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Study of Particle (Particulates Matter) Inside Ducting System

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Abstract: Air is very important in human life. Nowadays, the issue of Indoor Air Quality (IAQ) is relatively new in Malaysia. Environmental Protection Agency (EPA) stated that the Indoor Air Quality (IAQ) refers to the air quality within and around buildings and structures. In particular, it relates to the health and comfort of building occupants. By then, a comprehensive understanding of particle matters (PM) concentration in the HVAC system is essential to prevent and reduce contamination. Besides, this study is about the review of five previous researches in terms of the particle by gathering all information. Furthermore, the purposes of this study are to determine the significant standard, to compare the relevant standard requirement and to evaluate the method and result of duct cleanliness focusing on the particle from the previous study. It includes the comparison made between its method, results and standard. The comparison of standard is made based on the appropriate standard used in Malaysia due to IAQ condition and ducting cleanliness. Hence, the results show that majority of the researches under the category of medium cleanliness quality classes according to BS EN 15780 and the level of cleanliness are between ISO3 and ISO5.

Keywords: HVAC systems, IAQ, Particles

1. Introduction

Generally, IAQ can be known as the comfortable range of the elements inside the building which are temperature, humidity, ventilation, and chemical or biological air contaminants. According to [1] IAQ in buildings is related to occupants' health and comfort. Several parameters such as indoor pollutant emission, the intrusion of outdoor pollutants, chemical reactivity, sorption and desorption phenomena, air change rate, indoor temperature and relative humidity can also have negative impacts on IAQ. At the same point, IAQ concerns focus mainly on the potential health threats and the economic consequences of unsatisfied IAQ [2].

Besides, Indoor Air Quality also has a negative effect on occupants in the building. It is because of the poor air quality that can be caused a SBS. In other words, SBS can occur in building occupants

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along with Building Related Illnesses (BRIs). As duct system functioning to distribute supply air, there are many contaminants that living in the ducting systems such as particle, dust, fungi and bacteria. Usually, these microorganisms and particles will be stuck in the filtration system and other ducting equipment. According to [3], several health problems were also associated with poor IAQ and can cause people eye incitement, asthma, allergic dermatitis, pneumonia, and even death.

Duct systems are used to supply air conditioning between heating and cooling equipment and the occupied space in most commercial buildings. Often, ducts distribute ambient air to the occupied space and outside exhaust air. The interconnected duct sections and junctions typically are one of the parts that built for the duct system. Duct systems are usually constructed of many interconnected duct sections, and the junctions between sections as well as junctions between ducts and other components are often locations of air leakage [4].

The purpose of the Air pollution control act is to protect people's health. People stay indoors with more than 90.0 % of their total time every day in the present day, and this shows the importance of indoor air quality in the effects of human health [5]. Apart from that, the problem of air quality which is related the dust concentration of rooms in buildings is important for public health than outdoor air quality. Due to epidemiological evidence of its impact on health, studying the particulate matter effects in a room per person gained wide interest.

In other hand, the high level of dust in the air would also contribute to health problems as dust particles could blend in the air and when breathing it could enter the respiratory parts and lead to further health problems such as asthma. As dust particles, fungi spores can also be flown over by the air and if breathed in, it would cause a very crucial health problem such as allergy and fever. However, [6] highlighted that the size ranges of particles in loading depend on whether the building is a residential or commercial building, because of the commercial ventilation air intake. Therefore, outdoor air intake should be a major factor that contributes to the particles and dust in indoor spaces.

Furthermore, the term of respirable particulate matter (RPM) refers to the suspended particle fraction with an aerodynamic diameter smaller than 4 micrometers. Particulate matter (PM) is an atmospheric pollutant, a mixture of suspended solid and liquid particles. Generally, the measures are used to classify PM and the mass density of particles below 2.5 μm (PM2.5) and particles below 10 μm in diameter (PM10) are of health significance. While indoor air is only a small fraction of the planet's atmosphere, it occupies most of the indoor respirable air fraction. It is notable that average PM concentrations show a higher correlation with indoor than atmospheric PM concentration for many individuals [7].

