Sustainability in Building Environment: A Review and Analysis on Mould Growth in a Subtropical Climate

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Abstract: - A review on mould growth in buildings in a subtropical climate and the characteristics of moulds in a subtropical Central Queensland University (CQU), Rockhampton campus, Australia, buildings are presented and analysed. The mould (fungal spore) concentrations indoors and outdoors are compared and correlations between mould concentrations and environmental parameters such as temperature and humidity are developed. Specific genera of moulds and total spores were identified and recovered colonies were counted from the airborne samples. The SPSS (Statistical Product and Service Solutions) software was used for nonparametric data analysis. Total airborne mould concentrations were found highest in the dry season and lowest in the wet season and were positively correlated with relative humidity and temperature. Further studies are recommended for controlling mould growth in buildings in a subtropical climate.

Key-Words: - Airborne fungal spores, a subtropical climate, total fungal spores, Burkard spore trap, Spearman correlation coefficient.

1 Introduction

In recent years, much attention has been drawn to the airborne micro-organism, namely the mould concentration in the office environment and their roles in causing building related adverse symptoms (i.e. the "Sick Building Syndrome") [1]. For health and safety reasons, it is essential to have knowledge of prevalence and environmental determinants.

There are essentially no fungus-free environments in our vicinity. Fungi can grow within the human comfort range, and certain fungi can also survive or even flourish at low (–5°C) or high (60°C) temperatures, limited water activities (0.70 a_w) and very low oxygen content [1]. Fungal spores are abundant in outdoor air. Sources for indoor airborne fungi can be the outdoor air and/or indoor reservoirs [2, 3]. Fungal spores in outdoor air are a major threat for naturally ventilated buildings during the wet seasons [December-March] in tropical regions [4]. Although outdoor fungi do not penetrate easily into large buildings with central air-conditioning systems, concurrently the outdoor aerosol may dominate indoors [5]. Accumulated dust is also a potential indoor source of a bio-aerosol which can grow on nonliving materials if water content can support it [2]. Fungal exposures have been reported to cause allergic diseases and nearly 10% of people worldwide have a fungal allergy [6]. Fungal allergy has been blamed for non-specific building related symptoms (BRS) [7, 8]. Allergy and asthma are important health issues in the region with the most recent figures indicating prevalence rates of 13.5% for asthma and 11.4% for hay-fever. These figures represent an increase of approximately 3% from the previous health survey figures [9].

Modern technology provides the researchers with a variety of ways for analysing fungi while each method has certain advantages and drawbacks [10]. Many studies utilised culture-based analysis as well as total spore analysis using optical microscopes. Although the culture-based methods have several limitations including lack of reproducibility, selection effect, limitation of sampling time and underestimation of total number of fungal propagules, they only allow accounting for culturable fungi [11-13]. Culture-based analysis is commonly used when species level identification is needed and is a surrogate for viable fungi. The total spore count has shown better exposure to response relationship compared to the culture-based method [14]. However, in order to elucidate personal exposure to airborne fungi (mould) that may act as aeroallergens or pathogens in the residential environment, both the levels of culturable fungi and total fungal spores as well as culturability (the ratio of the culturable to total fungi) should be evaluated

accurately. The culturability of mould can also provide a relationship between the dynamics of airborne fungi and environmental variables [15]. In many published studies, the researchers utilised different sampling techniques for measuring culturable and total fungal spores [15-17]. However, it is expected that different samplers may differ considerably in their sampling efficiency characteristics such as the cut-off size, the spore extraction efficiency from the collection media (e.g., a filter or a slide, etc). If the samples enumerated for the colony-forming units (CFU) and the total spore number were collected with samplers which had different cut-off values and/or different properties of the collection surface, the comparison of the two databases should not be done because they may provide misleading information. Therefore, the airborne fungi should be collected using the same sampler and the same collection media for the CFU and total enumeration. Burkard spore traps are widely used for sampling the bioaerosol composition of the atmosphere. These volumetric samplers are based on the Hirst spore trap [18, 19]. In general, Hirst-type spore traps provide a reliable assessment of bio-aerosol [20].

