Effects of Wooden and Plastic Toys on Indoor Air Quality in Kindergartens

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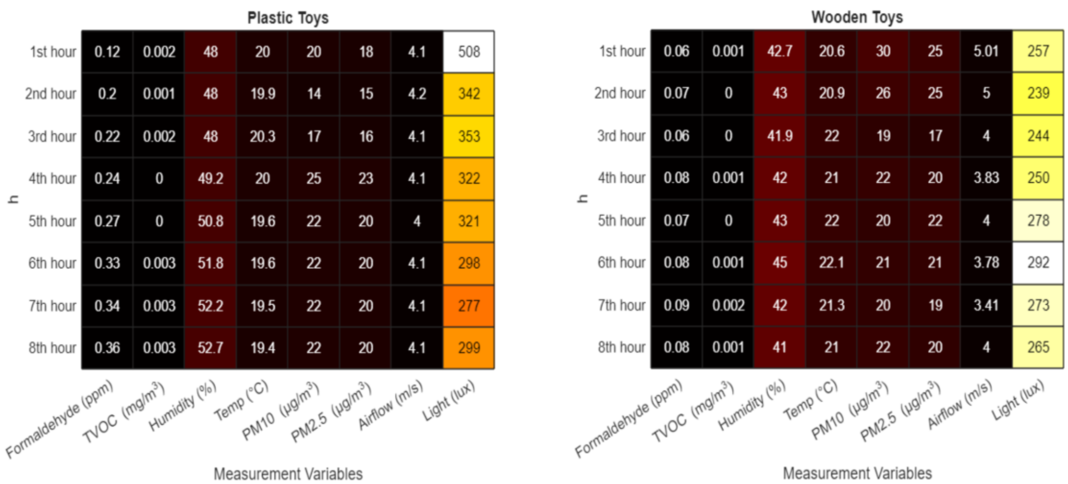
DOI: 10.15376/biores.20.1.1088-1109

GRAPHICAL ABSTRACT



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Recep Aykan,[a] Kazım Onur Demirarslan,[b,*] and Elif Işik Demirarslan [c]

This study was conducted in a kindergarten classroom in the Ayancik district of Sinop province, Türkiye, and examined indoor air quality under five scenarios. The measured parameters included formaldehyde, TVOC (total volatile organic compounds), PM10 and PM2.5 (particulates), humidity, temperature, airflow velocity, and illumination level. The study found that using wood and plastic materials, such as toys, tables, and chairs, significantly influenced the indoor air quality in the kindergarten environment. Wood materials reduced formaldehyde, TVOC, and particulate matter (PM) levels. Formaldehyde levels ranged from 0.03 to 0.22 ppm, TVOC values from 0.001 to 0.003 mg/m³, PM10 levels from 16 to 52 µg/m³, and PM2.5 levels from 15 to 46 µg/m³. In Scenario 5, the lowest levels of formaldehyde and TVOC were recorded. These findings offer important insights for improving air quality in kindergartens and provide a foundation for future research. Careful selection of toys, design elements, and materials in kindergarten classrooms is critical for protecting children’s health and promoting development. Prioritizing high-quality indoor air in these environments is essential for enhancing children's learning, health, and overall well-being.

DOI: 10.15376/biores.20.1.1088-1109

Keywords: Indoor air quality; Wood and plastic effect; Kindergarten health

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INTRODUCTION

Indoor air quality (IAQ) has emerged as an important global concern. Most individuals spend approximately 90% of their time in enclosed spaces. Although indoor air pollution is often deemed harmless, it is essential to note that interior air pollution presents a more significant health hazard than outside air pollution (Abu Mansor *et al.* 2020). Managing the IAQ in buildings is crucial for ensuring a safe and healthy environment for the people within and safeguarding their well-being. Optimal IAQ is particularly crucial in kindergarten classrooms, where children are present and engage in group play. Due to the age and activity of the inhabitants, managing IAQ is crucial in kindergarten classrooms because it directly impacts the health and well-being of children (Arar and Jung 2021). Because of the incomplete development of children’s immune systems and lungs, they are more susceptible to environmental stimuli than adults. Furthermore, children have higher respiratory rates than adults. Specifically, a resting child inhales twice as much air per unit of weight as an adult. As a result, developing tissues and organs are more exposed to environmental contamination (Anake and Nnamani 2023). Thus, the physiological disparities among children may render them more susceptible to environmental toxins and health hazards. Children often spend longer indoors, so they are more exposed to indoor air pollution. Scientific studies have demonstrated that indoor air pollution has the potential to affect the central nervous system of children and can result in enduring health issues. Furthermore, exposure to air pollution during the early stages of life may lead to the onset of respiratory conditions, such as pediatric asthma (Almeida *et al.* 2011; Calderón-Garcidueñas *et al.* 2014; Deng *et al.* 2015; Zhang *et al.* 2021). Studying the IAQ in kindergarten classrooms is crucial for three primary reasons. First, children are highly susceptible to the effects of air pollution. Furthermore, kindergartens are the primary indoor venues where young children spend a significant amount of time. Indoor air quality in kindergarten differs from that in primary and upper-level institutions (Mainka *et al.* 2015). The IAQ can be evaluated by quantifying the concentrations of carbon monoxide, carbon dioxide, nitrogen dioxide, sulfur dioxide, volatile organic compounds, relative humidity, temperature, oxygen, ozone, ammonia, air velocity, formaldehyde, and particle pollution (Bulut Karaca 2022).