2. Materials and Methods

The methodology process was explained in detail on the strategies to run the research by a few key points of the process flow such as instruments, techniques and suitable equipment to obtain and analyze the data. Besides, these preliminary studies will analyse the data from the result of previous researches due to particle concentration in building and ducting systems regarding to improve IAQ. Then, the IAQ standard used by the researcher was compared to the Malaysian and relatable Act and Regulation associated with IAQ measurement. Figure 1 shows a research methodology in which the flow of the study that has considered in this project.

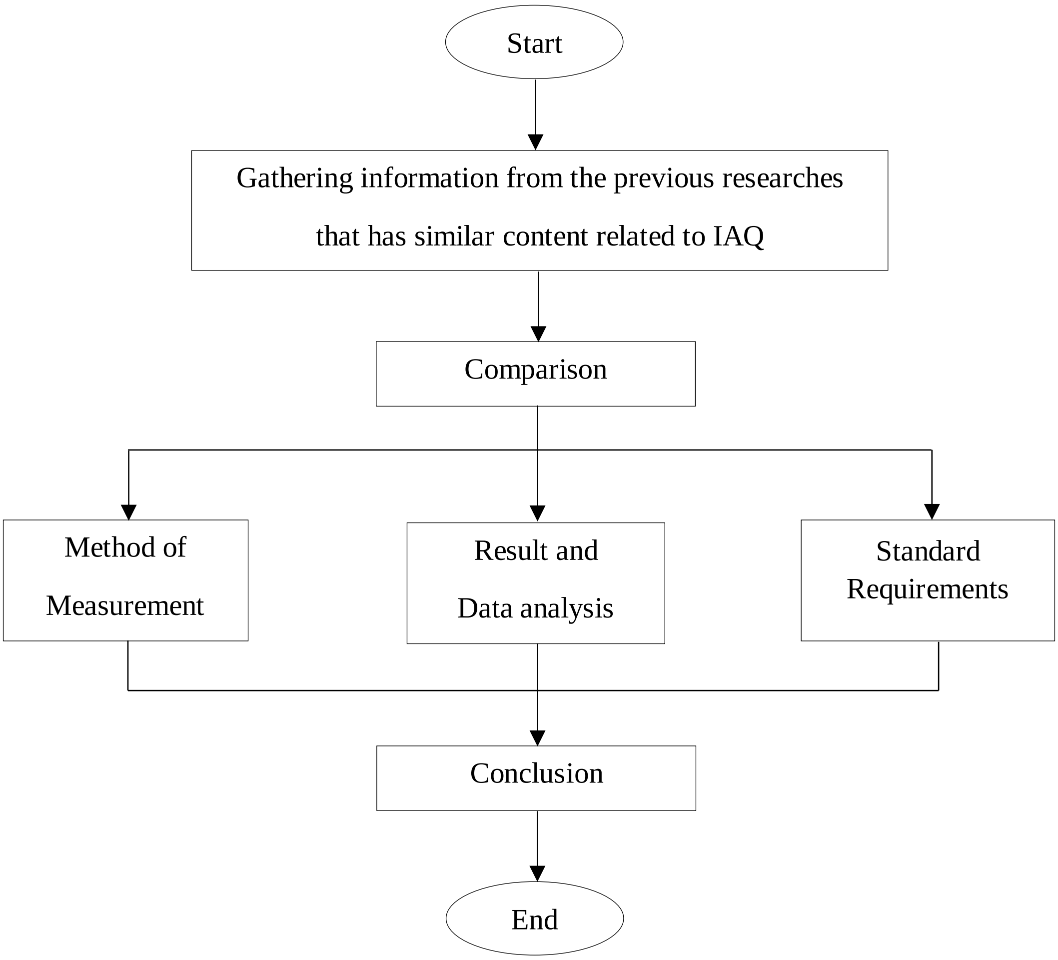

Figure 1: The flowchart of Research Methodology

2.1 Gathering Information from Previous Research

There are five main or top researches used either in Malaysia or international. The research was from any sources that have relatable to the ducting particle in the building or ducting system. Besides, all the researches have similar content as well as the topic discussed.

