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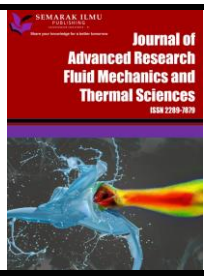

Comprehensive Review on the Relationship between Duct Cleanliness and Airborne Contaminants

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ABSTRACT

This study investigates the relationship between Indoor Air Quality (IAQ) and air duct cleanliness, addressing the rising concern for human well-being. Airborne contaminants like dust, mold, and bacteria are identified as significant threats to IAQ, with potential health consequences. The study will also explore the several established safety and health guidelines and duct characteristics that influenced IAQ. Consequently, the primary research goal is to examine the relationship between duct cleanliness and airborne contaminants in the building environment and determine whether air duct cleaning effectively reduces these contaminants. By thoroughly reviewing studies and established standards, we examine IAQ contaminants and explore the effects of duct cleaning, along with its potential health advantages. Findings emphasize duct cleaning's potential to enhance IAQ, reduce exposure to pollutants, and its importance for building owners, facility managers, and stakeholders in safeguarding occupants' health and comfort.

1. Introduction

In the past, people did not pay as much attention to Indoor Air Quality (IAQ) as they did to outdoor air pollution. However, it is now becoming a bigger concern for the public. Since we are discovering new indoor air pollutants, office buildings are often sealed off from the natural outdoors, and we are investigating problems like sick building syndrome [1,2]. Rahman *et al.,* [3] agree that maintaining excellent air quality is crucial to ensure the comfort of building occupants and to prevent any potential health concerns during their stay. The IAQ is closely linked to the Heating Ventilation and Air Conditioning (HVAC) system within a building. Installing an HVAC system in a building is a critical factor in ensuring both comfort and excellent IAQ. It helps create a comfortable working environment

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and significantly impacts their work performance and health, facilitating productive activities [4]. Air-Conditioning (AC) systems usually ensure thermal comfort and maintain high IAQ by regulating temperature, humidity levels, and air cleanliness during distribution. Consequently, utilizing the AC system to maintain optimal IAQ for building occupants is essential, promoting both comfort and health [5].

The health and well-being of building occupants rely heavily on IAQ. According to Hawkins *et al.,* [6], poor IAQ is linked to various adverse health effects, such as headaches, fatigue, and respiratory and cardiovascular issues. Building design plays an important role by offering a healthy, comfortable and satisfying environment. Simultaneously, it can help to reduce health problems and improve productivity [7]. Ha *et al.,* [8] supported the statement by introducing the idea of implementing green building practices to improve IAQ levels by reducing energy consumption, greenhouse gas emissions, and occupants' comfort and health. Basically, several factors are well known in the contribution of the IAQ level. This study focuses on the contribution of duct cleanliness to the IAQ level. Kolari *et al.,* [9] stated that ducting plays a crucial role in heating and cooling inside the building environment and is responsible for supplying, transmitting, and circulating fresh air throughout the space. However, the ducts will then be contaminated with dust, mold and bacteria. This contamination can directly impact building occupants since they are very small, easily transmitted into the air and harm people during inhalation. Nevertheless, researchers still debate whether the contamination inside the ducting can be transmitted to the IAQ level in the surrounding air. Some experts argue that the routine of duct cleaning is necessary to maintain surrounding air, while others advised that the benefits of duct cleaning are overstated. Hence, our main goal is to investigate how clean air ducts relate to IAQ. This research addresses a gap in existing knowledge by focusing on the impact of indoor air contaminants, specifically originating from unclean ducts and their connection to IAQ. Moreover, our findings hold the potential to make a valuable contribution to future research by paving the way for the development of user-friendly tools for assessing health risks. These tools would consider factors like duct cleanliness, IAQ, and their combined impact on health, making it easier for people to maintain healthier indoor environments.