Formaldehyde is an indoor air pollutant that can cause irritation in the eyes, nose, throat, and respiratory system, even in small amounts. It is extensively used in the production of construction materials and domestic goods and can be found indoors and outdoors. The acceptable indoor concentration of formaldehyde is 0.1 ppm, considering its impact on health and the threshold at which its odor may be detected (EPA 2023). Long-term exposure to formaldehyde is linked to health issues such as respiratory symptoms, irritation of the eyes, nose, and throat, and allergic contact dermatitis. Furthermore, it has been classified as a likely human carcinogen, and prolonged exposure is known to be linked to uncommon malignancies affecting the nasal passages and throat (Zhang and Rana 2018). Formaldehyde exposure poses a higher risk to children due to increased susceptibility to respiratory symptoms. Extended exposure may worsen respiratory symptoms and asthma (Lazenby *et al.* 2006).

Particulate matter (PM), a pollutant, may pollute the indoor air in kindergarten classrooms and pose significant health hazards. The PM is composed of solid or liquid particles suspended in the air, and its chemical composition changes depending on its source. The interplay between environmental conditions and several variables influences the PM levels in kindergarten classrooms. PM can affect the respiratory system, leading to coughing, wheezing, and difficulty breathing in children. Prolonged exposure can result in chronic respiratory diseases, asthma flare ups, and other respiratory problems (Anake and Nnamani 2023).

Cleaning agents and furnishings are the primary producers of volatile organic compounds (VOCs) in kindergarten environments. Outdoor pollution is also a significant contributor; VOCs and other contaminants from outdoor sources, such as vehicles, can infiltrate the interior environment (Sousa *et al.* 2012). The VOCs can irritate the eyes, noses, and throats of children's developing respiratory systems. Prolonged exposure is linked to severe health issues, such as cognitive impairment, hormonal regulation disturbance, and cancer development. Furthermore, VOCs have the potential to exacerbate pre-existing respiratory disorders by eliciting allergic reactions and asthma attacks (Bayati *et al.* 2021).

Air temperature, humidity, and air velocity are significant elements that influence IAQ. Proper ventilation is essential in kindergarten environments to maintain high IAQ. Studies have shown that each child requires around 20.4 m^3/h of ventilation, as highlighted by Lee *et al.* (2023). This underscores the need for sufficient air circulation to maintain a healthy learning environment. Moreover, ventilation standards such as EN 15251 (2007) and EN 16798-1 (2019) specify the minimum airflow rates required for various spaces. These standards ensure adequate air exchange by recommending a ventilation rate of 10 L/s per person and 2.0 L/s per square meter for high-quality indoor environments. Such guidelines help provide a safe and healthy learning environment, particularly in settings like kindergartens (Dovjak *et al.* 2020).

Indoor temperature in kindergarten environments substantially influences children's and instructors' health, comfort, and academic achievement. Establishing optimal temperature ranges is crucial for fostering an efficient learning environment. The optimal temperature range for kindergarten environments is 22 to 24 °C. The typical bedroom temperature should be maintained at 19 to 20 °C, while gyms/activity classes and medical offices should be kept at 22 to 24 °C. Extreme temperatures can divert students' attention and harm their learning and academic performance, underscoring the need to maintain ideal temperature conditions (Takaoka and Norbäck 2019; Dedyulin 2020; Yan *et al.* 2022).

The humidity levels in kindergarten environments notably influenced both the instructors and the children. Extended exposure to unsuitable humidity levels increases the risk of respiratory issues, including asthma exacerbations, coughing, wheezing, and bronchitis (Angelon-Gaetz *et al.* 2016). In addition, maintaining suitable humidity levels can enhance student performance and decrease absenteeism by minimizing virus and germ transmission. Scientific research indicates that it is crucial to keep indoor humidity levels within 40% to 60% relative humidity (RH) to provide a healthy learning environment (Dedyulin 2020).

Optimal learning environments in kindergarten environments require appropriate lighting. An illumination level of at least 300 lux is recommended because it ensures sufficient visibility, enhances attentiveness, and promotes better learning outcomes. Natural sunshine's physical and physiological benefits make it the most favored light source. Maximizing the utilization of windows and minimizing cladding enhances the utilization of natural light (Angelaki *et al.* 2022; XAL 2024).

This study was conducted at a kindergarten classroom in the Ayancik district of Sinop province, Turkey. The study involved measuring various parameters in the indoor atmosphere of the classroom, including formaldehyde, TVOC (Total VOCs), PM10, PM2.5, humidity, temperature, and airflow velocity. The objective of this study was to evaluate the emission of formaldehyde and TVOC from plastic toys and determine the health safety of wooden toys. The pollutants, such as PM10 and PM2.5, and parameters, like indoor temperature, humidity, airflow velocity, and illumination, were analyzed. The measurement data were compared, and differences were determined using an analysis of variance (ANOVA) and Duncan's tests. The ANOVA was used to assess variability and determine statistically significant differences among various scenarios and interior settings. The Duncan test was used to ascertain statistical disparities between groups by explaining the ANOVA findings (Permanasari *et al.* 2010).

MATERIALS AND METHODS

The research was conducted in a kindergarten environment in the Ayancık district of Sinop province, Turkey. The kindergarten was built in 2015. In 2021, laminate flooring was installed instead of old parquet flooring. The kindergarten environment was staffed by

16 individuals, including the principal, teacher, clerk, cook, and auxiliary personnel. A total of 121 children were currently enrolled. Figure 1 shows the study area.