In this study, a review on mould growth in buildings in a subtropical climate is presented first and then the characteristics of moulds formed at CQU buildings are analysed. The mould concentrations between indoors and outdoors are compared. Correlation between the mould and the environmental parameters such as temperature and humidity are developed and discussed. Recommendations on how to control mould growth are suggested.

2 A Review on Mould Growth

2.1 Mould Growth in Building Environment

Nowadays, provision of comfortable shelter and healthy environment in buildings has become an essential requirement. These are achieved by meeting the desired building design criteria and optimum building operating parameters. Today building design criteria are: (a) energy efficiency, (b) minimization of environmental impact and (c) protection of the health and safety of the inhabitants. Sick building syndrome (SBS) i.e. surrounding of buildings is contaminated and indoor mould growth has been recognized as a problem for couple of thousand years from biblical reference [21]. These types of phenomenon are typically referred as fungi.

Fungal growth in buildings starts at a water activity (a_w) near 0.8. The term water activity (a_w) is used to describe the moisture content of substrates. Water activity is the relative humidity of the substrate (the natural environment in which an organism lives, or the surface or medium on which an organism grows or is attached) expressed as a decimal fraction (e.g., 95% = 0.95 a_w). The range of water activities that individual species grow under varies from approximately 0.55 to 1.0 a_w. Species that require high water activities (>0.95 a_w) are described as hydrophilic or tertiary. Fungi grow based on the range of temperature conditions (<5°C to 60°C) as outline below:

- Mesophilic or primary level of fungi, the largest group, has an optimum temperature range of 20 °C to 30°C.
- Thermophilic or secondary level of fungi that are human pathogens grow well at temperatures of 35°C to 40°C;
- True thermophilic or tertiary level of fungi grows at temperatures of 45°C to 60°C, e.g., compost heaps. Another cold fungi called cryophilic fungi can grow at relatively low temperatures (<5°C), e.g., on materials in cold storage and in regions having cold climates [22].

Significant quantities of mycotoxins are not produced unless a_w reaches 0.95. Stachybotrys generates particularly high quantities of many chemically distinct metabolites in water-damaged buildings. During the last 10–15 years case studies have shown that people living and working in damp or mouldy buildings have an increased risk of adverse health effects including airway infections, impaired immune function, bronchitis, asthma, recurrent airway infections, and extreme fatigue [23].

The proportion of buildings with mould growth in Northern Europe and North America is perhaps as high as 20%–40%. Data from the UK suggest that 30%–45% of the buildings are mouldy [24], while it is 30% in Canada [25]. Australian bureau of statistics does not release such type of data though all over Australia's buildings are doing small scale preventive maintenance program for mould growth. However it should be recognized that this mould growth ranges from small areas covering a few cm^2 to widespread fungal proliferation in heavily contaminated buildings. To address current and future health issues associated with indoor moulds, it is essential to obtain clinically-valid analyses of occupants' complaints, to identify toxic metabolites present in buildings, and to determine hazardous exposure levels.

Buildings can be considered ''new'' man made ecosystems, whereas in other environments—a limited number of fungal species will dominate,

depending on humidity and nutrient availability [26]. Moulds growing on building materials can be divided into three groups [27] based on their water activity, a_w, requirements on laboratory substrates, and responses to changes in a_w [28]:

- Primary colonizers or storage moulds, capable of growing at $a_w < 0.8$ (many with optimal growth rates at a_w approaching 1). Penicillium chrysogenum and Aspergillus versicolor are the most common species.
- Secondary colonizers or phylloplane fungi, growing at a_w between 0.8 and 0.9. These are able to flourish under conditions, where marked changes in humidity occur during the day.
- Tertiary colonizers or water-damage moulds, needing $a_w > 0.9$, include many of the most toxic species such as Chaetomium globosum, Memnoniella echinata. Several of these are considered tropical fungi, which seems consistent with their propensity for growth in humid buildings.