2. Indoor Air Quality (IAQ)

IAQ refers to the quality of the air inside buildings and other structures, particularly as it relates to the health and well-being of occupants. The World Health Organization (WHO) defines IAQ as "the quality of indoor air inside buildings and structures, especially as it relates to the health and comfort of building occupants" [10]. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines IAQ as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction" [11]. The US Environmental Protection Agency (EPA) defines IAQ as "the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants, including both the physical and psychological aspects of IAQ" [12]. In Malaysia, the Department of Occupational Safety and Health (DOSH) [13] defined IAQ as the "quality of the air inside buildings and structures, especially as it relates to the health and comfort of building occupants." The definition of IAQ can vary depending on the specific context and goals of the research or policy being developed. However, most definitions emphasize the importance of maintaining healthy IAQ to protect the health and well-being of building occupants. US EPA and DOSH highlight on their website the importance of IAQ assessments and how they can affect individuals' comfort, health and work performance [13,14]. Various factors will be identified, and specific parameters such as temperature, humidity, mold and

bacteria, and chemical and ventilation rate will be measured to determine the IAQ status. In addition, Alwi *et al.,* [15] reported that poor IAQ can directly impact building occupants by causing discomfort, reducing work productivity and causing chronic health such as asthma and allergic reactions. Nowadays, on average, people spend more time indoors than outdoors for staying, working, or carrying out their daily activities and routines. Morsy *et al.,* [16] reported that about 90% of children and older people spent their time indoors. Moreover, Andualem *et al.,* [17] reported an increasing interest among researchers in topics related to IAQ since the information is easy to acquire. At the same time, numerous new studies have reflected growing awareness and concern about the impact of IAQ on people's health and well-being. Besides indoor air contamination, adequate ventilation is critical for maintaining healthy IAQ. Lenzer *et al.,* [18] stated that good air ventilation would improve air circulation inside the space and help to dilute indoor air contamination, maintaining a healthy humidity level by filtering indoor air and preventing contamination buildup in the ducting system and other components.

Furthermore, it is essential to consider established safety and health guidelines, especially Malaysian safety and health guidelines, to fulfill the Malaysian aspiration on safety and health issues, as listed in Table 1. Based on several established safety and health guidelines, the referring established guidelines are as follows.

Table 1
Several established safety and health guidelines

Established Safety and Health Guidelines	Role	References
WHO Guidelines for Indoor Air Quality	Provides information on health effects, sources, and exposure levels. Offers recommendations for reducing exposure to pollutants	World Health Organization [19]
USA OSHA: Occupational Chemical Database	Provides information on the hazards of various chemicals commonly discovered in workplaces. Provides information on the health effects, physical properties, and safe handling practices	Abdullah *et al.,* [20]
USA NIOSH: Pocket Guide to Chemical Hazards	Acts as a quick reference for workers and other stakeholders who need to understand the potential hazards associated with various chemicals and how to handle them safely in the workplace. It is a valuable resource for anyone who works with hazardous chemicals	Barsan [21]
Malaysian DOSH: Industry Code of Practice on Air Quality	Provides guidelines for ensuring good IAQ in workplaces. Guidance on the design, installation, and maintenance of ventilation systems, as well as recommendations for reducing the use of chemicals and other pollutants indoors	Department of Occupational Safety and Health [13]

3. Duct Cleanliness

Ductwork serves as the primary conduit for delivering air to the room environment. Maintaining clean and proper air distribution inside the building served by Mechanical ventilating and air-conditioning (MVAC) systems is important. To achieve this, regular maintenance of the ducting system must be practiced. As air is transmitted through the ducting system, particles like dust, pollen and mold can accumulate on the inner surface, potentially affecting IAQ level. As explained by Asim *et al.,* [22], if there is no regular maintenance of ducting systems, the contamination that accumulates inside the system might be released into the air and inhaled by people, leading to various health problems. Furthermore, the need for regular duct cleaning to maintain good IAQ can vary depending on the building uses and occupancy level. National Air Duct Cleaners Association (NADCA) [23] recommended duct cleaning respecting residential ducts every 3-5 years with more frequent for commercial and industrial ducts. In addition, it is advised to change the air filter regularly, seal up duct leaks and ensure the HVAC system operates efficiently.

