enclosed areas. A study conducted in Varanasi, India, also showed that open area near to the countryside showed the highest diversity of AAC (Sharma et al., 2006). In the present study, there was also heavy human movement in such open

Table III. Percentage occurrence of airborne algae and cyanobacteria according to site characteristics.

Level	Site characteristics					
	Human movement		Newness		Enclosure	
	Busy	Quiet	New ^a	Old	Open	Close
GF	0.0	0.0	0.0	0.0	0.0	0.0
1F	16.7	0.0	N/A	10.0	16.7	8.3
2F	23.1	14.3	25.0	19.0	21.4	16.7
3F	5.3	0.0	0.0	5.6	0.0	11.1
4F	6.3	0.0	5.0	N/A	6.7	0.0
Ground to fourth floor	9.2	4.2	6.9	8.5	8.6	7.1

^aN/A, not applicable – no new sites on first floor and all sites on fourth floor were new.

areas. However, on 3F, AAC were only recorded in enclosed areas. The air samples that contained algae and cyanobacteria at this floor were collected from the interior area of a computer laboratory (F2, E-lab 1), another busy area with heavy human movement. Although this was an enclosed area, human movement would have contributed to the load of AAC.

Factors such as temperature, relative humidity, wind speed and rainfall are important in affecting the concentration of AAC in the atmosphere (Tormo et al., 2001; Sharma et al., 2006). However, within an indoor environment, only factors such as temperature and relative humidity will be relevant and they remain relatively constant compared to the outdoor environment. This is particularly true for levels GF to 4F, where there were little variations in these parameters, suggesting that such factors may not be significant in affecting the occurrence of AAC. In comparison, the LGF and SB, which were exposed to the outdoor environment, were relatively more humid and warmer than the other levels of the building. Under humid conditions, the hygroscopic wall of algae may absorb water and this promotes settling of airborne algae (Sharma et al., 2006). However, the humid conditions also favour the growth of algae and cyanobacteria on painted walls, which could be the origin of the AAC, as shown in this study. This could account for the higher occurrence of AAC on LGF compared with other levels. Furthermore, cyanobacteria are generally able to survive over a wide range of relative humidity (23–100%; Gupta & Agarawal, 2008).

Air temperature is one of the most important factors that regulates the concentration of AAC under outdoor conditions (Sharma et al., 2007). The air-conditioning of the building maintained the indoor temperature at around 24 °C, which was lower than outdoor temperatures in Kuala Lumpur, which may range from 25–35 °C (Ng et al., 2011). However, the temperature difference may not exert a significant inhibitory effect on the survival of algae, as they are generally able to tolerate a wide range of temperatures (Teoh et al., 2010). If the origin of the AAC was mainly from the outdoor environment, the temperature difference would not be a limiting factor for their survival in the indoor environment.

As algae and cyanobacteria are photoautotrophic organisms, light will be an important factor that affects their distribution. Although light may not affect the dispersal of algae and cyanobacteria into the air, it can affect their growth and abundance on painted walls and in soils, which could be the origin of AAC in this study. However, algae and cyanobacteria on such habitats are capable of surviving at low light intensity compared

to those in aquatic habitats. For instance, some wall and soil cyanobacteria such as *Lyngbya major* Meneghini ex Gomont and *Aphanothece pallida* (Kutzing) Rabenhorst survive at very low light intensity, while some even survive darkness for more than two weeks (Gupta & Agrawal, 2008). In the present study, high occurrence of AAC was recorded at relatively dim places such as LGF and SB.

Possible health implications of indoor AAC

The health implications of the airborne algae found in this study are worth further investigations. Of particular interest are their allergenic properties, as reported for AAC such as *Phormidium* and *Chlorella* (Sharma & Rai, 2008; Genitsaris et al., 2011), which were also detected in the present study. The collection of indoor AAC cultures established from this study will be most useful for allergenicity testing. The degree of allergenicity of different species needs to be determined before the acceptable levels of allergens of AAC can be established (Sharma et al., 2007). Sensitisation in indoor environment with high abundance of algae and cyanobacteria may further increase the risk of a reaction to AAC outdoors (Tiberg et al., 1983). In addition, the occurrence of *Cylindrospermum* sp. in the air samples is noteworthy as some species of this genus are known to produce neurotoxins (Hitzfeld et al., 2000).

