ORIGINAL ARTICLE

A case study on the source apportionment of indoor air quality (IAQ) at a kindergarten in eastern Peninsular Malaysia using cluster analysis

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ABSTRACT

Background: Indoor air quality is an important concern for kindergartener because young children are more vulnerable to the effects of poor air quality. Poor indoor air quality can cause respiratory problems and other health issues, which can negatively affect a child's ability to learn and grow. Aim of this study is to determine the trend and status of indoor air pollutants in study areas by using descriptive statistics and cluster analysis.

Materials and Methods: Air temperature (T), relative humidity (RH), air movement (AM), carbon dioxide (CO2), formaldehyde (HCHO), and particulate matter (PM) are the monitored parameters. Monitoring was carried out in the kindergarten for three consecutive days starting from 8.00am to 12.00pm.

Results: Indoor carbon dioxide readings were higher at 0800 when parents drove to kindergarten to drop off their children without turning off the engine. In addition to this, the PM10 reading at 1000 was high but still within the standard range according to ICOP-IAQ 2010.

Conclusion: The findings highlight the importance of indoor air quality improvement measures for kindergarten buildings which can be used to improve indoor air quality in kindergarten environments.

KEYWORDS:
Indoor air quality, pollutants, kindergarten, cluster analysis

INTRODUCTION

Indoor air quality (IAQ) is crucial aspect of children's health and well-being, especially in a kindergarten setting where children spend a considerable amount of time indoors. Poor IAQ can have adverse effects on children's health causing respiratory problem, allergies, and other health issues. Therefore, it is crucial to maintain good IAQ in kindergarten setting to ensure children's safety and health. There are several factors that can affect the IAQ in kindergarten settings, including ventilation, humidity, and presence of pollutants such as mould, dust, and volatile organic compounds (VOCs). Poor ventilation can lead to the accumulation of pollutants which can adversely affect the IAQ. Additionally, high temperature and humidity levels can also contribute to poor IAQ by promoting the growth of mould and other harmful microorganism.

Excessive ranges of indoor air pollutants in kindergarten surroundings can have negative impacts on children's learning performance and increase the possibility of absenteeism due to breathing troubles.[1] Most activities that take part indoors are distinguished by complex chemical components in air quality. Indoor classrooms are a vital setting for young children to learn. Several studies have found that classrooms have high concentrations of these substances, which can be harmful to human health.[2,3] For example, carbon dioxide has been linked to headaches and sleepiness and the exposure to particulate matter can lead to respiratory problems such as asthma. Children are more susceptible to these pollutants than adults because their lungs are still developing, and they breathe more easily than adults.[3]

Children typically spend most of their time in the microenvironment of home and school. There is credible scientific evidence that spending time indoors can increase the likelihood of various respiratory illnesses caused by indoor air pollutant exposure, particularly in children.[4] Exposure to air pollution constitutes children are more likely to have asthma and other respiratory symptoms, even when they are exposed to low levels. Studies have been conducted over the last decade to examine indoor air quality in school settings in different regions.[5,6] The following pollutants were measured in the indoor air of kindergarten and day-care centres: sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ozone, carbon monoxide (CO) and carbon dioxide (CO_2), volatile organic compounds (VOC), bioaerosols, particulate matters smaller than 10 (PM10) or 2.5 ($PM_{2.5}$) microns, polycyclic aromatic hydrocarbons (PAHs), and few heavy metals including mercury.

To ensure that young children receive the best possible care, it is crucial to pay attention to the quality of their indoor environment.[7]

This article was accepted: 24 November 2023
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Kindergarten buildings are the second most common indoor environment after home regarding chemical exposure. Since children spend most of their day indoors, it is crucial to evaluate the adverse health effects of indoor pollutants on kids. According to Reda et al.,[8] approximately 40% of $PM_{2.5}$ comes from outdoor sources, particularly from the combustion of fossil fuels used for heating and transport, and the remaining 60% comes from indoor activities. Indoor $PM_{2.5}$ sources, such as cooking, are often a problem in kindergartens. The most common problems are poor ventilation, infrequently cleaned surfaces in the room, and large numbers of children in a small space.