Fig. 1. Study area

Measurements were conducted every hour for 8 hours between 9:00 a.m. and 5:00 p.m. in five different scenarios: Scenario 1 is an original classroom (The original classroom contains furniture and toys made of plastic, wood and metal, many of which are several years old.), Scenario 2 is an empty classroom, Scenario 3 is a classroom with only plastic toys, Scenario 4 is a classroom with a combination of plastic and wooden toys, and Scenario 5 is a classroom with only wooden toys. The plastic toys were from a famous toy company in the field of plastic toys, and the production date was 2022. Plastic (polyvinyl chloride, PVC), which is claimed to be harmless to human health and can be recycled, was used in these plastic toys. Wooden toys were produced in 2023. The wooden toys used in the study were produced from beech, the most commonly used tree species on the market, and without glue. Many different types of paints and varnishes are used in wooden toys commonly found on the market. Since the study was primarily aimed at comparing wooden toys with plastic toys, there was no paint or varnish on the wooden toys. Later, different studies will be conducted with toys painted with specially selected varnishes and paints. To ensure the safety of the children, measurements were conducted during the kindergarten holiday when the children were not present. This approach not only minimizes potential safety concerns but also increases the reliability of the measurement process and ensures accurate data collection. Before each scenario, the classroom floor was cleaned using only water, without any cleaning agents, and the classroom was ventilated for 10 minutes afterward.

The classroom has a surface area of 36 m^2 and a capacity of 108 m^3. The flooring is laminate parquet, while the doors and windows are made of polyvinyl chloride (PVC). The walls are covered with plastic paint, and the windows are equipped with roller shades.

In Scenario 1, measurements were conducted while maintaining the original arrangement of the classroom in which the students performed their activities. The classroom was equipped with two tables made of particleboard-plastic-metal composite materials, 22 plastic chairs designed for children, spongy materials, a collection of toys consisting of 5% wood and 95% plastic, a printer, a television screen, a sound system, and handcrafted toys made of cardboard (Fig. 2).

Fig. 2. Scenario 1 classroom

Fig. 3. Scenario 2 classroom

In Scenario 2, measurements were conducted after the furniture and objects were removed, as well as the cleaning and ventilation of the classroom (Fig. 3).

Measurements in Scenario 3 were conducted in a classroom using 4 plastic tables with metal legs, 10 plastic seats, and 30 plastic toys, as shown in Fig. 4. In Scenario 4, measurements were conducted using plastic and wood materials in a classroom.

Fig. 4. Scenario 3 classroom

Fig. 5. Scenario 4 classroom

The classroom had a collection of 4 plastic tables with metal legs, 10 plastic chairs, 30 plastic toys, 5 wooden tables, 10 wooden chairs, and 30 wooden toys. The wooden tables, chairs, and toys did not have surface treatments such as varnish or paint (Fig. 5). The supplies included 5 tables, 10 seats, and 30 toys made of wood (Fig. 6).

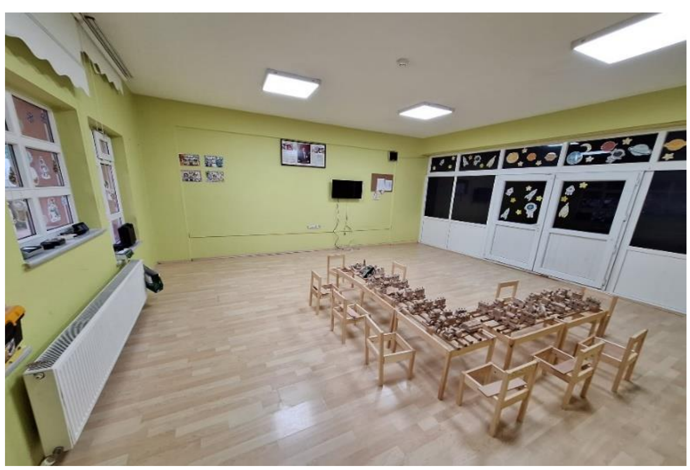

Fig. 6. Scenario 5 classroom

The formaldehyde sampler, which uses electrochemical sensor technology, measures the formaldehyde concentration in the air. It has a detection range of 0 to 5 ppm, a response time of less than 30 s, and a resolution of 0.01 ppm. The rate of long-term drift is below 10% annually, and the level of repeatability is below ± 2% (HAL-HFX205 2015). The detector used in TVOC, PM10, and PM2.5 measurements, employing semiconductor detection technology, measures PM10 and PM2.5 concentrations and TVOC levels. The measurement range for PM10 and PM2.5 is 0 to 999 µg/m³ and 0 to 9.999 mg/m³ for TVOC (OCTOPUP 2024). The anemometer used for indoor airflow measurements has a flow rate measurement range of 0 to 30 m/s and resolution of 0.01 m/s. The accuracy of the measurement is ± 0.10 m/s or ± 5% within the range of 0 to 5 m/s and ± 0.30 m/s or ± 5% within the range of 5 to 30 m/s. The accuracy of temperature measurement is ± 1 °C (HWA 2024). The device measures temperature and humidity in ambient air with an accuracy of ± 0.8 °C and a resolution of 0.1 °C within the range of 0 to 50 °C and ± 4% accuracy and 0.1% resolution within the range of 10% to 90%. The measurement speed and recording interval can be adjusted to 5, 10, 30, 60, 60, 120, 300, and 600 s or set to automatic, demonstrating the device's adaptability. The device can function at temperatures from 0 °C to 50 °C and humidity conditions from 0 °C to 90% (AHM 2024). The device used to measure illuminance levels has a measurement range of 0 to 400000 Lux. The accuracy of the measurement was within the range of ± 5% of the reading plus ± 10digit (10,000 Lux), while the repeatability was 3% (Cem DT-1309 2024).