As the size of AAC found in this study ranged from 1–15 µm, such bioparticles can be retained by the mucosal membrane of the respiratory system and consequently may cause respiratory disease and allergy (Schlichting, 1974). It is estimated that under normal conditions, an adult human may inhale 240 algal cells/h in a tidal breathing zone (Schlichting, 1969).

The AAC are also known to play a role in the transportation of pollutants such as heavy metals and pesticides and may be associated with pathogenic bacteria, fungi and viruses (Schlichting, 1974). Studies to correlate the occurrence of AAC and health status of the building occupants are worthwhile to further assess the potential harmful effect of such bioparticles. If the algae and cyanobacteria are proven to have an impact on human health, it is recommended that AAC be included in the criteria for the assessment of IAQ.

Conclusion

This is the first report on the occurrence of AAC within the indoor environment of an office building in the tropics. The cyanobacterium *Phormidium angustissima* was the dominant species, as it was found at almost every level of the building. Highest

percentage occurrence of AAC was recorded in the surrounding areas of the building, suggesting that the outdoor environment could be a major source of the indoor AAC. This could be the reason for the high occurrence of AAC on the LGF, which was exposed to the surrounding areas. The algae and cyanobacteria growing on painted walls and in the soil of potted plants could be other sources that contributed to the load of AAC within the building. High occurrence of AAC was recorded in busy areas, suggesting that human movement is an important factor in affecting the dispersal of the bioparticles within the building. Further studies are warranted to investigate the potential health implications of the AAC to the building occupants, especially in terms of their allergenic properties. The collection of algae and cyanobacteria cultures established from this study will be most useful for such purposes.

The assessment on the occurrence of AAC was only based on cultured materials in this study. There may be underestimation as some AAC are not cultivable. Nevertheless, the baseline data on the occurrence of AAC within the building will be most useful for further studies. A quantitative survey will be worthwhile to determine the abundance of such algae and cyanobacteria in the building. This can be conducted by setting up traps commonly used in pollen monitoring, such as the Burkard-type aerobiological trap, which can be used for continuous sampling (Tormo et al., 2001). In addition, more surveys for longer periods should be conducted to chart the occurrence of AAC at different times.

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Appendix

Table AI. List of sampling sites for algae and cyanobacteria within the building, and their characteristics.