Water activity, also referred to as equilibrated relative humidity, is undoubtedly the most important factor in determining whether or not mould growth is initiated on building materials [29]. It is essential to understand that local differences in ventilation and surface temperature can generate micro-climates with very high a_w in a room with an otherwise low relative humidity (RH). For this reason, a measurement of indoor RH is a very poor predictor of mould problems [29]. Variations in indoor humidity and temperature exert a profound influence upon mould growth [30, 31], where the period of time when water availability exceeds the threshold a_w for mould growth, and the number of dry periods during the day are key parameters [30]. A bathroom is a good example of an indoor environment with transient high humidity, and has a specific mycobiota dominated by phylloplane fungi including species of *Alternaria, Aureobasidium* [32].

Identification of mould species is vital for studies on mycotoxin production by indoor moulds. Chemotaxonomy based on the species-specific production of metabolites. It is also an important tool that can help exclude problems caused by incorrect identification based on microscopy, contamination of cultures, and erroneous claims of mycotoxin production [33]. Chemical analysis has proven very effective in studying *Aspergillus* and *Penicillium*, where there are clear relationships between metabolite production and certain species, and where even experts find it very difficult, or impossible, to discriminate between species by classical microscopic examination [34].

2.2 Human Exposure to Mould

Recently it was considered that the inhabitants of mould-contaminated buildings were exposed to mycotoxins via the inhalation of spores and spore-sized fragments of mycelia [35]. For this reason, spore counts were valued for assessing the potential for mycotoxin exposure. However, it has been shown that particles far smaller than spores (down to 0.3μm) are released from colonies growing on building materials [36]. There is no correlation between the concentration of particles and spores. Combined with lack of techniques for quantifying particles smaller than spores, it is easy to appreciate why it has proven so difficult to correlate data on viable or total airborne fungi with health problems in mould-contaminated buildings.

Airborne mycotoxins have been detected in environments with high concentrations of airborne spores, including farms and compost handling facilities [35]. But mycotoxins have only been detected sporadically in indoor air, where *trichothecenes* and *spirocyclic drimanes* have been detected in dust and air samples obtained from homes contaminated with *Stachybotrys* [37].

Thus, mycotoxin production in buildings seems to occur when a_w at the surface of the construction material exceeds 0.9, but significant toxin synthesis does not begin until a_w reaches 0.95. For this reason, the worst-case scenario for the development of an indoor mould problem involves a series of water intrusion events that allow large quantities of biomass and mycotoxins to form, and then a period of drying that promotes the dispersion of spores and colony fragments, followed by their deposition throughout the building.

In many hot and humid climates, conventional air conditioning units are unable to meet the latent load and the relative humidity exceeds the comfort threshold of 60% RH. This has led to the growing application of heat and moisture transfer devices which can reduce the latent load on air conditioning units [38]. With these devices it is possible to provide an acceptable indoor climate even in hot and humid climates.

2.3 Analytical Methods and Sample Collection of Moulds

The detection of mycotoxins is a difficult task requiring careful work by analytical chemists with knowledge of fungal metabolites plus access to state-of the-art instrumentation. Building materials represent new ‘‘matrices’’ with an infinite number of combinations of materials (e.g., wallpapers, paints, dust, etc.) that may interfere with the analytical

methods. The identification of specific mycotoxins is further complicated by the fact that fungi generate so many different metabolites.

Sample collection is a key step in the analysis of mycotoxins in buildings. The collection of pieces of building material can be problematic because: (i) biomass can be lost during handling of the material or can be transferred to the inner surface of the sampling container (and lost in subsequent analyses); (ii) large quantities of components that interfere with the chemical analyses are introduced which necessitates several clean-up steps [39]. Therefore, surface sampling using ultra-clean swabs [28], or by vacuuming (e.g., onto 0.1µm pore size Teflon filters), is recommended.