This study measured indoor conditions in five distinct scenarios to investigate variations across different settings. The measurements were conducted using designated instruments positioned at the midpoint of the classroom. A single measurement of each parameter was recorded hourly, resulting in a total of 8 readings. Before the initial measurements, the classroom windows were opened and aired out for 10 min. The proposed method aims to correctly and reliably analyze parameters related to indoor air quality.

Statistical Analysis

In this part of the study, statistical analyses were conducted to compare measurement findings acquired under various scenarios and to ascertain differences in interior circumstances. The measurement outcomes were derived from five distinct scenarios, and ANOVA (analysis of variance) was employed to assess significant variations among these results. The ANOVA is a statistical technique employed to ascertain the significance of mean differences among groups. This study utilized it to compare indoor air quality measures across several settings. Upon identifying significant differences among groups by ANOVA, Duncan's test was conducted to ascertain the specific groups exhibiting these differences. The Duncan test is a multiple comparison technique employed to analyze mean differences among many groups, identifying the specific events that distinguish them. The statistical analysis was conducted using IBM SPSS version 19.0 software (IBM Corp., Armonk, NY, USA).

RESULTS AND DISCUSSION

This study measured formaldehyde, TVOC, PM10, PM2.5, humidity, temperature, airflow velocity, and illumination parameters under five scenarios in a classroom where children performed their activities.

Scenario 1

Figures 7A and 7B show the recorded formaldehyde and TVOC concentrations in the ambient atmosphere. Based on the measurements, the formaldehyde concentrations ranged from 0.03 to 0.22 ppm (Fig. 7A). In contrast, TVOC levels varied between 0.001 and 0.003 mg/m^3, as shown in Fig. 7B. Formaldehyde concentrations consistently exceeded those of TVOCs. A significant increase in formaldehyde concentrations was observed at 5 h and 7 h, whereas no significant change in TVOC levels was noted. Figure 7C shows that hourly PM10 and PM2.5 levels differ. In the first hour, PM10 levels were 50 µg/m^3, which was slightly higher than PM2.5 levels at 40 µg/m^3. While PM10 and PM2.5 levels generally increased and decreased in tandem, there were notable deviations in some hours. These differences, such as the one observed at 5 h, when PM10 peaked at 52 µg/m^3, surpassing PM2.5 levels at 46 µg/m^3, are crucial to our understanding of air quality dynamics. Figure 7D shows the hourly humidity and temperature values in the classroom. The humidity level ranged from 52.3% to 62.0%, and the temperature ranged from 16.3 °C to 19.6 °C. According to Fig. 7E, the airflow velocity fluctuated between hours 1 and 8. The maximum recorded velocity was 4.5 m/s at 4 h, while the minimum recorded velocity was 3.6 m/s at 8 h. Based on the light intensity measurements shown in Fig. 7F, the maximum recorded value was 411 lux at the 2nd hour, while the minimum recorded value was 292 lux at the 8th hour.