2.2 Comparison of Method Measurement

The method of measurement was different for five kinds of researches and had a similar objective which is to study the number of particles in building or ducting systems due to its cleanliness with standards respectively. Plus, the method was belongs to the researchers on how they collect data and the apparatus set up for taking the measurement.

2.3 Comparison of Result and Data Analysis

The data of the result between five researches were compared to show which method is more effective in determining the number of particles. The standard analysis has been made after comparing the research gained with the standard requirements. At the same time, the comparison was made to gain information about the correlation between IAQ and ducting cleanliness.

2.4 Comparison of Standard

The results of data collection finally determined with standard respectively related to ducting particle and its cleanliness. The standard used for the previous researches were suitable regarding the latest standard. By then, it was compared to the acceptable standard used in Malaysia such as ICOP, NADCA and ISO.

3. Results and Discussion

It will discuss more about the condition of IAQ which is correlated to the particle content in the building or the system. Apart from this, the result and data analysis between five international researches were compared through their methodology, results from data and their standards due to the number of particles.

3.1 Summary of Selected Journal

Table 1 shows the selected research was brief in summary about the topic content. It is one of the processes of providing a concentrated summary of the completed research study published in a peer-reviewed, academic journal. Plus, this research overview provides prospective readers with a brief concise commentary and offers some insight into the subjects of the researcher, building type, location, number of building, evaluation method and dust or particle concentration value.

Table 1: Summary of the five journals that has been summarized

Research	Building Type	Location	Number of Building	Evaluation Method	Dust/Particle Concentration value
Liu et al., (2015) [8]	Office	Beijing, China	24	Gravimetrical Techniques	33.37 g/m^2
Wei et al., (2015) [9]	Public	China	1	Numerical and Simuation Method	-
Li et al., (2017) [10]	University	Shenyang, China	1	Aerosol Detector	35 – 75 $\mu g / m^3$
Lv et al., (2017) [11]	Office, Classroom, Rural and Urban Residential	Daqing, China	110	Particle On-Line Monitors	20 – 34 $\mu g / m^3$
Park & Jeong, (2017) [12]	Apartment	Seoul, Korea	15	Vacuum, Taping and Wiping	11.6 - 114.8 $\mu g / m^2$

3.2 Comparison of Method Measurement

The measurement of method for five researches has been mentioned in the subtopic before. Besides, Table 2 shows the code presentations in terms of the method used while running the test and the period of time taken for the data measurement. There have four different evaluation method used which represented in code of EM01, EM02, EM03 and EM04 while the equipment or instruments used was listed in the code of EI01, EI02 and EI03. The last code presentation is the period of time of test conducted which represented in the code of PT01 and PT02.

Table 2: The differences of methods used in five previous researches

Journal	EM 01	EM 02	EM 03	EM 04	EI 01	EI 02	EI 03	PT 01	PT 02
(Liu et al., 2015)	/							/	
(Wei et al., 2015)		/	/						/
(Li et al., 2017)					/			/	
(Lv et al., 2017)						/		/	
(Park & Jeong, 2017)				/	/		/		/
Total	1/5	1/5	1/5	1/5	2/5	1/5	1/5	3/5	2/5

Table 3: Code abbreviation for Table 2

Code	Descriptions
EM01	Gravimetrical Techniques: Gravimetric analysis describes a set of methods used in analytical chemistry for the quantitative determination of an analyse based on its mass
EM02	Numerical Methods: Use formula of algorithms that use numerical approximation to calculate the data required
EM03	Simulation Methods: Use software of STREEM to figure out the motion of particle distribution and velocity contours
EM04	Weightage Method (Vacuum, Taping and Wiping): Vacuum is the most effective to collect dust from duct surface while taping and wiping use to air ducts with low amount of dust
EI01	Aerosol Detector/Monitor: Detect and monitor the number of particle concentration
EI02	Particle On-Line Monitors: The data will be collected at five minutes in every fifteen minutes for seven days
EI03	Optical Particle Counter: Measuring efficiencies of particle control equipment
PT01	Period of Time: 3 months
PT02	Period of Time: Less than 3 months