3 Experimental Description

3.1 Study Locations and Heating, Ventilating and Air Conditioning (HVAC) Systems of Selected Buildings

The study was carried out at CQU, Rockhampton campus in Australia, located in a subtropical climate with an annual mean temperature of 28.3^0C and rainfall of 805.2 mm. The mean daily temperature ranges from 32.1^0C in December (warmest month) to 23.1^0C in July (coolest month); rainfall is highest during the wet season months (February average, 140.5 mm) and lowest in late dry season (September average, 23 mm) [40]. The five buildings on the campus namely A, B, C, D and E were selected for sampling and analysis. The levels of the buildings are 4, 3, 3, 3 and 3 respectively. Four administrative offices (A, B, C, and D) selected from these five buildings are controlled by four different chiller units and all are constant air volume systems. The fifth building (E) is served from a package air conditioning system. These buildings (A, B, C, D and E) are supplied by several air handling units (AHU) and fan coil units (FCU). Temperature sensors are installed in every room and are monitored by the Building Management System (BMS) in the management office. At least 10% outside air is nominally supplied to these five buildings. However, specific outdoor air supply amounts were not available for each sampling site, and carbon dioxide concentration was used as a surrogate for outdoor air supply.

3.2 Sample Preparation and Procedures

Mould complaint office areas of buildings A, B, C, D and E and their vicinity outdoor locations were identified for sampling. The complaint areas were chosen with assistance from the mould remediation contractors (MRC) and characterized by excessive mould growth prior to remediation. The outdoor samples were collected within 10 m of the entrance/exit of the corresponding buildings. All samples were collected soon after one another and always within 30 minutes of each other.

Sampling plates were prepared for Burkard portable air sampler by pouring about 40 mL of half strength Potato Dextrose Agar from a CQU microbiology laboratory aseptically into 90 mm×15 mm sterile plastic Petri dishes through a sieve plate so that the gap between the nozzles and agar surface met the manufacturer's operational specification [41]. All inside surfaces were maintained in a sterile condition until sampling. Burkard portable air sampler is the industry standard impaction sampler [42] with 100 holes (1 mm diameter), and it was operated at a flow rate of 10 L/min. Samples were collected approximately 1 m above the ground, in the centre of every room using a convenient base. After sampling for 8 min the plates were removed from the sampler and placed in individual sterile bags in a cooler pack at normal temperature. The plates were then sent to the CQU microbiology laboratory for mould counts and identifications. Fungi were identified using microscopic techniques. Samples were incubated at 22^0 C for 4 days prior to analysis. Similarly Burkard volumetric air samplers' glass slides (7 mm × 26 mm) were prepared by pouring two drops of a mixture of petroleum ether (70%) and Vaseline (5%) for total count of spores. The flow rate and timing were similar to the Burkard portable air sampler.

The microscopic analysis was applied to obtain the concentration of total fungal spores. The fungal spores were identified and counted under the 1000 X magnification of a high-resolution light microscope in at least 40 randomly selected microscopic fields [43]. The identification of fungi was conducted to the genus or species level based on their morphological characteristics. The culturability of airborne fungi, was calculated as

$$\text{Culturability of airborne fungi (\%)} = \frac{\text{Concentration of culturable fungi (CFU/m}^3\text{)}}{\text{Concentration of total fungal spores (spores/m}^3\text{)}} \times 100$$

3.3 Temperature, RH & CO_2 Measurements

In all sampling locations temperature and RH were continuously recorded on an hourly basis by using battery-operated data loggers, HOBO-Temp, and HOBO-RH [44]. Carbon dioxide concentration level was measured through CO_2 transmitters installed by the CQU Building Management System.

4 Results and Discussion

From the selected five buildings, a total of 30 indoor samples and 30 outdoor samples were collected through Burkard air samplers and analysed. Moulds were sampled bimonthly. Data of RH, temperature, carbon dioxide (CO_2) were taken as average values of working hours (0900h- 1700 h). Table 1 summarises the indoor and outdoor mean values and standard deviations for the mould and environmental parameters, namely culturable mould, total moulds, RH, temperature and CO_2.