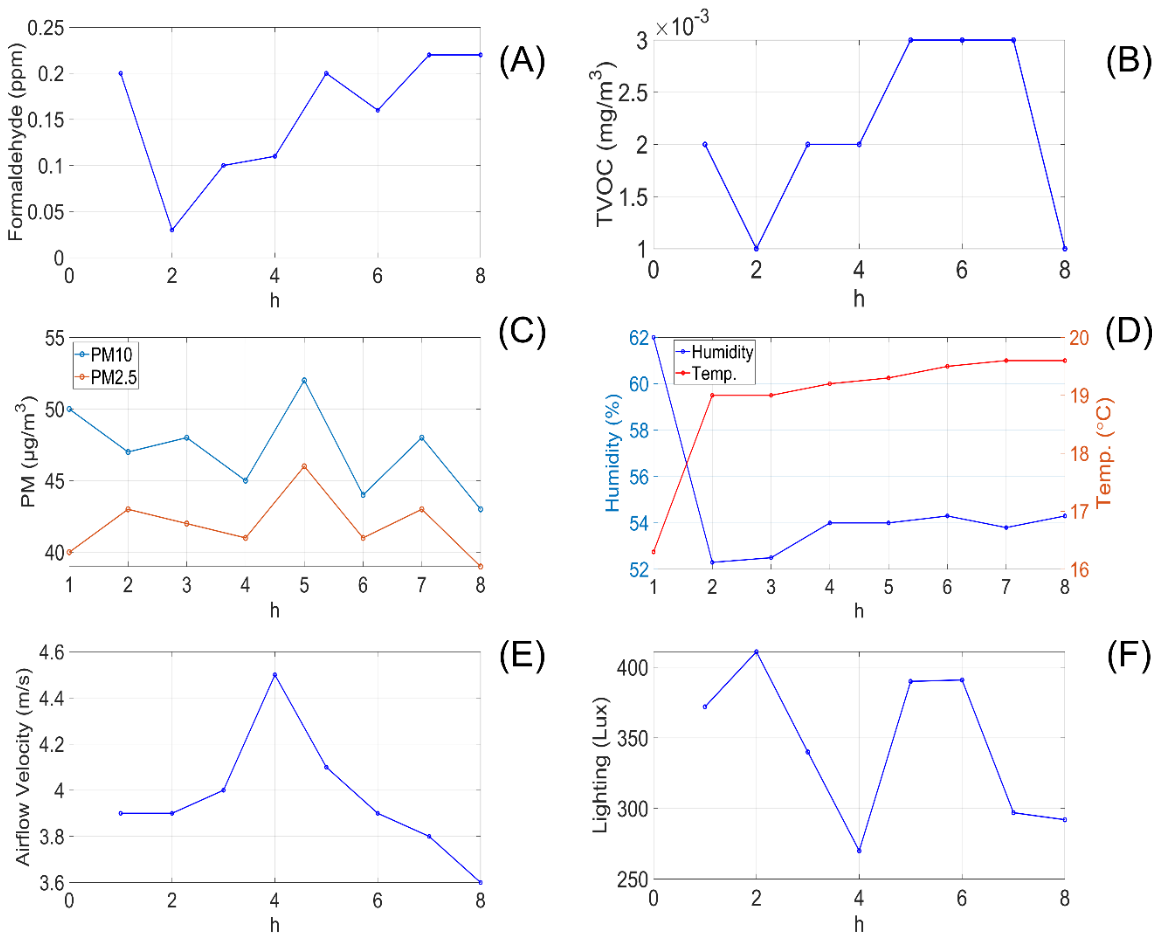

Fig. 7. Scenario 1 measurements (A: Formaldehyde; B: TVOC; C: PM; D: Humidity-Temperature; E: Airflow; and F: Lighting)

Scenario 2

Figure 8 displays the data obtained from the measurements in Scenario 2. The formaldehyde levels peaked at 0.12 ppm during the first hour and then declined to their minimum levels of 0.06 ppm during the 3rd and 7th hours. The TVOC concentration reached its highest point at 0.002 mg/m³ during the first and second hours and then dropped to 0 mg/m³ in the 3rd h. The PM10 and PM2.5 levels exhibited comparable variations across measurement durations. PM10 was recorded at 20 µg/m³ in the first hour and 15 µg/m³ in the 6th and 8th hours. The humidity decreased from 49% at 1.0 h to 43% after 5 h, while the temperature increased from 17.6 °C at hour 1 to 21°C after 7 h. The airflow velocity, which affects the pollutant distribution and thermal comfort, was 4.1 m/s at hour 1, rose to 4.5 m/s at hour 6, and then dropped to 1.2 m/s at hour 8. Initially recorded at 911 lux in hour 1, the light intensity reached its minimum level of 650 lux in 7 h and was subsequently measured at 670 lux in 8 h.

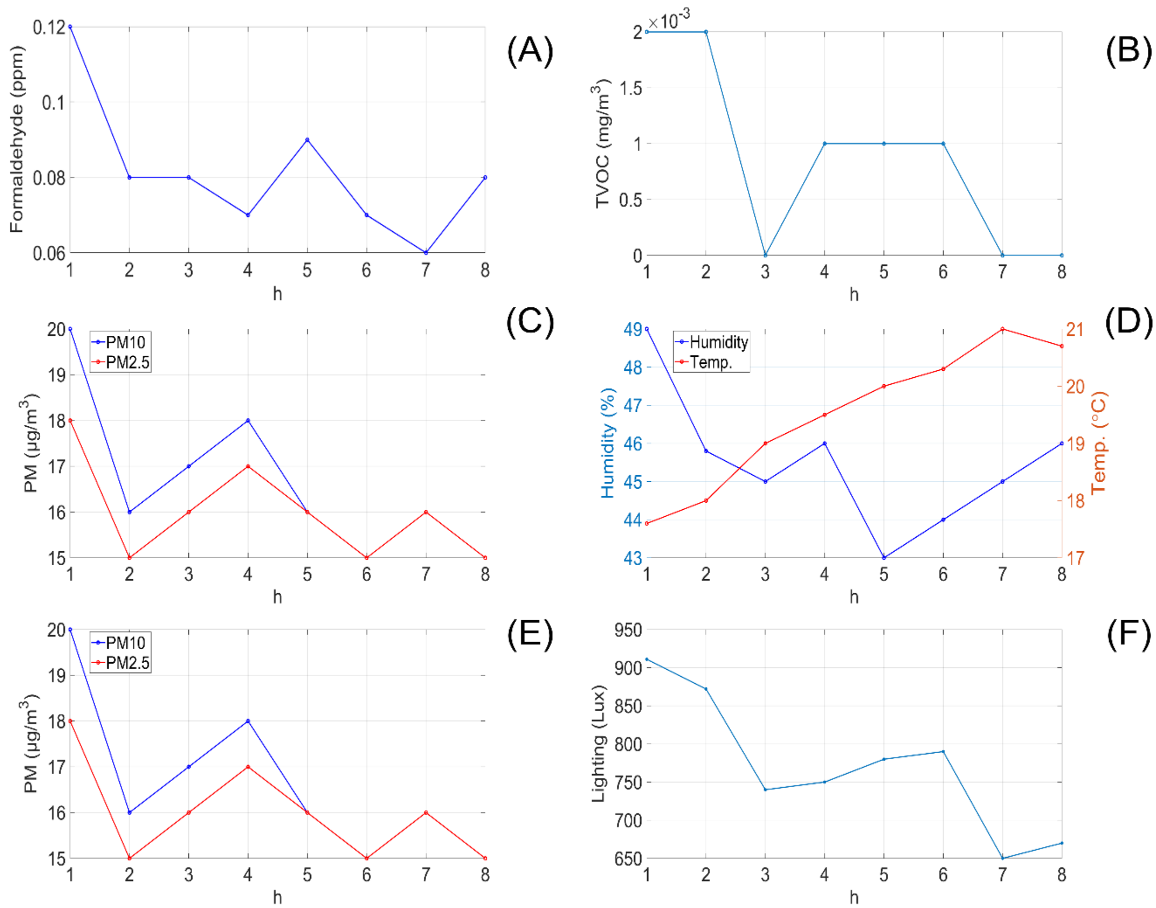

Fig. 8. Scenario 2 measurements (A: Formaldehyde; B: TVOC; C: PM; D: Humidity-Temperature; E: Airflow; and F: Lighting)