Level	Sampling site	Description	Site characteristics					
			Human movement		Newness		Enclosure	
			Busy	Quiet	New	Old	Open	Enclosed
SB	A1	In front of the elevator	x		x		x	
	A2	Far end of the car park near the main staircase		x		x	x	
	A3	Middle of the car park		x		x	x	
	A4	Left end of the car park exposed to sunlight		x		x	x	
	A5	L-shaped corner (right)		x		x	x	
	A6	Middle of the car park		x		x	x	
	A7	Renovated compartment (beside the drain)	x		x		x	
	A8	L-shaped corner (left)		x		x	x	
	A9	Entrance to the car park (left side)		x		x	x	
	A10	Entrance to the car park (on the divider)		x		x	x	
	A11	Left side of the car park		x		x	x	
	A12	Middle of the car park		x		x	x	
	A13	Right side of the car park		x		x	x	
	A14	Right far end of the car park		x		x	x	
	A15	Left far end of the car park		x		x	x	
	A16	Middle of the car park		x		x	x	
	A17	Entrance to the car park (right side)		x		x	x	
	A18	Compartment leading to the staircase	x		x		x	
	A19	First few parking lots in front of the entrance		x		x	x	
	A20	At the entrance (on the divider)		x		x	x	
LG	B1	Beside the drain		x		x	x	
	B2	Behind the staircase		x		x	x	
	B3	Parking lots (inside)		x		x	x	
	B4	Bright compartment leading to the staircase	x		x		x	
	B5	Right side of the car park		x		x	x	
	B6	Middle of the car park		x		x	x	
	B7	At the entrance (parking lots)		x		x	x	
	B8	At the entrance (divider)		x		x	x	
	B9	At the entrance (behind the guard's table)		x		x	x	
	B10	Opposite LRT station (near the guard's table)		x		x	x	
	B11	Right side of the car park		x		x	x	
	B12	Parking lots for motorcycles		x		x	x	
	B13	Left side of the car park (exposed to outdoor)		x		x	x	
	B14	Beside the pillar facing the LRT station – Site 1		x		x	x	
	B15	Beside the pillar facing the LRT station – Site 2		x		x	x	
	B16	Middle of the car park		x		x	x	
	B17	Parking lots		x		x	x	
	B18	Middle of the car park		x		x	x	
	B19	In front of the elevator (leading to research lab)	x		x		x	
	B20	Facing Vista B (bright area, on the divider)		x		x	x	
GF	C1	Atrium, in front of the Clinical Skills Unit (CSU)	x			x	x	
	C2	Ping pong room		x		x		x
	C3	VK bookstore	x			x		x
	C4	Behind the platform (beside VK bookstore)	x			x	x	
	C5	Administration department	x			x		x
	C6	In front of the escalator	x			x	x	
	C7	Atrium (in front of ping pong room)	x			x	x	
	C8	Pigeon holes behind CSU		x		x	x	
	C9	Corridor behind CSU		x		x	x	
	C10	Canteen 2	x		x			x
	C11	Canteen 1-site 1	x		x			x
	C12	Canteen 1-site 2	x		x			x
	C13	Behind nursing dept (In front of the elevator)		x		x	x	
	C14	Canteen 2	x			x		x
	C15	On the podium (right, beside a plant)	x			x	x	
	C16	On the podium (left, beside a plant)	x			x	x	

(Continued)

Table AI. (Continued).

Level	Sampling site	Description	Site characteristics					
			Human movement		Newness		Enclosure	
			Busy	Quiet	New	Old	Open	Enclosed
1F	C17	Beside the main entrance (left)	x			x	x	
	C18	Beside a pillar	x			x	x	
	C19	CSU	x			x		x
	C20	Old entrance (coming up from the car park)	x			x	x	
	D1	In front of lecturers' office	x			x	x	
	D2	Seminar Room (SR) 3	x			x		x
	D3	Problem-based learning (PBL) room 12		x		x		x
	D4	Corridor behind postgraduate room (near lockers)	x			x	x	
	D5	Lab (near fridge)	x			x		x
	D6	Postgraduate room	x			x		x
	D7	Cashier office	x			x		x
	D8	Administration department	x			x		x
	D9	Behind the old lecturers' office (on the cupboard)		x		x	x	
	D10	Far end of 1 st floor (on the table near the exit)		x		x	x	
	D11	Lab (beside the incubator)		x		x		x
	D12	Toilet (behind the lab)	x			x		x
	D13	Lab (behind postgraduate room)	x			x		x
	D14	Lab (above refrigerator)		x		x		x
	D15	Lab (butterfly's garden)		x		x		x
2F	D16	Lecturers' letter box		x		x	x	
	D17	SR 3	x			x		x
	D18	SR 1	x			x		x
	D19	Bright area in front of the elevator (far end of research lab)		x		x	x	
	D20	Lab (beside the sink)	x			x		x
	E1	Academic Administration Department (AAD)	x			x		x
	E2	Far end of lecturers' office		x		x	x	
	E3	Near the barrier, overlooking the atrium, 30° right of the podium	x			x	x	
	E4	Corridor leading to the elevator/toilet		x		x	x	
	E5	In front of the Centre of Medical Education		x		x	x	
	E6	In front of new offices	x		x		x	
	E7	Right side of the escalator	x			x	x	
	E8	Left side of the escalator	x			x	x	
	E9	Near the barrier, overlooking the atrium, 60° left of the podium	x			x	x	
	E10	Guest office	x		x			x
	E11	Near the barrier, facing the podium of the atrium	x			x	x	
	E12	Open area near the temporary office (under a plant)	x		x		x	
	E13	Near the barrier, overlooking the atrium, 90° left of the podium	x			x	x	
	E14	Dean's office	x		x			x
	E15	In front of the elevator (behind temporary lecturers' office)		x		x	x	
3F	E16	Exam hall (Front)		x		x		x
	E17	Exam hall (Middle)		x		x		x
	E18	Surau (praying room)	x			x		x
	E19	Near the barrier, overlooking the atrium, 60° left of the podium	x			x	x	
	E20	Staircase (near the elevator behind exam hall)		x		x	x	
	F1	Outside E-lab 2	x			x	x	
	F2	Inside E-lab 1	x			x		x
	F3	Near the barrier, overlooking the atrium, 60° right of the podium	x			x	x	
	F4	Old library (behind the door)	x			x		x
	F5	Old library (beside book shelf)	x			x		x
	F6	Lockers in front of E-lab 1	x			x	x	
	F7	LT2	x			x		x