Based on Table 3, every research has its own methods and instruments used. [6] prefer to use EM01 instead of other code according to Chinese Hygienic Standard. The researcher used sterile non-woven fabric to wipe at the deposition of dust with an area of equal to 50 cm^2. Then the final average of dust weight can be obtained and dust loading was calculated by using the equation as shown below in (Eq. 1). Since the measurement actions were conducted in summer from 6 July until 15 September (3 months), the code presentation used is PT01.

$$L_{dust} = \frac{\Delta M}{S} \qquad \textbf{Eq.1}$$

Besides, [6] used EM02 and EM03 for their methods. These studies also use the formula equation for their numerical method and helped by motion simulation of STREEM software to view the particle distribution and velocity contours. These two methods were related to each other in order to complete the results of the research. The simulation also used the equation in (Eq. 2). Since the measurement actions is less than three months, so the code presentation is PT02.

$$\frac{du_p}{dt} = F_D \, \frac{g(\rho_p - \rho)}{\rho_p} + F_L \qquad \textbf{Eq.2}$$

Furthermore, [6] used EM04 which is weightage methods. It includes vacuum, taping and wiping. Hence, the instruments orequipment used is Aerosol Monitor which is in the code of EI01. The indoor measuring point was in the center of the air inlet which located 0.5 m from the window and 1.5m from the ground. This study time was in December and January. The code used is PT02 since the period of time conducted is less than three months. The experimental equipment required for the measurement process is shown in Table 4 below.

Table 4: The experimental equipment required for the measurement process

No	Equipment Name	Instrument Type	Test Content	Data Unit
1	Aerosol Detector	TSI Dust TrakTM DRX 8530	PM2. 5 Concentration	Converted into µg / m^3
2	Temperature and humidity from the instrument	RR02	Temperature	^{0}C
3	Multi-function ventilation tester	TSI 9565	Wind speed	m/s

For the fourth research is from [10]. The researchers prefer to use EI02 where the instrument for collecting the data is Particle On-line Monitor. It was used to collect the data at five minutes for every fifteen minutes in seven days at each measurement point. The measurement was focused on outdoor and indoor. The outdoor measurement point was located close to the outside window while the indoor measurement point was located in the middle of the room which is 1.1 m away from the ground. However, the measured time was from June to August in 2016. Since it was been done for three months, it is under code PT01. The measurement building information is shown in Table 5 below.

Table 5: The measurement building information

Building Type	No	Location Area	Exterior Wall Structure	Measurement Time	Ventilation Mode
Office	01	Sartu District	Glass Curtain Wall	2016.6	Natural Ventilation
	02	Longfeng District	Concrete Wall		
Classroom	C	Longfeng District	Concrete Wall	2016.9	
	H1	Sartu District	Concrete Wall	2016.8	
Urban Residence	H2	Ranghulu District	Concrete Wall	2016.8	
	H3	Longfeng District	Concrete Wall	2016.8	
Rural Residence	H0	Honggang District	Concrete Wall	2016.8	

Moreover, [11] used EM04 which is a weightage method such as vacuum, taping and wiping while the instruments used for tests conducted in the code of EI01and EI03 which represented for Aerosol Monitor and Optical Particle Counter. The sample was conducted in the supply duct at fifteen occupied single-family homes. It was selected from three multi-family residential complexes located in suburban areas of Seoul Korea. The specific floor area of sample homes ranged from 82 to 163 m^2 and most of the families include two children and two adults. The field measurements were conducted from September to November in 2013, so it was considered three months period of time in the code of PT01. Methods and materials of the field measurements are shown in Table 6.

Table 6: Methods and materials of the field measurements

Parameters	Materials	Sampling Point and Interval
Supply airflow rate	Digital manometer (TSI, Alnor EBT721)	3 times at each diffuser
Particle number concentration	Optical particle Counter (TSI, Aero Trak 9306)	1 min at both supply air diffuser and living-dining room
PM10 mass oncentration	Aerosol monitor (TSI, Dust Trak 8532)	1 min at supply air diffuser
Temp, RH, CO2	Indoor Air Quality Monitor (KANOMAX, Model 2211)	1 min at living-dining room

In overall comparison of method measurement, [9] and [11] were using the same instrument to collect the data. The instrument is Aerosol Detector in the code of EI01 which functions to capture and measured the particle mass concentration in μg / m^3. In other hand, [6], [9]and [10] doing their research in a long term period of time in the code of PT01. They took three months for completing the data due to their research. It is because the data collected can be proved and presented in the graph. Plus, the result can get a better insight into the relationship between the data and its variables.