Scenario 3

Figures 9A and 9B show that the formaldehyde and TVOC levels increased with time. Although the formaldehyde level was at 0.12 ppm and TVOC level was at 0.0020 mg/m³ in the first hour, these levels increased to 0.36 ppm and 0.0030 mg/m³ in the 8th hour, respectively. Figure 9C shows that PM10 and PM2.5 levels were initially measured as 20 µg/m³ and 18 µg/m³, respectively, while these levels increased to 25 µg/m³ and 23 μg/m³ at the 4th hour. Variations in these levels were observed over time. However, the most dynamic changes were observed in Fig. 9D, where the humidity and temperature levels experienced significant fluctuations. While the humidity was at 48% and the temperature was 20.0 °C in the first hour, it increased to 50.8% and the temperature decreased to 19.6 °C in the 5th hour. According to Fig. 9E, the airflow velocity was initially measured as 4.1 m/s, decreased to 4.0 m/s at the 5th hour, and generally remained around 4.1 m/s. In Fig. 9F, the illumination level was initially at 508 lux, decreasing to 321 lux at the 5th hour and 298 lux at the 6th hour.

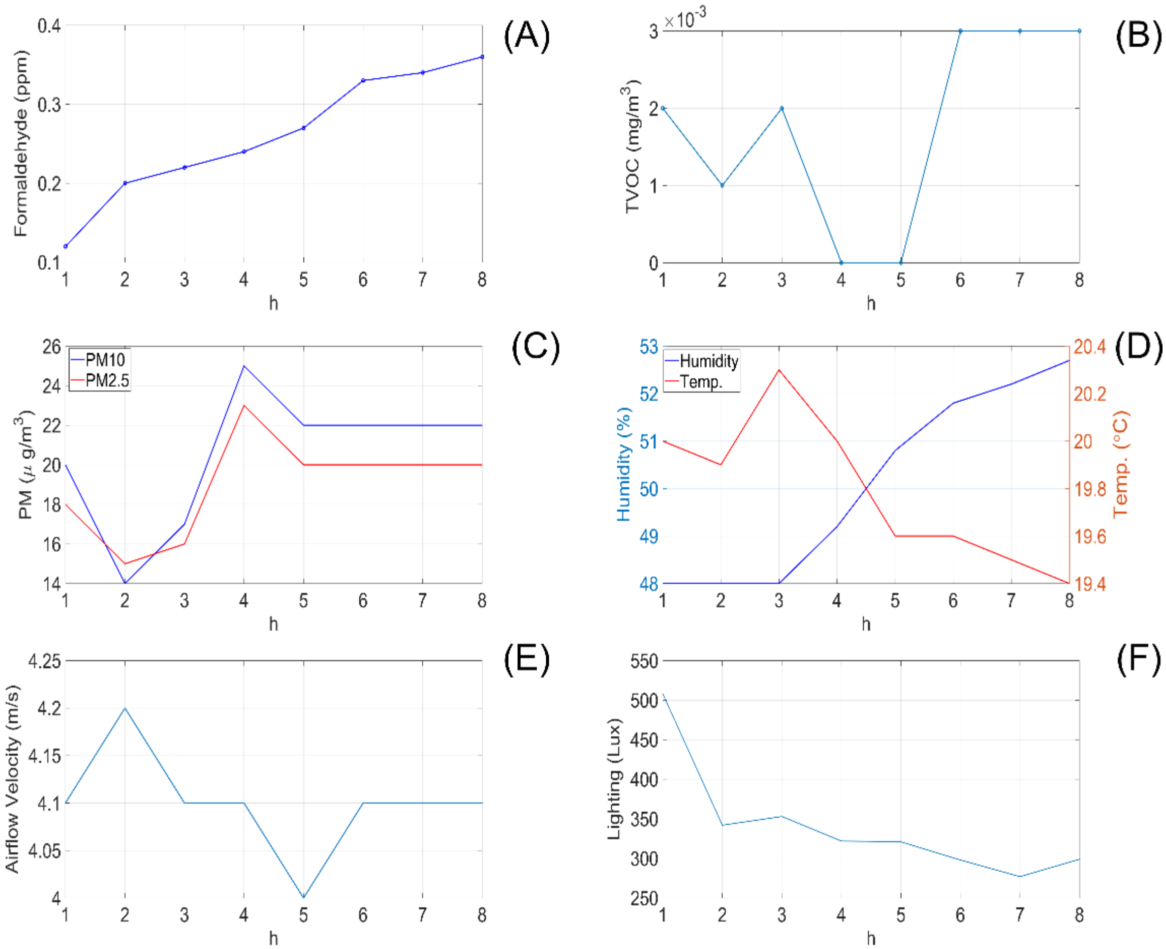

Fig. 9. Scenario 3 measurements (A: Formaldehyde; B: TVOC; C: PM; D: Humidity-Temperature; E: Airflow; and F: Lighting)