Kindergartens are locations where indoor air quality must be a key concern, as they are places where children spend an essential step for their development. When parents and guardians think about the school and classrooms, they expect them to be healthy and sustainable, maximising each child's learning potential. A truly effective classroom needs to be more than just a healthy environment; it must also have good indoor air quality.[9] Nowadays, the advantages of good indoor air quality in schools are recognised around the world. Good air quality inside a building lead to fewer absences, healthier occupants, and better learning environment. Studies show that students tend to get better grades and higher test scores when the temperature of their school is moderated.[10]

Mainka et al.,[11] stated that the carbon dioxide is not an indoor pollutant, but it can indicate a low level of ventilation. It has been correlated with decreased learning abilities by 5% and respiratory illnesses. Indoor air pollution from outdoors can also be an issue because pollutants like VOCs and PMs penetrate the building envelope. Materials such as paint and carpet act as sinks for emissions, taking up pollutants such as VOCs and PMs. These materials include fabric partitions and other fleecy materials in nursery schools, particularly those used by younger children during naptimes.[12]

The Department of Occupational Safety and Health (DOSH), Ministry of Human Resources in Malaysia developed an industry code of practice aimed at improving indoor air quality in 2010. This standard is applicable to any enclosed space served by a mechanical ventilation and air conditioning (MVAC) system, and those with air-cooled split systems. Maintaining a good IAQ is critical to health and wellbeing. Effective measures should be put in place to ensure that the IAQ is of the highest standard possible to protect children's health and enhance their learning and development.

MATERIALS AND METHODS

Study Location

The study was located at the Cahaya Elit Kindergarten (5.374221, 103.111613), Kuala Nerus, Terengganu. The location of the kindergarten is in a residential area closed to the roadside. It is considered a strategic place for performing the monitoring of indoor air quality since motor vehicles always passing by the point. This kindergarten operates from 7.00 am until 5.30 pm.

Data Collection and Management

The ICOP-IAQ, 2010 provides a general criterion for sampling campaign. This includes the following: 1) The placement must cause as little disturbance to work operations as possible inside the research area. 2) It must be located at least 0.5m away from partitions, walls, corners, other vertical surfaces, and windows. 3) Avoid standing directly in front of floor fans, induction units, or air supply diffusers.

The level of indoor air pollutants (IAP) in the kindergarten was determined by measuring the indoor air quality (IAQ). Assessment related to IAQ was referred to the Industry Code of Practice (ICOP) for IAQ (2010), which has been provided by the Department of Occupational Safety and Health (2010). In this study, there are two parameters involved and being measured, which are chemical and physical parameters, and carbon dioxide as an indicator of the indoor ventilation. The physical parameters measured are temperature (T), air movement (AM), and relative humidity (RH), and for chemical parameters, particulate matter with a diameter of less than 10µm (PM10), and formaldehyde. The monitoring was performed during the school day for three consecutive days for four hours, starting at 8.00 am and ending at 12.00 pm, with every five minutes of interval. Microsoft Excel version 28.0 (Microsoft 365 MSO version 2205) and Statistical Package for the Social Sciences (SPSS®) version 28.0 were used for data analysis.

Data Analysis

The descriptive statistics were conducted using SPSS Version 28.0 for all parameters. To summarise the main statistical parameters, the mean, standard limit, median, standard deviation, variance, kurtosis, skewness, and minimum and maximum indoor parameters for the selected kindergarten were evaluated. Descriptive research, on the other hand, is primarily concerned with describing the nature or condition as well as the details of the current situation. This method is used to describe the characteristics of the phenomenon as it exists at the time of the study as well as to investigate the cause(s) of a specific situation. This phenomenon in turn should be discussed or explained by means of data analysis gathered through objective forms of measurement.

