Research approaches on factors influencing indoor fungal infestation and its potential treatment technologies from 2010 – 2020: A systematic review

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ABSTRACT

Fungal infestation in indoor environment promotes indoor air pollution and consequently leads to severe impacts on the occupants. This environmental issue has received a major attention as dispersion of the fungal spores from vary species of invisible microbes through airborne may affect indoor air quality and comfort. This paper is intentionally to review existing studies that consider on the factors influencing indoor fungal infestation and the potential treatment technologies for controlling their growth. A systematic literature search of ResearchGate, Google Scholar, ScienceDirect, PubMed and Wiley Online Library from 2010 to 2020 was conducted based on PRISMA Guideline without excluded other relevant articles found during the search. The findings are evaluated through an overview on the relation between the contributing factors and explore the strengths and weaknesses of existing treatment technologies in order to determine each potential for management of indoor mould. Abatement of technologies are necessary since controlling and minimizing at sources are insufficient, economically unviable and technically unfeasible. These treatment technologies seem to impact positively on the reduction of fungal spores and environmental factors that support the fungal growth indoor.

Keywords: Fungal infestation, indoor environment, factors, treatment, technology

ABBREVIATIONS

aw	Water activity
CAP	Cold atmospheric plasma
E-nose	Electronic nose
EPA	Environmental Protection Agency
EPSS	Electrostatic precipitators with superhydrophobic surface
ES	Electrostatic
ESPs	Electrostatic precipitators
HEPA	High efficiency particulates air
HVAC	Heating, ventilation and air conditioning
PCO	Photocatalytic oxidation
PPE	Personal protective equipment
RH	Relative humidity
SBS	Sick building syndrome
UV	Ultraviolet
UVC	Ultraviolet irradiation
UV-PCO	Ultraviolet-photocatalytic oxidation
VOCs	Volatile organic compounds
WHO	World Health Organization
µm	Micrometre
°C	Celsius

1.0 INTRODUCTION

Mould becomes a major public health concern in indoor environment including at homes, workplaces and classrooms. Previous studies have clarified that people start to concern on indoor air quality as they spend more time indoor rather than outdoor (Ismail *et al.*, 2010). Fungal growth that damages the building surfaces also contributes to erosion, reduce the life of the building structure and negatively affect human health through inhalation, ingestion and dermal contact with spores (Raffaella et al., 2020).

In 2012, World Health Organization (WHO) reported that about 4.3 million premature mortality are caused by indoor air pollution globally. To specify, fungal infestation is biological pollution that favours to grow in a condition of sufficient temperature and moisture (Srikanth et al., 2008; Nazaroff, 2013).

Generally, fungi require oxygen, humidity, nutrients and water to grow. As they grow, their tiny spores are widespread to inhabit indoors (Suriani et al., 2014). It spreads through a circulation of doorways, windows, ventilation systems or air conditioning systems. *Cladosporium, Penicillium, Aspergillus* and yeast are the commonest fungi species infested the buildings (Verma et al., 2011).

An exposed occupant with immunologically sensitized to mould spores can trigger the building-related symptoms, called as sick building syndromes (SBS) (Fung et al., 2003). Plus, the significant impacts due to exposure of indoor mould potentially to affect a large number of building occupants that results to the significant costs including the healthcare expenses, sick leave and lost productivity (Persily et al., 2012).

In buildings with Heating, Ventilation and Air Conditioning (HVAC) system, the common indoor mould such as *Penicillium* and *Aspergillus* are found to consequence hypersensitivity pneumonitis meanwhile one may suffer to allergic bronchopulmonary aspergillosis and allergic fungal sinusitis when fungi infest inside the airway and emits their spores and allergens. (Vardouakis et al., 2015)

Nevertheless, the pathogenic reaction depends on the condition of the building and the exposure duration to airborne fungi. According to Rolka et al. (2014), the emerging clinical symptoms from the exposure can be slowly disappeared as the amount of infested mould decreases. For that reason, it is important to implement effective control strategies in controlling fungal contamination in indoor environment.

Today, the rapid development of technology portrays a key role in providing a healthy indoor air environment with numerous technology-inspired solutions for the treatment of fungal contamination. Hence, the quality of the occupant health can be enhanced to be balanced with the continuous transformation of technologies and innovations. According to Environmental Protection Agency (2017), indoor air quality can be improved by three basic strategies such as controlling at sources, designing ventilation systems to dilute and exhaust the contaminated air and cleaning the air environment.