According to previous studies, ventilation systems can be significant sources of sensory pollution [24-27]. Hence, the quality of the indoor environment depends on the outdoor air and tends to be influenced by mechanical components from the HVAC system, building occupant activities and the cleanliness of the equipment and ducts it passes through before reaching the occupied space. Table 2 explains the duct characteristics with previous studies as references and their impact on the indoor air environment.

Table 2
Duct characteristics that influenced IAQ

Duct characteristic	Effect to IAQ	References
Duct material	Choosing good and right duct materials for different conditions is important to measure the minimal emission of harmful chemicals such as volatile organic compounds.	Holzemer *et al.,* [28]
Duct cleanliness	It is important to clean the duct to prevent the buildup of dust or any pollutants affecting IAQ.	National Air Duct Cleaners Association [23], Božić and Ilić [29]
Duct location	It is important to design a ductwork system that minimizes the risk of moisture and breeding ground for mold and other microorganisms.	Sharma and Sharma [30]
Duct design	Duct poorly designed systems may cause uneven airflow and poor ventilation, leading to stagnant air and poor IAQ. Properly designed duct systems should promote even airflow and adequate ventilation to maintain good IAQ.	Palcan *et al.,* [31]
Duct leakage	The duct leakage can lead to the introduction of outdoor pollutants and moisture into the indoor environment, adversely affecting IAQ. Leaky ducts can also cause energy waste by reducing the efficiency of the HVAC system.	Hurel and Leprince [32], Fisk *et al.,* [33]

4. Airborne Contaminants

Airborne contaminants refer to any particles or substances present in the air we breathe. These contaminants include dust, pollen, bacteria, viruses, gases, and chemicals. These microorganism spores can become airborne, leading to infectious diseases and causing allergies and respiratory irritations among occupants. Elevated indoor humidity levels and mold growth have been attributed to issues related to ventilation, design, and the improper operation and maintenance of HVAC systems [34]. Airborne contaminants can negatively affect human health, especially if they are present at high levels or if a person is exposed to them for prolonged periods. Notably, airborne microorganisms or bioaerosol are transmitted through the air, and the contribution of airborne transmission in hospital infections has received less attention [35]. Bioaerosol larger than 5 micrometer can only be affected by the nearest building occupants, while smaller particles (1-5 micrometers) are more dangerous since they can be aero-transported at larger distances. Furthermore, particulate matter like $PM_{2.5}$ and Total Volatile Organic Compounds (TVOC) have the potential to enter the human respiratory system, potentially affecting the health of both individuals and workers [36]. Common sources of airborne contaminants in indoor environments include outdoor air pollution, building materials, furniture, cleaning products, and activities such as cooking and smoking.

Additionally, the health effects of human exposure to indoor bioaerosols are determined by the characteristics (including chemical, physical, and biological characteristics) of the bioaerosols, as well as the number of indoor bioaerosols to which occupants are exposed [37]. The characteristics of

bioaerosols vary depending on the species of the bioaerosols present. In indoor spaces, the amount of indoor bioaerosols to which occupants are exposed is positively related to the indoor bioaerosol concentrations, which are determined by indoor bioaerosol dynamics [38]. Therefore, it is important to investigate both the species of indoor bioaerosols and indoor bioaerosol dynamics to understand the health effects of human exposure to indoor bioaerosols and to develop effective approaches to controlling indoor bioaerosol levels. Moreover, indoor air pollution often contains common bioaerosol contaminants, primarily carbon monoxide and carbon dioxide, which can lead to fatigue among building occupants. Other than that, fatigue manifests as an excessive state of physical and mental exhaustion [39].