(Continued)

Table AI. (Continued).

Level	Sampling site	Description	Site characteristics					
			Human movement		Newness		Enclosure	
			Busy	Quiet	New	Old	Open	Enclosed
4F	F8	Lockers beside the lab	x			x	x	
	F9	Behind the staircase (in front of the Medical Museum)	x			x	x	
	F10	E-lab 1	x			x		x
	F11	Pigeon holes in front of the new library	x			x	x	
	F12	Medical Museum (MM)	x			x		x
	F13	Pigeon holes outside MM	x			x	x	
	F14	New library – Site 1	x		x			x
	F15	New library – Site 2	x		x			x
	F16	Far end of the corridor of LT1/2 (in front of elevator)	x			x	x	
	F17	Between two water coolers (in front of LT)	x			x	x	
	F18	Near the barrier, overlooking the atrium, 30° left of the podium	x			x	x	
	F19	IT department	x			x		x
	F20	Staircase behind IT department		x		x	x	
	G1	In front of the escalator (near potted plants)	x		x		x	
	G2	Student lounge	x		x			x
	G3	One corner of Multi-Purpose Hall (MPH) 6		x	x			x
	G4	In front of the elevator		x	x		x	
	G5	Open area in front of auditorium (area with tables & chairs)	x		x		x	
	G6	Open area in front of the auditorium	x		x		x	
	G7	Side entrance of the auditorium (near the toilet)	x		x		x	
	G8	Beside the lockers near ping pong tables	x		x		x	
	G9	Side entrance to the auditorium (student lounge)	x		x		x	
	G10	Side entrance to lecture theatre (LT) 3 (near the toilet)	x		x		x	
	G11	At the staircase from E-lab (under a plant)	x		x		x	
	G12	Entrance to the emergency exit		x	x		x	
	G13	Immediately after the staircase (near LT 3)	x		x		x	
	G14	Front entrance to LT 3	x		x		x	
	G15	Bridge	x		x		x	
	G16	In front of student lounge (after the bridge)	x		x		x	
	G17	Auditorium	x		x			x
	G18	Inside LT 3	x		x			x
	G19	Multi-disciplinary Lab (MDL) 5&6	x		x			x
	G20	Bright area in front of MPH 6	x		x		x	

Table AII. List of sampling sites for airborne algae and cyanobacteria (AAC) in the surrounding outdoor areas of the building.

Sampling site	Description
H1	Near LG car park facing LRT station
H2	Old basketball court
H3	Beside animal lab – Site 1
H4	Beside animal lab – Site 2
H5	Beside the new basketball court
H6	On the way to old basketball court
H7	Old basketball court
H8	Beside the new basketball court
H9	In front of Vista B
H10	Beside Commonwealth Hill
H11	LRT station
H12	In front of a condominium