This paper therefore presents a comprehensive review on the factors influencing fungal infestation in indoor environment and the potential technologies for mould treatment in order to discuss the limitations for the future development of indoor mould management.

2.0 METHODOLOGY

Systematic reviews and meta-analysis require in gathering and analyzing the data from the different studies conducted for a particular research. It is a tool to summarize the research views and limitations. This review based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline (Moher et al., 2009). The collected databases are derived from ResearchGate, Google Scholar, ScienceDirect, PubMed and Wiley Online Library by searching the keywords such as *fungal infestation, indoor environment, factors, treatment* and *technology.*

Initially, a total of articles (*n*=102) is retrieved from provided databases. From the total, twenty-three articles (*n*=23) have met duplicate citations, thus so they were removed for review. Again, the articles left (*n*=47) are screened for eligibility through retrieving published full text from the electronic sources. In second review, relevant articles are removed (*n*=24) in accordance with consideration towards inclusion and exclusion criteria. Final collection indicates a total of twenty-three articles (*n*=23) regarding on the factors influencing indoor mould growth and its treatment technologies are used for further evaluation as shown in Figure 2.1.

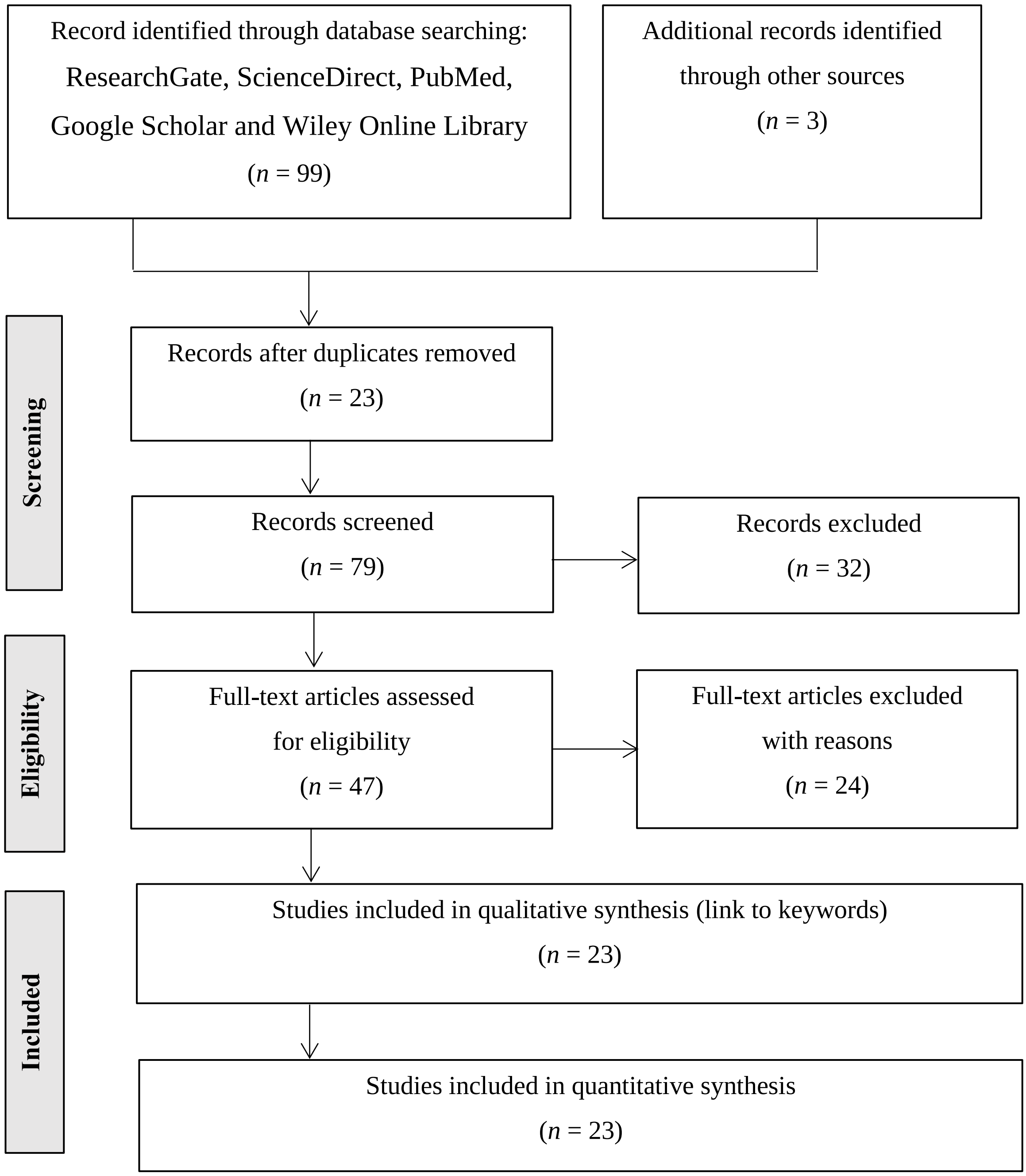

Figure 2.1 The outlines of a systematic review of the factors influencing indoor fungal infestation and its potential treatment technologies based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline (Moher et al., 2009).

3.0 RESULT

Table 3.1 Studies that focused on factors influencing indoor fungal infestation, 2010 to 2020.

Author	Year	Sources	Factors
Precha et al.	2020	Flooding	Building structure, climatic region, mycofloral characteristics
Kazemian et al.	2019	Building structure, biodeterioration of building material, low airtightness, HVAC systems	Age of building, type of flooring, dustiness, humidity, temperature, variation of structural frame, occupancy level, type of room
Khalid et al.	2018	Insufficient design, corrosion of paint on building, water leakage	Zero air movement, relative humidity, temperature, air velocity
Annila et al.	2017	Walls in soil contact, base floors structures	Extensive moisture
Kamaruzzaman et al.	2017	Inappropriate ventilation design, flooding	Climatic factor, extreme temperature
Karmegam et al.	2017	Paper dust, dead skin, water damage, water leakage, wet spot, biodeterioration of painted materials	Dampness, climatic factor, nutrient source