4.1 Colonies of Mould Recovered from Indoor and Outdoor Samples

The concentrations of indoor culturable moulds were found to be between 2 and 88 CFU/m^3 with a median of 18 CFU/m^3 and outdoor concentrations 11, 197 and 73 respectively. According to Wilcoxon signed rank test, the indoor and outdoor CFU levels integrated over the entire test period (dry and wet seasons) are not significantly different (P=0.0001, P→significance level). Approximately 95% confidence interval was found for the difference between indoor and outdoor culturable concentrations (medians -61.5 to -37.5 with Median difference = -47 according to StatsDirect Statistical software) [45]. The indoor and outdoor culturable fungal spore concentrations obtained in this study are higher in the dry season and lower in the wet season. Ren *et al*. [46] reported similar findings whereas opposite findings were reported by Shelton *et al*. [47]. Regional variation might be the cause of such discrepancy. Shelton *et al*. [47] also reported that the indoor and outdoor culturable fungal spore concentrations do not vary substantially by season but by climatic region.

The indoor and outdoor culturable fungal spore concentration levels obtained in this study are mostly lower than those reported in earlier studies. For example Garrett *et al*. [16] reported that the median levels of indoor and outdoor culturable fungi were 812 and 1042CFU/m^3 respectively in 80 homes in Latrobe Valley, Australia. The climate conditions and vegetation in Rockhampton (Queensland) and Latrobe valley (Victoria) are not similar which might be the reasons for the difference of culturable fungal spore concentration levels.

4.2 Fungal Genera and Species

Thirty four different mould species belonging to twenty one genera were found. The most common mould recovered from outdoor and indoor air were *Cladosporium*, *Aspergillus*, *Curvularia*, *Penicillium*, *Fusarium* and *Phoma*. *Cladosporium*, *Aspergillus*, and *Curvularia* were detected in 60% to 80% indoor samples. *Cladosporium, Penicillium, Fusarium and Phoma* were detected in 50% to 85% outdoor samples. Ren *et al*. [46] reported similar findings. Most importantly, the very hazardous moulds *Stachybotrys* and A*spergillus fumigatus* were not found in the current study.

4.3 Total Mould Spores Recovered from Indoor and Outdoor Samples

The indoor concentrations of total mould spores were between 7 and 3001CFU/m^3 with a median of 25 CFU/m^3 and outdoor concentrations were 37, 816 and 109 respectively. The indoor concentrations of total mould spores integrated over the entire year were significantly different from those detected in outdoors (P<0.0001). According to Wilcoxon signed rank test the indoor concentrations integrated per season were found significantly different between the dry and the wet seasons (P<0.0001 for the dry season and P=0.0004 for the wet season).

Forty-six different types of spores were detected from indoor and outdoor samples. The most prevalent spores recovered from outdoors and indoors were *Aspergillus, Penicillium, Cladosporium and Epicoccum*. The most prevalent genera detected were *Aspergillus* and *Penicillium* 60% to 80% followed by ascosporic fungi and *Cladosporium* 50% to 70% in indoor samples. *Cladosporium* and *Penicillium* 60% to 65% and *Fusarium* and *Epicoccum* 50% to 60% spores were found in outdoor samples. Many unidentified spores of <70% were detected in outdoor and indoor environments. Two very dangerous moulds, *Stachybotrys* and *Aspergillus fumigatus*, were not found in the current study. A significant variation in airborne fungal concentrations, RH, and temperature were found between dry and wet seasons. Airborne fungal concentrations and RH were highest in the wet and lowest in the dry seasons. Temperatures were slightly higher in the wet than in the dry season. This study did not find significant seasonal variation in CO_2 concentrations.

4.4 Spearman Correlation Coefficient

Spearman correlation coefficient ranges from +1 (perfect positive correlation), through 0 (no correlation), to -1 (perfect negative correlation) are used to identify type of correlation between moulds and environmental parameters. In general terms, correlation coefficients:

- up to 0.33 are considered weak relationships.
- 0.34 to 0.66 are medium strength relationships.
- over 0.67 indicate strong relationships.

Table 2 shows Spearman Correlation Coefficients among the concentrations of airborne culturable fungi, total fungal spores, and measured environmental variables. The outdoor culturable fungi have a positive correlation among indoor culturable fungi, indoor total fungal spores, indoor temperature, and indoor RH. The indoor culturable fungi have a strong positive correlation with indoor total fungal spores but have medium strength correlation with outdoor total fungal spores. The indoor total fungal spores showed medium strength correlation with the outdoor total fungal spores but negative low correlations with outdoor temperature and indoor CO_2 indicated very weak linear negative correlations. Because CO_2 inversely associated with ventilation and outdoor temperature has very little impact over central air-conditioned buildings. The concentration of airborne fungi correlated better with temperature than indoor relative humidity. Thus, different airborne species react differently with different environmental variables. Temperature and relative humidity seemed to be the most important environmental variables [48].