Scenario 4

The formaldehyde levels in Figs. 10A and 10B varied between 0.21 and 0.24 ppm. The TVOC levels initially measured at 0 mg/m³ and reached a maximum of 0.003 mg/m³. Figure 10C shows that the PM10 level was 16 μg/m³ and the PM2.5 level was 15 μg/m³ during the first hour. However, there was a notable decrease in both levels by the seventh hour. Based on Fig. 10D, the initial humidity level was 44.4% and subsequently increased to 52.3%. Similarly, the initial temperature was 21.6 °C and descended to 19.7 °C. The airflow velocity in Fig. 10E ranged from 3.5 to 6.78 m/s. The light levels in Fig. 10F ranged from 278 lux to 704 lux.

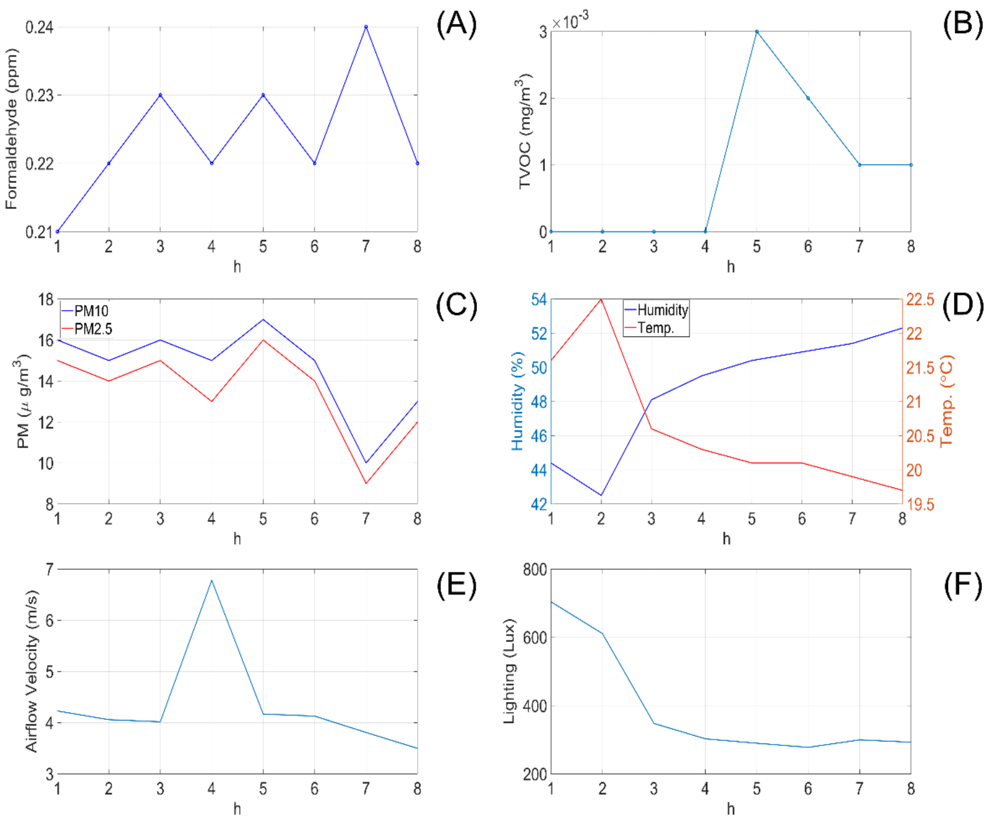

Fig. 10. Scenario 4 measurements (A: Formaldehyde; B: TVOC; C: PM; D: Humidity-Temperature; E: Airflow; and F: Lighting)

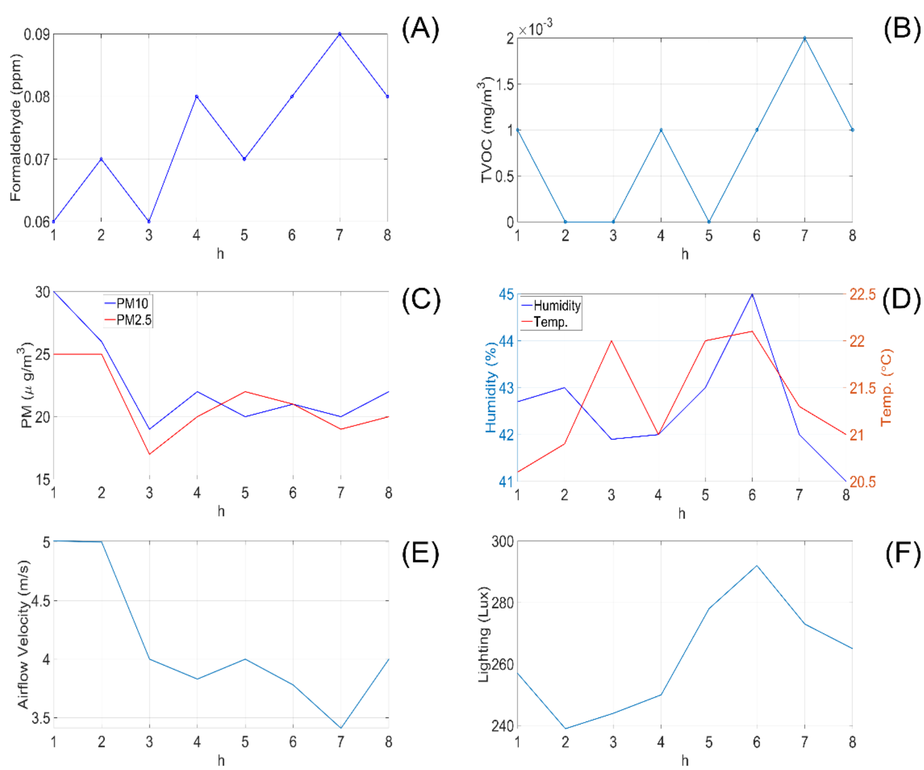

Fig. 11. Scenario 5 measurements (A: Formaldehyde; B: TVOC; C: PM; D: Humidity-Temperature; E: Airflow; and F: Lighting)