Author	Year	Sources	Factors
An & Yamamoto	2016	Cold outdoor temperature, dew condensation	Dampness, climatic factor
Othman et al.	2015	Rainwater, shortness of awning, poor workmanship, water drop, corrosion at roof gutter, building defect, ventilation systems	Moisture, condensation, building design
Cheong et al.	2013	Water damage, damp indoor environment	Water activity (*aw*) of building material, temperature, type of nutrients
Wahab et al.	2013	Insufficient height of wall, atmospheric condition, surface of wall, building defect	Condensation, changes of temperature, tropical climate, improper building design
Montanari et al.	2012	Volume bindings, compactus shelves	Heat resistance, humidity exchange between micro-environment, hygroscopic material
Yassin & Almouqatea	2010	Mechanical movement within enclosed space, confined space	Excessive humidity, high water content of building material, mycofloral characteristics, occupancy level, hygienic standard, quality of household system

Table 3.2 Studies included potential treatment technologies for indoor fungal infestation, 2011 to 2020.

Author	Year	Technologies	Strengths	Weaknesses
Garbacz et al.	2020	Electronic nose based on gas sensor array (E-nose)	▪ Lower cost ▪ Shorten analysis time	▪ Humidity fluctuates sensor response ▪ Incapable to detect specific compounds ▪ For analysis purpose
Guo et al.	2020	High efficiency particulate air (HEPA) filter	▪ Filter proportion of bacteria higher than dust ▪ Cleaning air	▪ Cost to replace the filter ▪ Mould spores may infest on the filter surface
Veronika et al.	2020	Cold atmospheric pressure plasma (CAP)	▪ 89% inactivation of the tested microorganisms ▪ Environmentally friendly ▪ Energy-efficiency	▪ Depending on plasma intensity and plasma treatment area
Kwag et al.	2019	Auto-controlled centralized exhaust ventilation systems	• Discharge humid air to outside • Maintain the zones thermal comfort	• Limited in adjusting parameters • Limited volume flow rate of ventilation system

Author	Year	Technologies	Strengths	Weaknesses
Hashimoto & Kawakami	2018	HEPA air purifier fan	• Rapidly remove airborne fungi and spontaneous reduce the concentration to a normal range	• Only effective during operation period • Cannot eliminate the sources of fungal contamination
Hirschi & Herron	2018	Dry fog	▪ Inexpensive ▪ Energy-efficient ▪ Control humidity in large spaces ▪ Long term treatment	▪ Require liquid disinfectant and compressed air ▪ Cause secondary pollution
McDowall	2017	Photocatalytic oxidation (PCO)	▪ Energy-efficient ▪ Effective against *Penicillium chrysogenum* ▪ Effective on wide range of contaminants	▪ Require UV light ▪ Inability to kill mould spores at higher relative humidity