3.3 Comparison of Result and Data Analysis

The comparison of the results for five researches listed in Table 7. Regarding the results, there have many aspects that need to be considered while running the test. Hence, the aspect is representing in code of analysis in Table 8 in terms of the parameter, data unit, the number of building and focus area. There have three different parameters used such as basic data IAQ, PM2.5 and PM10 which represented in the code of RP01, RP02 and RP03. Besides, the unit of data was listed in the code RD01 while the number of building in the code of RB01 and RB02. The last code presentation is the focus area of test conducted which represented in code of RM01 and RM02.

Table 7: The differences of results in five previous researches

Journal Code	Liu et al., (2015)	Wei et al., (2015)	Li et al., (2017)	Lv et al., (2017)	Park & Jeong, (2017)	Total
RP01	/		/	/	/	4/5
RP02	/	/	/	/		4/5
RP03	/	/		/	/	4/5
RD01			/	/	/	3/5
RB01		/	/			2/5
RB02	/			/	/	3/5
RM01				/		1/5
RM02	/	/	/		/	4/5

Table 8: Code abbreviation for Table 7

Code	Descriptions
RP01	Basic IAQ Data: Temperature (^{0}C), Relative Humidity (%), Air Velocity (m/s)
RP02	Particulate Matter: PM 2.5
RP03	Particulate Matter: PM 10
RD01	Data Unit: μg / m^3
RB01	Number of Building: 1 Building
RB02	Number of Building: More than 1 Building
RM01	Focus Area: Air Handling Unit (AHU)
RM02	Focus Area: Heating, Ventilation and Air Conditioning (HVAC)

Based on Table 7, there have several parameters due to IAQ measurement. In Malaysia, the basic parameters need to be taken to perform IAQ analysis related to standard requirements. The basic data of IAQ was presented in the code of RP01. Regarding this code, [6], [9], [10] and [11] were conducting basic IAQ data. It includes the measurement of temperature, relative humidity and air velocity as their first performance analysis of IAQ. For example, the statistics of the environment parameters and dust loading in the 24 HVAC systems are shown in Table 9 below. Therefore, [6], [8], [9], [10] and [11] were studying about the particle mass concentration.

Table 9: The statistics of the environment parameters and dust loading in 24 HVAC systems [8]

MEAN±GSD	Return Air	Fresh Air	Mixture Air	Cooling	Supply Air
Temperature (ºC)	25.6 ± 2.2	33.1 ± 1.5	28.8 ±1.5	17.8 ± 0.8	19.7 ± 1.0
RH (%)	59 ± 5	77 ± 3	66 ± 6	91 ± 2	86 ± 2
Air Velocity (m/s)	7.0 ± 0.7	3.5 ± 0.7	3.4 ± 0.3	2.0 ± 0.4	6.7 ± 0.7
Dust Loading (g/m^2)	167.9 ± 2.59	30.79 ± 7.69	27.7 ± 7.1	9.35 ± 2.83	6.28 ± 1.98

Particulates matter are known as particle pollution. It consists of solid and liquid particles. Regarding the researches, there are two major groups based on size which are PM2.5 and PM10. However, the high level of dust particles can affect to the human respiratory system. Apart from that, it was listed in the code of RP02 and RP03.[6], [8] and [10] focused on both of the parameter PM2.5 and PM10 in their studies. Besides, [9] just focusing on PM2.5 while [11] is PM10.

Furthermore, the code of RD01 represents for data unit used in their research particularly to particle concentration mass. In Malaysian standard, the measurement for particle size is usually in μg / m^3. Three kinds of research that use this unit were [9], [10] and [11] while others use in terms of counter/m^2. However, it can be converted into μg / m^3.