4.5 The Culturability of Fungal Spores

The culturability data are plotted in Figure 1. The indoor levels ranged from 1% to >100% with a median of 54% and outdoor levels were between 1% and >100% with a median of 45%. Throughout the two seasons tested in this study, the indoor culturability levels of airborne fungi were significantly greater than those obtained from outdoor samples ($p = 0.01$). The indoor median values of culturability of airborne fungi for wet and dry seasons were 46% and 58% respectively, and the outdoor median values for these seasons were 40% and 65% respectively. The overall culturability of fungal spores was higher during the dry season. Similar findings were also reported by Lee *et al*. [49]. The median of Input/Output (I/O) culturability ratio was greater than one when integrated over the whole year. In conclusion, the culturability of indoor airborne fungi was mostly greater than that of fungi measured outdoors. Consequently, it indicates that indoor environments provide more favourable conditions for survival of airborne fungal spores. Similar results have been reported elsewhere [28, 34, 48, 50].

Table 1: Distribution of environmental variables in different seasons over a year

Seasons	No. of samples	Cultural able fungi(CFU/m^3)		Total fungal spores(spore/m^3)		Relative humidity (%)		Temperature(^{0}C)		CO_2 (ppm)
		Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor
Dry	30	21.67 ±22.54	53.33 ±38.29	58.7 ±88.99	173.07 ±229.11	51.33 ±4.56	55.92 ±13.78	22.68 ±0.59	19.13 ±7.30	510.07 ±51.81
Wet	30	21.53 ±18.71	95.57 ±51.58	188.83 ±601.41	165.60 ±83.55	64.27 ±5.20	60.25 ±9.93	23.27 ±0.73	25.73 ±5.61	545.38 ±67.32

Each cell contains mean value with standard deviation

Table 2: Spearman correlation coefficients between indoor and outdoor environmental variables

Variables	**Cultural able fungi(Outdoor)**	**Cultural able fungi(Indoor)**	**Total fungal spores(Indoor)**	**Total fungal spores(Outdoor)**
Cultural able fungi(Indoor)	0.532 (<0.0001, n=60)	—	—	—
Total fungal spores(Indoor)	0.467 (<0.0001, n=60)	0.800 (<0.0001, n=60)	—	—
Total fungal spores(Outdoor)	0.771 (<0.0001, n=60)	0.432 (0.0003, n=60)	0.397 (0.0009, n=60)	—
Indoor temperature	0.367 (0.0011, n=58)	0.177 (0.087, n=58)	0.179 (0.085, n=58)	0.197 (0.066, n=58)
Outdoor temperature	0.0264 (0.420, n=58)	0.030 (0.403, n=58)	-0.035 (0.604, n=58)	0.105 (0.212, n=58)
Indoor relative humidity	0.389 (0.012, n=58)	0.227 (0.041, n=58)	0.139 (0.143, n=58)	0.245 (0.029, n=58)
Outdoor relative humidity	0.049 (0.353, n=58)	0.159 (0.112, n=58)	0.171 (0.095, n=58)	0.158 (0.114, n=58)
Indoor CO_2	—	0.027 (0.418, n=58)	-0.063 (0.684, n=58)	—

(Significant correlations are bold faced, *p* values and sample numbers are indicated in the parenthesis)