Author	Year	Technologies	Strengths	Weaknesses
Liu et al.	2017	Photocatalysis	▪ Have wide range of purification ▪ No adsorption saturation phenomenon ▪ Long service life	▪ Slow purification process ▪ Cause secondary pollution
		Plasma negative ions	▪ Accelerate metabolism ▪ Strengthen cell function ▪ Effective to some diseases	▪ Emit ozone ▪ Cause secondary pollution ▪ Deposition of dust
		Ultraviolet sterilization	▪ High efficiency on microorganisms ▪ No residual toxicity ▪ Safe and convenient ▪ Small resistance	▪ Poor dynamic sterilization effect ▪ Mould spores tend to be resistant

Author	Year	Technologies	Strengths	Weaknesses
Gong et al.	2014	Ultraviolet irradiation (UVC) with ozone	▪ Reduce the production of hydroxyl radicals ▪ Inactivate fungal spores faster than exposed to only UVC	▪ Produce reactive radicals ▪ Cause secondary pollution
Zheng et al.	2013	Electrostatic precipitators (ESPs)	▪ Effective and efficient to destroy fungal spores ▪ Work best on particulates above 0.1 µm	▪ Emit ozone ▪ Cause secondary pollution
Han et al.	2011	Electrostatic precipitators with superhydrophobic surface (EPSS)	▪ Concentrate fungal spores into water droplets ▪ Improve detection of fungal spores at low concentration ▪ Less noise	▪ Emit ozone ▪ Cause secondary pollution

4.0 DISCUSSION

This systematic review included 23 publications that detailed on factors contributing to mould infestation indoor and the potential technologies for its treatment.

4.1 Factors contributing fungal infestation

Referring to Table 3.1, the most common factors that have been reported are humidity, temperature, dampness, climatic and building conditions.

4.1.1 Humidity

Normal flora of mould is not harmful, yet environmental conditions have influenced their growth indoor. Favourable humidity can increase levels of contamination with biotic substances such fungal allergens. Mould species can develop in indoor environment even by small changes in humidity due to night and day alternation (Montanari et al., 2012). Presence of water in building material or condensation may increase the humidity level which then lead to the extensive fungal growth. *Acremonium*, *Fusarium* and *Stachybotrys* are hydrophilic moulds that favour to grow in higher moisture content meanwhile *Aspergillus* and *Penicillium* may pose adverse effects to some building occupants in presence of minor moisture (Wahab et al., 2013).

However, the levels of humidity between materials can also affect the susceptibility of mould growth. Some materials initiate the mould growth at low relative humidity (RH) while other materials can withstand without mould growth in condition of higher moisture level (Johansson, 2014). According to Meller et al. (2017), his experimental study reported that dry building materials with 50 % RH which are exposed to 90 % RH are resistant to mould growth only for a limited period while organic building materials can be very vulnerable when exposed to water. He also concluded that high moisture and water damage should be prevented during the construction period as well as the interior building surfaces should not exceeds 75 % RH.

4.1.2 Temperature

In addition, RH condition is based on the surface temperature as the growth conditions. Surface temperature is a quite different compared to ambient air, for instance, the inner surface of an interior wall can be colder than the ambient indoor air in cold climates, thus the RH can be considered higher than the ambient air. This is important because amount of mould only can be visually detectable in higher RH levels (Riordan, 2016). Temperature of building plays a key role in promoting the growth of fungi. Building with 20 to 250 ℃ allows the growth of mesophilic fungi but if the temperature below optimum level, fungal growth can be delayed (Vacher et al., 2010; Hoang et al., 2010). Schenck et al. (2004) also added that most of mould favour to infest at 15 to 30 ℃ eventhough there others can grow below or above these temperatures.

4.1.3 Climatic conditions

Furthermore, hot and humid conditions become the contributing factors to mould infestation, yet the conditions are influenced by the climatic factor. Climate change as outdoor source may lead to an earlier appearance and prolonged exposure to seasonal aeroallergens (Kennedy & Smith, 2012). Plus, long rainy season may suffer the buildings due to high humidity and condensation meanwhile long hot season also can be a favourable condition for mould growth (Dang et al., 2019). Cold outdoor temperatures found to be a major indoor source of dampness and dew condensation during winter heating seasons in South Korea (Yamamoto, 2016).