Cluster analysis is a useful tool for this study because it helps find out where the pollutants in the air in a kindergarten come from. Cluster analysis is known as a technique for identifying and classifying objects in data sets (clusters). As a result, objects with the same information are grouped together, while the remaining are separate from one another. K-means, density-based clustering, and hierarchical methods are a few examples. Hierarchical agglomerative clustering analysis (HACA) is one of the clustering techniques used in air quality studies. The term "hierarchical" refers to clustering in which clusters are grouped from previously clustered clusters in each process. In the meantime, the word "agglomerative" stands for how the clusters combine until they form a single cluster containing all observations. The application of HACA is commonly used for identifying air pollution behaviour at air quality monitoring stations based on their locations.[13] A study by Dotsel et al.,[12] has been done by using bivariate k-means cluster analysis with the aim of

Table I: Descriptive statistics for indoor air pollutants

	TEMP (°C)	RH (%)	AM (m/s)	CO_2 (ppm)	HCHO (ppm)	PM_{10} (mg/m^3)
Mean	31.59	79.44	0.21	505.43	0.03	0.07
Standard Limit	23-26	40-70	0.15-0.50	C1000	0.1	0.15
Median	29.60	79.65	0.17	518.50	0.03	0.06
Standard Deviation	21.87	3.64	0.12	63.93	0.01	0.03
Variance	478.53	13.28	0.02	4087.07	0.00	0.01
Kurtosis	143.38	-0.87	3.81	-0.35	1.62	0.20
Skewness	11.96	-0.07	1.82	-0.54	-0.27	0.95
Minimum	28.10	72.10	0.08	372.00	0.01	0.03
Maximum	29.20	85.30	0.75	646.00	0.05	0.15

TEMP = Air Temperature; RH = Relative Humidity; AM = Air Movement; CO_2 = Carbon Dioxide, HCHO = Formaldehyde; PM10 = Particulate Matter; ppm = parts per million; m/s = metre per second; mg/m^3 = milligram per metre cube

recognising and obtaining the areas that have a high value of PM_{10}. The k-means clustering process involves clustering the data around k points chosen at random from the space represented by the objects being clustered into k groups to form initial group centroids. As a result, the six-cluster solution was discovered to record high concentration regions of PM_{10} that had previously been observed separately on the polar plot.

RESULTS

Trend and Status of Indoor Air Quality (IAQ)

Table I show the descriptive statistics for the indoor air pollutants parameters, which consists of the mean, median, variance, standard deviation, skewness, kurtosis, maximum, and minimum of the data in the kindergarten. Skewness ranges from -0.2680 to 11.9619 along with kurtosis that ranged from -0.3514 to 143.386. The data distribution that is normal must have skewness close to zero and kurtosis close to 3. Unfortunately, the data set from this study were distinct from the statement because of different activities such as the movement of the children in the kindergarten area. Thus, the data are non-parametric. Since the sample size is small (n=35), to determine the normality distribution, a Shapiro-Wilk test was carried out and it appeared that the distribution is not normally distributed due to the significant value (p-value) being less than 0.05 ($p<0.05$). There are many possibilities causing to an abnormality of the data like the number of people that wander around the kindergarten and activities that the children do from inside along with outside the kindergarten. This study involved 35 students in kindergarten and during the first session of the class, all children were gathered in one spot to do their activities.

Figure 1 shows the physical parameters of the IAQ including air temperature, relative humidity, and air movement. The highest temperature reading was at 9.00am. This is because all the children have already started gathering in the play area to start their activities which will be causing an elevated temperature due to their active movement while the main sliding door was closed. As the temperature increases, the relative humidity is low. The ability of air to retain water vapour is entirely dependent on its temperature. The ability to retain moisture increases or decreases as air temperature changes, affecting relative humidity, and the tendency of air to maintain water vapour is completely determined by temperature. The relative humidity-temperature relationship is inversely proportional because as temperature rises, the relative humidity decreases, making the air drier. Indirectly the reading of the air movement also shows an increment. Air movement plays a significant role to determine good ventilation for indoor air. Increased air movement can help to enhance thermal comfort while also providing a pleasant internal sensation.[14] Based on ICOP-IAQ 2010, the recommended indoor air temperature ranges from 23–26˚C, with 40-70% of relative humidity. Meanwhile, the air movement should be 0.15-0.50m/s maximum as stated in the ICOP-IAQ 2010.