Table 3
Pollutants, sources and health effect

Indoor Air Contaminants	Acceptable limit (ICOP-DOSH 2010)	Source	Health effect	References
Carbon dioxide (CO_2)	C1000 ppm	Chimney, Incomplete combustion, Tobacco smoke, biological activities of occupants	Drowsiness, dizziness, fatigue, headache, nausea, breathlessness	Angelova *et al.,* [40], Kapalo *et al.,* [41]
Carbon monoxide (CO)	10ppm	Improperly vented furnaces, malfunctioning gas ranges, exhaust fumes	Drowsiness, dizziness, fatigue, headache, nausea, breathlessness	Thomas and Jaiswal [42]
Nitrogen Dioxide (NO_2)	-	Chimney, Incomplete combustion, Tobacco smoke	Irritation of eyes, nose and throat, coughing, Respiratory complaint	Cincinelli and Martellini [43]
Formaldehyde (HCHO)	0.1ppm			Kim *et al.,* [44], He *et al.,* [45], Dan *et al.,* [46]
Total Volatile Organic Compound (TVOC)	3ppm		Allergy, eye diseases, upper respiratory effects and coughing	Kraus and Šenitková [47]
Respirable Particulate ($PM_{2.5}$)	150 µg/m³	lead-based paint, burning of wood, oil, or coal, diesel engine	Allergy, eye diseases, upper respiratory effects and coughing	Mack *et al.,* [48]
Ozone (O3)	0.05 ppm		Severe cough, pain on deep inspiration and shortness of breath, obvious distress	Cincinelli and Martellini [43], Lippmann [49]
Total Bacteria count	50 cfu/m³	Damp or wet areas such as cooling coils, humidifiers, condensate pans, or unvented bathrooms	SBS symptoms, inability to concentrate	Onklay *et al.,* [50], Lutfi [51]
Total Fungal Count	1000 cfu/m³	Damp or wet areas such as cooling coils, humidifiers, condensate pans, or unvented bathrooms	SBS symptoms, inability to concentrate	Zawawi *et al.,* [52], Mui *et al.,* [53]

Bioaerosol pollutants from indoor and outdoor air (bacteria and fungi) are a major global public health problem, especially in areas with high densities of occupants, such as hospitals [54]. In addition, bioaerosol consists of bacteria and fungi that can promote allergic reactions and bacterial

disease, lower respiratory illness, recurrent wheezing, atopic dermatitis, infections, and rhinitis in indoor air [55,56]. Hence, people with a higher inhalation rate, such as children and some patients in a hospital ward, are more vulnerable to bioaerosol since they breathe more air daily [56]. The presence of bioaerosol (fungi and bacteria) in indoor and outdoor air is particularly linked to several factors, such as environmental air parameters. This includes temperature and relative humidity, air conditioning system, seasonal factors, sunny, rainy and cloudy days, inadequate ventilation, personal care, building materials, dust and soil and inadequate disinfection. Table 3 provides a summary of various pollutants from the sources and their health effects.

5. Conclusions

Based on the investigation conducted in this research, it can be concluded that there is a strong relationship between duct cleanliness and airborne contaminants. The findings indicate that dirty air ducts can harbor various contaminants, including dust, debris, mold, and bacteria, which can circulate throughout the indoor environment and pose health risks to building occupants. Moreover, the study discovered that regular cleaning and maintenance of air ducts can help reduce the concentration of airborne contaminants and improve IAQ. Furthermore, the use of appropriate cleaning methods, equipment, and cleaning agents, in accordance with industry codes of practice and regulations, can effectively remove contaminants from the duct system and prevent their re-emergence. Hence, it is recommended that building owners and managers prioritize the cleanliness and maintenance of their HVAC systems and air ducts to ensure good IAQ and protect the health and well-being of occupants. This research provides valuable insights and evidence for the importance of duct cleanliness in relation to IAQ and highlights the need for continued research and education in this field.

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