Flooding and/or storming that creates more damp indoor spaces can result the mould infestation as the moisture condition can be established. *Alternaria, Aspergillus, Cladosporium, Penicillium* and *Stachybotrys* are the mould species found in flooded dwellings (Solomon et al., 2006; Dumon et al., 2009). Flooding transports the moisture into indoor environment and negatively affects the quality of the building structures and hygrothermal properties of the construction materials (IOM, 2011).

Vardoulakis et al. (2015) justified that climate change is probable to be a risk modifier of indoor environment as it risks to human health such as exposure to high indoor temperature, air pollutants, water damage, allergens and mould, and worsen health inequalities. In Malaysia, the average temperature at constant 26 ℃ throughout the year, humidity around 80 % and high rate of evaporation have led to a heavy exposure to moisture problems that may have effects on human health, deteriorate the building and its functionality faster (Othman et al., 2015).

4.1.4 Dampness

Therefore, mould tend to grow bigger and digest in sufficient conditions for reproduction when their spores land on a damp spot due to water damage or storm leakage. Referring to Karmegan et al. (2017), many researchers reviewed dampness with different perspectives based on its factors such as “visible mould” and “condensation” due to high indoor RH while “damp stains”, “damp spots”, “damp water damage” and “bad smell and odour” are often due to moisture in construction. Indeed, mould growth depends on the moisture available in the environment, which is commonly referred as water activity (a*w*). Leong et al. (2011) reported that fungi favours on condition with 0.95 to 0.99 *aw* while 0.65 to 0.90 *aw and* 0.88 to 0.99 *aw* are enough for the growth of xenophilic fungi and yeasts. The longer a material over 0.75 *aw*, the greater the risk of fungal contamination (Viitanen et al., 2010).

Besides, the persistent dampness due to condensation can lower the aesthetic of a building due to the damages from furnishing and fitting of mould. Condensation occurs because the water vapour is accumulated around the exterior building surfaces in uncontrolled RH levels. Poor ventilation and surface temperature dynamics may lead to condensation and local micro-climates with localized peaks of *aw* greater than indoor environment (Montanari et al., 2012). For that reason, *aw* of a building material should be lower as possible in order to prevent potential damages and fungal colonisation as high level of water activity can provide moisture as an essential requirement for fungal growth.

4.1.5 Building conditions

Other than that, building condition also an important contributor towards indoor fungal infestation. Contaminated building due to surface-growing mould are associated with various sources such as water damage, building defects, faulty designs, usages of building material, water leakage, ceiling leakage, air leakage, plumbing spill, insufficient dehumidification by HVAC system, poor condensate drainage due to HVAC system deficiency and enclosure of wet materials in building (WHO, 2009; Wahab & Hamid, 2011; Othman et al., 2015; Dang et al., 2019).

Dang et al. (2019) mentioned that air leakage through air cavity of the building walls has led to severe hygrothermal exchange, changes in temperature and humidity migration that then promotes condensation and fungal spores. Failure to select durable building materials to control the occurrence of building defect can be one of the improper design factors. It is important to highlight that the hygroscopic or wet materials are able to initiate fungal infestation.

Moreover, airborne fungi can be carried indoor together with dust particles through the movement of occupants and the ventilation systems (Nevalainen & Morowaska, 2009). Dust serves as good substrates for the growth of *Aspergillus fumigatus* and *Aspergillus versicolor* (Samet & Spengler, 2003). Last but not least, zero air movement within building can limit the air exchange within the building and consequence insufficient ventilation for the fungi to exit the building. This condition thus supports the fungal reproduction inside the building (Khalid et al., 2018). Malaysia with humid and warm climates are quite common to contaminate the aged buildings with mould if lack regular maintenances.

Fungal infestation is the result of a complex interaction between the existing factors. It can be prevented earlier when such described factors are put into consideration during the design, construction and maintenance of a building.

4.2 Treatment technologies

Potential technologies treatment approaches include CAP, PCO, ESPs, EPSS, HEPA air purifier fan, dry fog and auto-controlled centralized exhaust ventilation systems as mentioned in Table 3.2. Surely, these technologies contribute their own pros and cons towards the performance, economic, maintenance and environment.