At 10.00am, the PM_{10} reading was high but nonetheless, the reading is still within the standard limit according to ICOP-IAQ 2010. Just compared to the reading at other times, the reading at 10.00am was higher because the students were doing cleaning activities at the activity area before they went for recess. Since the kindergarten is near to the road, PM10 may be caused by adjacent traffic. The next pollutant that was monitored is formaldehyde, the reading for formaldehyde does not exceed the standard limit. The highest reading was recorded at 0.0275ppm at 8.00am and the readings went down to 0.0255ppm at 9.00am and the reading rose to 0.0263ppm at 10.00am.

Factor Analysis of IAP

Cluster analysis (CA) is a collection of multivariate techniques that are frequently used to gather objects into groups with a similar number of classes or clusters, just hence the objects in different clusters are distinct from one another. CA greatly increases case correlation in each cluster while trying to minimise dissimilarity between previously unknown groups.[15] A dendrogram known as a tree diagram, which shows the measured similarity or distance between any two variables, illustrates the classifications of objects in CA.[16] CA was used to analyse the variables of indoor air quality pollutants from 8.00am to 12.00pm, with an average linkage between groups. Six variables were collected and applied to HACA. The illustrated dendrogram as shown in Figure 3 demonstrated the variables that took place during the monitoring. From 8.00am to 9.00am, the reading for CO2 concentration was higher than the rest of the hours and variables. The mean and median of CO2 concentration were 505.43ppm and 518.50ppm, respectively. Nonetheless, both reading does not exceed the standard limit based on ICOP-IAQ 2010. With HACA, the variables of Cluster 1 (C1) are the mean and median for temperature and relative humidity

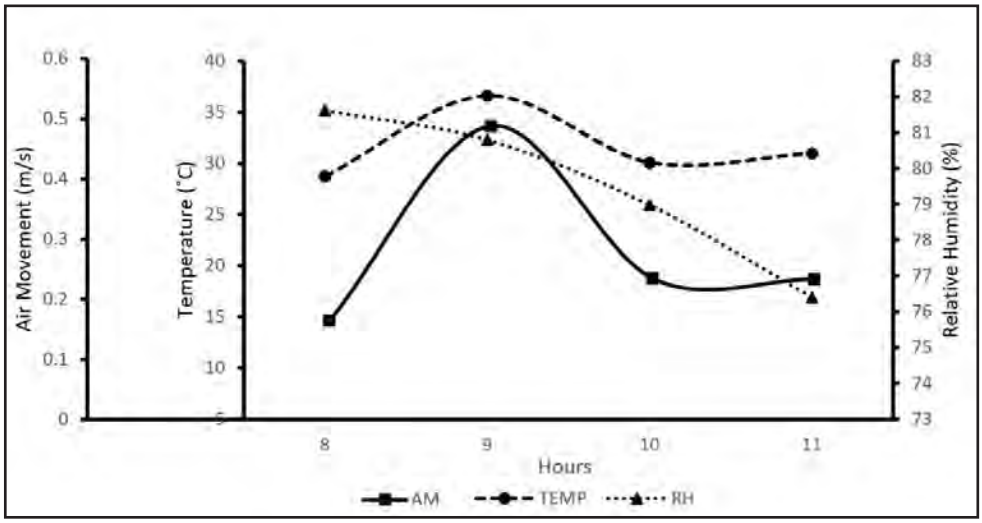

Fig. 1: Physical parameters of air movement (AM), temperature (TEMP), and relative humidity (RH)