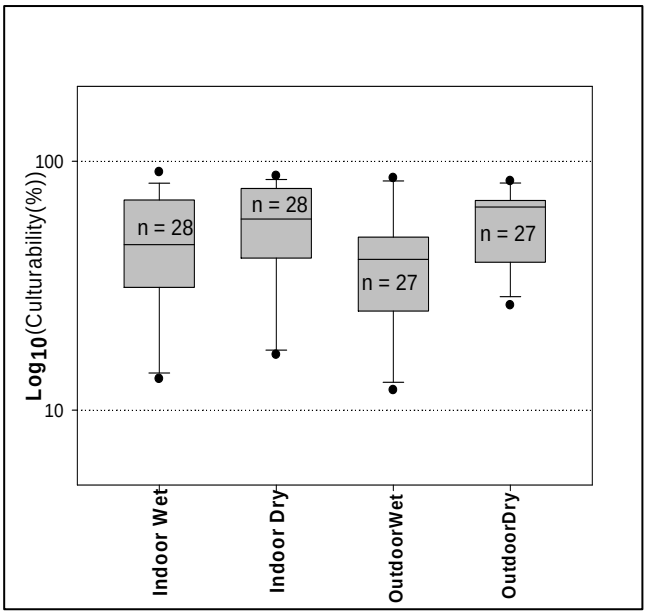

Fig.1. The box plots of indoor and outdoor culturability (%) for mould. Here, n is the number of samples.

5 Control of Mould Growth

The proper combination of interior and exterior vapour control and insulation control must be employed in buildings for control of mould growth. If buildings are equipped with air conditioning equipment, moisture transport from the interior can be regulated. Buildings must be designed to accommodate some form of synchronized moisture control that utilizes drying towards the interior as well as the exterior. Aerated concrete walls that incorporate such features can be developed with substantially higher moisture load tolerances for any climatic region, without necessarily requiring special cavities or other expensive changes in design.

Today, by effectively employing holistic moisture engineering analysis, integrating material properties, system and sub-system performances (lab and field studies) and advanced modeling building envelope systems can be optimally designed. Study on mycotoxins in buildings is a multidisciplinary task, demanding knowledge of environmental engineering chemotoxonomy, fungal metabolism and biosynthetic pathways, fungal physiology and growth, analytical chemistry, and toxicology. Collaboration with specialists in fungal identification is also essential. Therefore a taskforce of environmental and bio-chemical specialists are needed in these disciplines for the proper solution of particular problem of mould growth in buildings.

Water is a major limiting factor in the growth of moulds. Most of the mould species require at least 70% RH for germination, and optimal substrate moisture for initial infestation is also necessary for subsequent mould growth [22]. Mould can grow over a range of temperatures (< 5 to 60^{o}C) and most of them can survive in the human comfort temperature range. 64.3 ± 5.2 average humidity was found in this study in indoors in the wet season and total mould spores count was higher in the wet season than in the dry season which indicates relative humidity might be the reason for mould growth. The study advances the understanding of mould growth in a subtropical climate through their review, measurement, identification and analysis. This study suggests that humidity control through dehumidification could be one of the recommendations for the control of mould growth in CQU buildings. Dehumidification could be one solution for controlling humidity. Most of the CQU buildings have constant air volume system air conditioning. Water condensation in duct areas near air handling units is a quite common criterion in big central air conditioned buildings. For instance, duct liner areas of CQU building number one (the library building) out of five case study buildings, has plenty of infestation according to MRC of CQU. Ultraviolet light is widely used for mould infestation remediation inside the duct area. About 99% mould remediation is possible by Bio-Fighter UV-C Light Systems (Ultra Violet radiation “C” band light, wave length 100 to 290nm) [51]. Further study is recommended in order to investigate the opportunity for introducing UV-C in existing systems.

6 Conclusion and Recommendation

Indoor and outdoor airborne fungal spore concentrations were measured and analysed in a subtropical CQU buildings. It was found that the culturable outdoor moulds are mostly greater than the culturable indoor moulds. The indoor and outdoor mould concentrations have a positive Spearman correlation. Modern, mechanically ventilated large institutional or office buildings prevent the intrusion of a large number of outdoor moulds. High humidity and water condensation are the sources of mould infestation which are the by-products of buildings’ HVAC systems. Future investigations are required to identify the moulds that are the sources of allergy and asthma which are the major growing health concern in this region. An opportunity for introducing UV-C in existing HVAC

systems' ducting should be investigated further in order to control the mould growth.

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