4.2.1 Electrostatic air filters

First and foremost, electrostatic air (ES) filter is a combination of electrostatics, filtration and washable to act as air filter. Generally, this technology traps the airborne particulates and purify the air environment by the static charge when air flow through a maze of static prone fibres, then it will be removed by washing. Specifically, electrostatic precipitators (ESPs) are commonly applied in industry as it demonstrates an effective and efficient way at destroying fungal spores (Zheng et al., 2013). It works best with small particles sizes that above 0.1 µm.

Besides, electrostatic precipitators with superhydrophobic surface (EPSS) showed a positive accomplishment as it able to concentrate airborne fungi such as *Cladosporium cladosporioides, Penicillium melinii and Aspergillus versicolor* into 10 µl or 40 µl water droplets (Han et al., 2011). These deposited particulates on the collection electrode are eliminated when water droplet is introduced (Han & Mainelis, 2008; Han et al., 2010). This is because the fungal spores are hydrophobic, and their airborne concentration relies on the surrounding conditions such as wind speed and turbulence (Levetin, 1995).

EPSS also can detect fungal infestation in indoor environment at low concentration as collection efficiency is considered higher at < 50 % (Han et al., 2011). Air Commander Permanent Electrostatic Air Filters company clarified that their electrostatic air filters are registered and approved by Environmental Protection Agency (EPA) as anti-microbial materials that able to inhibit mould and bacteria growth on the air filter surface. Fortunately, the filtration test is proven to achieve 82 to 94 % efficiency through different air filters.

Despite its efficiency in removing such particles, they can pose secondary pollution to the environment with ozone production and other compounds derived from the ionization of volatile organic compounds (VOCs). According to Siegel et al. (2011), the ion generator may increase the concentrations of ultrafine particles (< 0.1 µm), ozone and the by-products such as formaldehyde and nonanal due to the reactions initiated by the ozone. Lin et al. (2011) then suggested that ozone production can be managed by adopting alternating voltage.

4.2.2 Cold atmospheric pressure (CAP)

Basically, cold plasma is nonthermal plasma presents an efficient decontamination of both fungal spores and airborne bacteria at 85 to 98 % in a very low exposure time (0.06 s) (Gallagher et al., 2007; Liang et al., 2012). Veronika et al. (2020) detailed on the capabilities of cold atmospheric pressure plasma (CAP) to have decontaminating properties. CAP that acts as air purifier has achieved an inactivation of the tested microorganisms such *Escherichia coli* by 89 % depending on plasma intensity and the size of the plasma treatment area. Furthermore, some studies reported that CAP treatment is effective in inactivation of fungal species such as *Aspergillus, Penicillium, Fusarium* and *Cladosporium* compared to UV irradiation and ozonation (Ishikawa et al., 2012; Suhem et al., 2013; Hashizume et al., 2013; Ouf et al., 2015).

Nevertheless, the persistence of the fungal spores must be considered to contain hydrophobic properties in order to ensure spores can clump together and form aggregates in aqueous solution (Linden et al., 2005). For example, Ouf et al. (2016) justified that double atmospheric pressure cold plasma is necessary to inactivate different mould species during washing.

It clearly shows that CAP is an extremely effective, energy-efficient and environmentally friendly as it produces free radicals and oxidant species but unfortunately it has limitations in application for real-world large-scale processing, especially in industry. Hence, it requires more investigation on the technology in terms of their physical-chemical pathways and biological outcomes before adoption into industry (Martina et al., 2019).

4.2.3 Photocatalytic oxidation (PCO)

Photocatalytic oxidation (PCO) is a powerful air purification technology that has ability to destroy particles as small as 0.001 µm including mould spores compared to HEPA filters at 0.3 µm. It degrades and mineralizes the airborne contaminants using a semiconductor and irradiation in the presence of oxygen. It often works with ventilation systems such HVAC system that pulls air that passes through installed ultraviolet light or titanium dioxide chambers (Thorne, 2020). McDowell (2017) investigated on the potential of PCO in eliminating mould spores in homes of New Zealand. The result demonstrated that PCO is effective against *Penicillium chrysogenum* under certain conditions. Exposure of UV light can activate the PCO process and reduce mould growth. This UV-PCO benefits in indoor application such as can minimize the building energy consumption, reduce by-products at higher flow rate and remove ethanol at higher efficiency (Farhanian et al., 2013). Photocatalysis method is considered affordable as it requires less maintenance and low power consumption (Shiraishi & Ishimatsu, 2009).