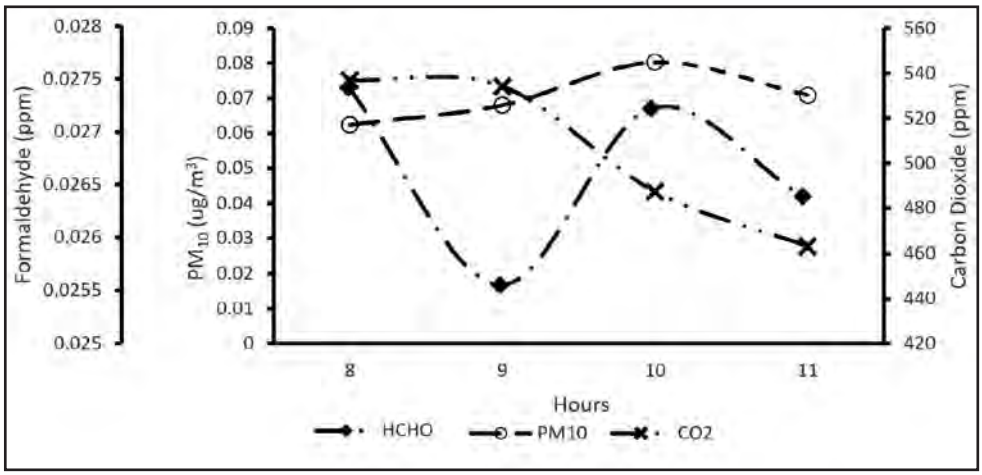

Fig. 2: Chemical parameters of formaldehyde (HCHO), particulate matters (PM10), and carbon dioxide (CO_2)

that exceeded the standard limit. This is because, during the morning, the temperature was between 28-29˚C, and the relative humidity was increasing so the air will become wet. The relationship between temperature and relative humidity is inversely proportional.

DISCUSSION

According to Table I, parameters for Indoor Air Quality (IAQ) were all within the acceptable range as in the Industry Code of Practice on Indoor Air Quality 2010 (ICOP IAQ 2010) except for air temperature and relative humidity which were slightly higher than the stated limit. A study show that air quality can be influenced nearly by all environmental parameters that include relative humidity, air movement, and air temperature.[17] Based on Table I also, HCHO gave the lowest value which is 0.03ppm. HCHO as in known is the most common source of the indoor air pollutant. Though at very low concentrations, it can inflame a person's throat, lungs, and eyes, as well as trigger an asthma attack. In a worse case, if the exposure is prolonged, it will be linked to cancer.[18] Furthermore, the reading for CO_2 showed that the level does not give rise to an immediate risk to health. In a way, if the levels of indoor CO_2 are high, it may thus indicate that the air ventilation rate is insufficient for the number of people living in the room.

Figure 1 represents the physical parameters of the IAQ. The temperature has exceeded the limit as Malaysia is known to be in a tropical area that is humid, and warm so the temperature range was within 29-31˚C that are known to be outside the comfort temperature range (1). The kindergarten is also using fans as their mechanical ventilation. Cabovská et al.,[19] stated that ventilation can help to bring good Indoor Air Quality (IAQ). The main cause of ventilation is to dilute or get rid of the pollutants in the air that was released from building occupants, indoor activities, and building materials. According to Lazovic et al.,[20] humidity and indoor air temperature are the main keys to the thermal comfort of the occupants. Reda et al.,[20] stated that thermal comfort is known as a state of mind that indicate satisfaction with one's surrounding.