In conducting test,the number of building also play an important role in the data collected. It depends on the types of buildings when running the test because different building presents different results. Hence, the code of RB01 and RB02 represented one building and more than one building used. [8] and [9] just use one building while [6] [10] and [11] more than one building for their data collection. For example, the contribution rate of indoor and outdoor particle sources to the concentration of indoor particulate matter for four building types is shown in Table 10.

Table 10: The contribution rate of indoor and outdoor particle sources to the concentration of indoor particulate matter for four building types [11]

Building type	Indoor Average PM2.5	Outdoor Average PM2.5	F_{inf}	c_s	Contribution Rate Outdoor source	Contribution Rate Indoor Source
Office	20 μg/m^3	22 μg/m^3	0.7214	4.8256	79.4%	28.5%
Classroom	21 μg/m^3	20 μg/m^3	0.9199	1.6783	87.6%	12.2%
Urban Residence	30 μg/m^3	30 μg/m^3	0.7499	6.6417	75.0%	21.1%
Rural Residence	34 μg/m^3	34 μg/m^3	0.9019	3.0859	90.2%	9.8%

The last codes are RM01 and RM02 which represented for the focus area of conducting tests such as AHU and HVAC. In theoretical, AHU is an appliance used to circulate air and HVAC is the central unit to which AHU is connected. There only one research focusing on AHU system which is from [8] while[6], [10] , [9] and [11] were focusing into the HVAC system.

3.4 Comparison of Standard Requirements

The comparison of the standards for five researches listed in Table 11. It presents in demography questions in terms of analysis code. All of those codes have their own category part related to the standard of how the researchers perform their study. For example, SI01 is for inspection factor, SD02 is for ducting cleanliness, SP03 is for the parameter of particle in the system and ST04 is for testing conduct. Apart from that, each code has a specific demography question due to its category part.

Table 11 : Demography of question related to standard

Research Code	Demography of question	Description	Liu et al., (2015)	Wei et al., (2015)	Li et al., (2017)	Lv et al., (2017)	Park & Jeong, (2017)	Score	Total
SI01	Inspection	Is there any visual inspection mentioned before the research being carried out?	/	/	/	/	/	5/5	13/20
		Is there any dimensional area mentioned in the study?	/				/	2/5	
		Is there any classifying type of building?	/		/	/	/	4/5	
		Is the researcher mention about ducting shape and size specification?		/			/	2/5	
SD02	Ducting cleanliness	Is there any mention about last date of system being assessed or maintenance?	/					1/5	5/20
		Is there any recommendation for future studies as improving ducting cleanliness?	/					1/5	
		Is there any suggestion at the end of the study on maintenance interval?	/	/				2/5	
		Is there any related SBS and BRI in the study?	/					1/5	
SP03	Particle Evaluation	Is there any size of particle mentioned in the study?	/	/	/	/	/	5/5	10/15
		Is there any correlation made between particle concentration and ducting condition or its cleanliness?	/					1/5	
		Is there any acceptable range of particle was followed by standard requirement?	/		/	/	/	4/5	
ST04	Conducting Test	Is there any IAQ parameter was record?	/		/	/	/	4/5	18/25
		Is there any location of sampling point mentioned?	/	/	/	/	/	5/5	
		Is the unit of data followed the standard requirement?			/	/	/	3/5	
		Is there any standard used in the study?	/		/		/	3/5	
		Is there any standard of method has been mentioned while conducting test in the study?	/	/	/			3/5	

Based on Table 11, the result of five previous researches obtained by the demography of question which related to standard requirements. There is scores of 13 out of 20 and the question is focus to the inspection. It includes the visual inspection, dimensional area, classifying types of building and ducting shape or size specifications. Majority, the five researches doing an inspection before conduct test [12], visual inspection is the subjective method to evaluate cleanliness level of surface [12]. The purposes of doing inspection are to check if the ventilation system is dirty and needs to be cleaned. Besides, it is to evaluate cleanliness after the cleaning work. Table 12 provides a recommended inspection schedule for major HVAC components within different building use classifications. Furthermore, [13] has mentioned the cleanliness quality classes based on the different types of building as shown in Table 13 below [13].