4.2.4 HEPA air purifier fan

Next, Hashimoto and Kawakami (2017) have evaluated the ability of a high efficiency particulates air (HEPA) purifier fan in reducing the fungal concentration in indoor environment in Japan. There were differences in number of airborne fungi between with and without HEPA air purifier. In presence of the air purifier, the number of airborne fungi, *Aspergillus* has been reduced between 1.5 and 6 times faster compared to the absence of it. Clean air change rates which have been calculated after 15 minutes operation resulted to the cleaning of air environment. HEPA air purifier fan able to drop the fungal concentration within a normal range, but it only can be effective during the operation.

Plus, it is incapable to eliminate the sources of fungal contamination instead it only can reduce the concentration level of fungal inhabitation. Despite this fact, HEPA-based products especially their filters require frequent maintenances since the absorbed particulates like dust can be trapped on the filter and provide nutrients for mould spores to potentially grow and get released back to pollute the air environment.

4.2.5 Dry fog

Other than that, Hirschi and Herron (2017) performed a study to determine the effectiveness of a two-step dry fog technology for mould remediation process. The study is conducted intentionally to explore the potential of dry fog as treatment for long term mould prevention. Dry fog application system involved in releasing of gas or vapour with micron sized particles (6 to 8 µm) that able to widely cover, penetrate and encompass mould spores. It is a mobile treatment system that comprises compressed air, spray nozzles and the dry fog box.

To summarize, the dry fog treatment indicated a great reduction of mould in ground levels and able to withstand over the duration of the six months after the operation. Application of dry fog technology with EVERpure^{TM} disinfectant enables to enhance and maintain the reduction of fungal concentration over time. Hence, the uses of liquid disinfectant shall be compliant to the standard requirement in order to prevent any other adverse effects on human health due to chemical exposure. Overall, it presents rapid and quantifiable improvement to indoor air quality, but it also requires proper training and costs for the equipment and installation.

4.2.6 Auto-controlled centralized exhaust ventilation systems

Kwag et al. (2019) found that auto-controlled centralized exhaust ventilation systems are efficient to manage indoor air quality especially in maintaining the zones thermal comfort. Thermal comfort is influenced by air temperature and humidity level, thus this ventilation system is developed to control the performance of the RH-sensor. Moisture can be nutrient source for building fungi, hence controlling indoor humidity can prevent excessive water vapour generation that may cause a condensation and building deterioration (Lim et al., 2015). However, the auto-controlled exhaust ventilation restraints to decrease the humidity level in higher temperature environment. Plus, lack of studies is implemented on the relation between auto-controlled exhaust ventilation and the chance for fungal infestation in the building.

5.0 CONCLUSION

This review clearly indicated that the fungal infestation is influenced by the humidity, temperature, dampness, climatic and building conditions. Fungal contamination in indoor environment comes from a complex interaction between the existing factors. Humidity level is depending on the changes of temperature, then higher humidity leads to the presence of moisture and condensation thus resulting to the building defects. Climatic factor and level of occupancy also can cause mould contamination. These factors can provide sufficient nutrients and conditions for the colonization of the airborne fungi. Consideration to the contributing factors can prevent the fungal growth in building earlier during the design, construction and maintenance of the building.

It is a crucial to focus on the potential treatment technologies that can be applied in managing the fungal contamination indoor as people spend more time indoor rather than outdoor. It is almost impossible, especially to change certain building structures and the designs of the aged buildings that are contaminated by the surface-growing moulds. Besides that, uses of treatment technologies can reduce intensive manpower and dependence towards personal protective equipment (PPE) during the removal and prevention processes. CAP, PCO, ESPs, EPSS, HEPA air purifier fan, dry fog and auto-controlled centralized exhaust ventilation systems have potential to act as mould treatments in building but the effects on the human and environment should be given an attention in order to prevent any secondary pollution.

It is surely difficult to justify the mould treatments based on indoor air quality without specification regulations for mould spores. AIJ (2013) supported that it contributes a limitation to set a standard value for indoor fungal concentration when the contributing factors are due to outdoor environment. Further research is recommended to focus on the appropriate treatment technologies for fungal inhibition in indoor and outdoor environment, respectively.

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