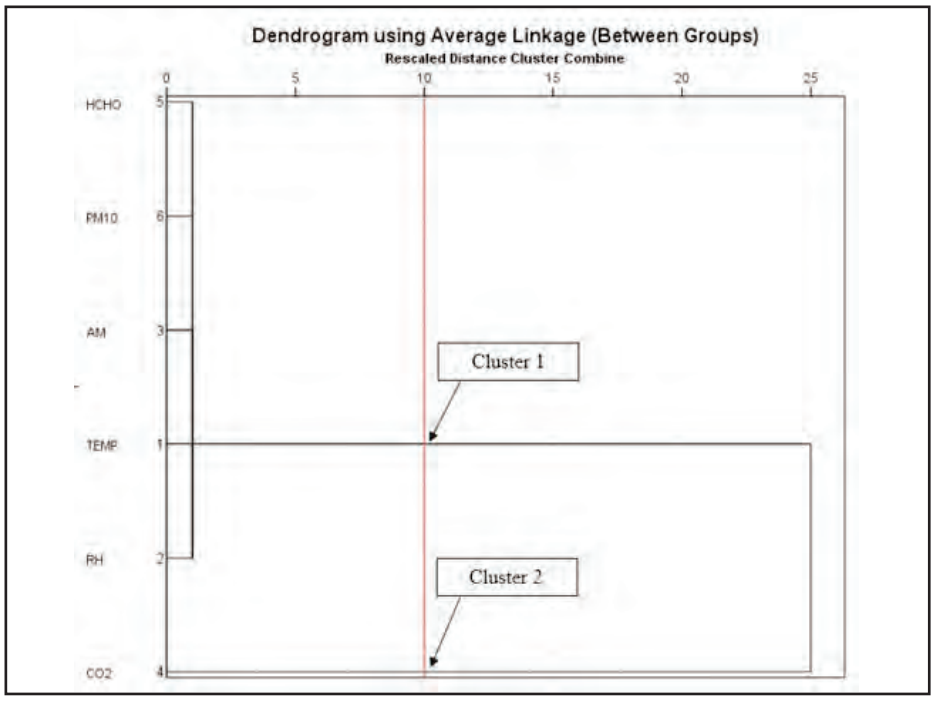

Fig. 3: Data collected using cluster analysis

Mechanical ventilation usually will result in faster ventilation rates as well as lowered CO_2 concentration.[16] As the time goes from 10.00am to 11.00am, it shows a decrease in the CO_2 concentration as the students were getting ready and having their recess time at the back of the classroom which is an opened-air area and has natural ventilation. A study by Zakaria et al.,[1] has done an analysis regarding indoor air pollution in Malaysian kindergartens. The author combined through the local scientific literature regarding the levels of indoor air pollution in kindergartens and derived the data from 17 studies that have been published over a ten-year period. They indicated that children's respiratory activity was the main source of indoor CO_2 and is also usually used as an alternative to represent ventilation rate. After the recess period was over, the indoor CO_2 trend remained lower because students were separated into their respective classrooms according to their schedules and doing their activities outdoors. Indirectly, the concentration of CO_2 falls due to the doors opening and fewer occupants in the living area.

Since the kindergarten is nearby the road, PM_{10} might be generated from the road traffic nearby. As stated by Mansor et al.,[21] it is found that cleaning activities or cooking will significantly help in elevated PM concentration, leading to a raise in PM concentrations in the building. The next pollutant that has been monitored is formaldehyde, the reading on formaldehyde does not exceed the standard limit. It is possible that the reading was influenced by the outdoor activities as this kindergarten is located nearby the roadside where there were multiple vehicles passing by from time to time.[23,22]

Based on the result from CA, it is verified that CO_2 was grouped in Cluster 2 (C2) while the other variables were positioned in Cluster 1 (C1). Regarding the result of the study made by Singh et al.[2], it shows that relative humidity and temperature have a major effect on the production of CO_2 concentration. It is proven based on this cluster that there is a correlation between relative humidity and temperature with CO_2. The contrast between CO_2 concentration and the rest of the variables was the main reason based on the result.

CONCLUSION

In conclusion, parameters of temperature and relative humidity in the kindergarten did not comply with the standard limit, while other parameters are within the acceptable limit by the Department of Occupational Safety and Health, Malaysia. Cluster analysis has shown that ventilation and indoor air pollutants are among the contributor towards poor IAQ in kindergarten, executing by Cluster 1 and Cluster 2. Thus, we suggest for opening windows and doors or running a window air conditioner with the vent control open increases the outdoor ventilation rate. Local bathroom or kitchen fans that exhaust outdoors remove contaminants directly from the room where the fan is located and also increase the outdoor air ventilation rate.

ACKNOWLEDGEMENTS

We are especially grateful to the owner of the agriculture farm and the staff of the Environmental Health and Safety Laboratory for their assistance during data collection and experimental work.

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