Table 12: HVAC Cleanliness Inspection Schedule (Recommended Intervals) [12]

Building use Classification	Air Handling Unit (AHU)	Supply duct	Return duct/ exhaust duct
Residential	1 year	2 years	2 years
Commercial	1 year	1 year	1 year
Industrial	1 year	1 year	1 year
Healthcare	1 year	1 year	1 year
Marine	1 year	2 years	2 years

Table 13: Typical Applications of Cleanliness Quality Classes [13]

Quality Class	Examples
Low	Rooms with only intermittent occupancy e.g. storage rooms, technical rooms
Medium	Offices, hotels, restaurants, schools, theatres, residential homes, shopping areas, exhibition buildings, sport buildings, general areas in hospitals and general working areas in industries
High	Laboratories, treatment areas in hospitals high quality offices

For the second code, SD02 is representing for ducting cleanliness. This is the lowest category which scores 5 out of 20. It includes the last date of the system being assessed or maintenance, level condition of the system, suggestion at the end of the study on maintenance interval, and the relation of SBS and BRI in the study. According to [13], HVAC systems shall be routinely inspected for cleanliness by visual means [13]. Plus, British Standard (2011) stated that there are the limit values for cleanliness quality classification samples due to ducting cleanliness as shown in Table 14 below [12]. However, [6] has recommended for future studies in conducting the test due to airborne fungi spore to develop cleaning and disinfection strategies in the HVAC systems in China.

Table 14: Acceptable Cleanliness Levels [12]

Cleanliness Quality Class	Acceptable Cleanliness Level (Supply Duct)	Acceptable Cleanliness Level (Recirculation or Secondary Air Ductwork)
Low	< 4.5 g/m^2	<6.0 g/m^2
Medium	< 3.0 g/m^2	< 4.5 g/m^2
High	< 0.6 g/m^2	< 3.0 g/m^2

Next, code SP03 is representing for particle evaluation in the system. The score obtained is 10 out of 15. It includes the size of the particle, any correlation made between particle concentration and ducting condition or its cleanliness and acceptable range of particle followed by standard requirement. According to International Standard ISO (2016), the particle is a minute of matter with defined physical boundaries while particle size is the range from $\geq 0.1\mu m$ to ≥ 5 µm which to be used to determine air cleanliness particle concentration for classification [14]. Besides, particle concentration is the number of individual particles per unit volume of air. Hence, there has ISO class numbers for particle concentration due to air cleanliness as shown in Table 15 below.

Table 15: ISO classes of air cleanliness by particle concentration [14]

Cleanliness Level	ISO Class Number	Maximum allowable concentrations (particles/ m^{3}) for particles equal to and greater than the considered sizes,					
		≥ 0.1 µm	≥ 0.2 µm	≥ 0.3 µm	≥ 0.5 µm	≥ 1 µm	≥ 5 µm
Extremely	ISO 1	10	2				
Clean	ISO 2	100	24	10	4		
↓	ISO 3	1000	237	102	35	8	
	ISO 4	10000	2370	1020	352	83	
	ISO 5	100000	23700	10200	3520	832	29
	ISO 6	1000000	237000	102000	35200	8320	293
	ISO 7				352000	83200	2930
	ISO 8				3520000	832000	29300
Clean	ISO 9				35200000	8320000	293000

The last code is ST04 which represented for conducting tests. The code obtained 18 scores out of 25. The code is including the IAQ parameter, location of sampling point and standard used due to research and methods while conducting tests. According to International Standard ISO (2016), the sampling locations were based on the area of each cleanroom or clean zone to be classified and provides at least 95.0 % confidence of the cleanroom area that does not exceed the class limits [14]. Furthermore, the particle count testing should be prepared which verifies all the relevant aspects of the cleanroom or clean zone that contribute to its integrity are complete and functioning in accordance with its performance specifications.

In the overall comparison of the result, the majority of all five kind of research were following the standard requirements. All aspects were being taken at the beginning until finish their study. Lastly, the standard related to study is being stated and can be a reference for future study in their upcoming research made.

3.5 Discussions

For further study, the test that will be conducted should be more on the experimental of particle evaluation in order to find the relation between condition of indoor air quality and ducting particle inside ducting system. It is because of the increasing of pollutant from both outdoor and indoor sources. Plus, duct cleaning can prevents health problem, due to dirty air ducts which can increase the particle levels in buildings.

Regarding the results, all the five previous researches were using the appropriate standards as a guide and reference either to conduct the testing or sampling method due to the IAQ condition and ducting cleanliness. To achieve the standard requirement used by the researcher, a demography question is made to make strong proof that they were still following the correct procedure in completing their study. Thus, the demography question was made based on the checklist of the standard used by Malaysia such as British Standard (BS EN 15780), Industry Code of Practice (ICOP), National Air Duct Cleaners Association (NADCA) and International Organization for Standardization (ISO).

Based on the demography question, the code of SD02 which represented for ducting cleanliness is getting the lowest score five out of 20. There is a lack of ducting cleanliness information in respect to particle concentration. After that, there are just only two journals that make the correlation of particles acceptable range towards the allowable standard as shown in Table 11. Plus, only one reseacrh makes the relation of SBS and BRI due to ducting cleanliness which is [8].

Apart from that, there has several kinds of methods and instruments used in conducting the test. However, it is still in the correct ways and depends on how the test was conducted because a different method produces different results. In addition, the understanding of dust and particle is quite different but still interrelated. The unit used for dust is in g/m^2 and particle concentration is in $\mu g / m^3$.

3.6 Recommendation/Contribution

Based on this study, there are recommendation needs to improve for the next study approach. First of all, the method and instrument used must be mentioned and explaining more in detail based on its specification and specialization on what criteria or part of range conducted. Then, the measurement of basic data IAQ such as temperature, relative humidity and air velocity should be on testing first before conducting another test related to HVAC system. It is because the researchers need to know the condition of system based on the parameter measured and it has high correlation towards particle.

Second, the researcher should mention the standard used either national or international standards for their case of study. The information on the part in the standard used must be listed out to ensure the reader more understands what they trying to deliver. Besides, the standard must be in the latest edition which in allowable standard based on the part categorization in the system.

The third recommendation is based on their result. It should have the suggestion needs from the researcher in detail for improving IAQ in the building. In improving the condition of the system, there must have mentioned about several maintenance advices to keep the system functioning well based on its performance towards the building.

Furthermore, the limitation of the study should be mentioned clearly in terms of building type specification, the parameter used, and test categorization. In other hand, it can guide and help the potential researcher to overcome future work and study. The content of the study can be delivered in easy way.

Lastly, the contributions of this study are to help and guide the building's owner for making the inspection followed by the standard required to keep the ducting cleanliness and to ensure the ducting operator can be functioned as well as its performance to serve fresh air and quality of the air in the building. The maintenance interval also can be scheduled to maintain the operation of the HVAC system.

4. Conclusion

In conclusion, the comparison made between five previous researches were responded to three objectives of this study which are to determine the significant standard of duct cleanliness, compare the standard requirement duct cleanliness with respect to particle and evaluate the method and result of duct cleanliness focusing on the particle from previous study.

The majority of all types of buildings mentioned in the previous researches are under the category of medium cleanliness quality classes according to BS EN 15780. Besides, there are only three of the researchers refer to the standard in their study. [6] used Chinese Hygienic Standard while [9] used standard stated from Environment Protection Department (GB 3095) and [11] used ASHRAE 62.2 standard.

According to the result obtained by [9] the concentration of pollutants in the room is close to the standard because the acceptable range is between 35 $\mu g / m^3$ and 75 $\mu g / m^3$. In terms of ISO standard, it can be classified in ISO 3 for PM 2.5 maximum concentration limits. Besides, [10] obtained the average of PM 2.5 between 20 $\mu g / m^3$ to 34 $\mu g / m^3$ and the cleanliness level by ISO standard also in

ISO 3 which in the intermediate of extremely clean. Study by [11] obtained 114.8 μg / m^3 for PM 10 loading and it can be classified in ISO 5.

Lastly, HVAC systems are usually used to provide fresh and clean air by removing the pollutants. Hence, ducting cleanliness is very important in the HVAC system. It contributes to the performances of IAQ in the building because poor IAQ can cause problems to human health with respect to SBS and BRI.

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