Scenario 5

The formaldehyde concentrations ranged from 0.06 to 0.09 ppm, whereas TVOC concentrations were measured between 0 and 0.002 mg/m³ (Figs. 11A and 1B). The PM10 concentrations, indicative of larger particulate matter, ranged from 19 µg/m³ to 30 µg/m³, whereas the PM2.5 values, which represent smaller particulate matter, ranged from 17 µg/m³ to 25 µg/m³ (Fig. 11C). The humidity ranged from 41% to 45%, and the temperature ranged from 20.6 °C to 22.1 °C (Fig. 11D). The airflow velocity ranged from 3.41 to 5.01 m/s, as shown in Fig. 11E. The light intensity was recorded within the range of 239 lux to 292 lux, as shown in Fig. 11F.

All measurements conducted for each scenario are collectively presented as a heatmap in Fig. 12. The figure illustrates the factors influencing indoor air quality across five different scenarios. In Scenario 1, the concentration of particulate matter (PM10 and PM2.5) was significantly higher compared to the other scenarios, where these levels were considerably lower. Relative humidity generally ranged between 40% and 62%, while the temperature remained stable at 16 to 22°C. Lighting levels exhibited a general decreasing trend across all scenarios. Notably, Scenario 3 showed a significant increase in formaldehyde concentrations. The formaldehyde level, measured at 0.12 ppm in the first hour, rose to 0.36 ppm by the 8th hour, indicating a substantial shift in air quality over time.

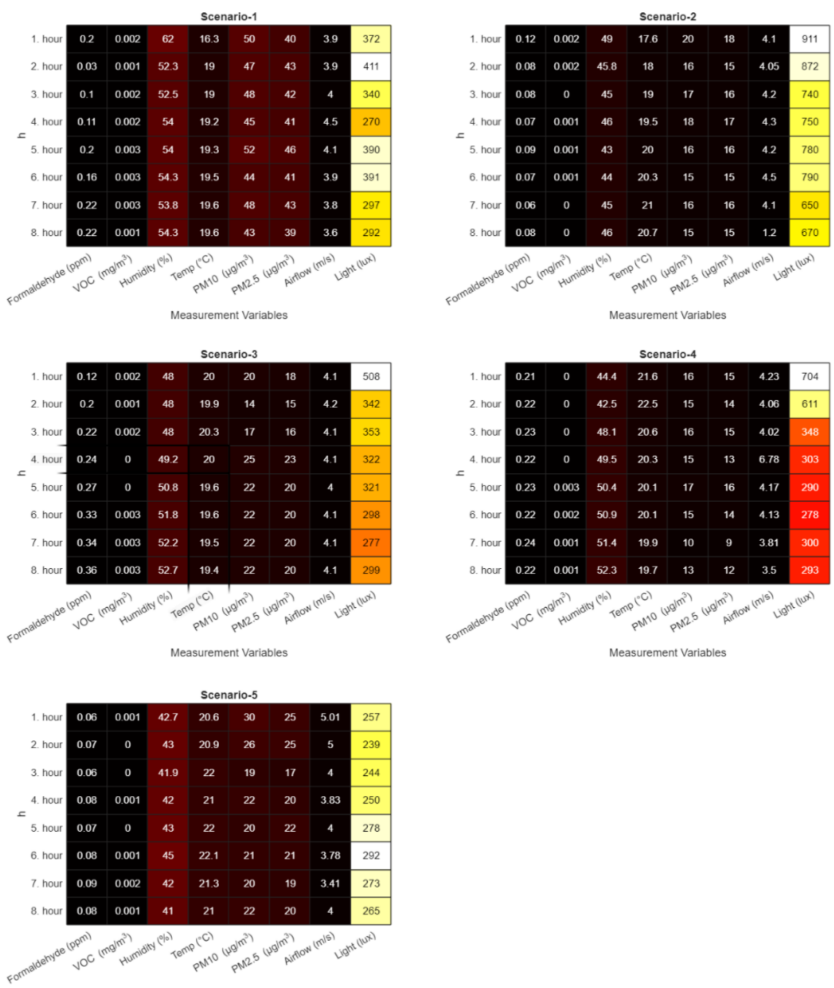

Fig. 12. Heatmap representation of measurements across all scenarios

Statistical Analysis: Scenarios Analysis

This study utilized ANOVA and Duncan tests to identify significant disparities among measurement outcomes in five distinct scenarios. The findings of these examinations are presented in Table 1.

The differences in the number of measurements conducted across various scenarios stem from the requirements of the experimental design. In specific scenarios (*e.g.*, Scenario 1, Scenario 3, and Scenario 4), 9 measurements were performed to enable a more detailed analysis of potential variations in variables such as formaldehyde, PM10, PM2.5, humidity, temperature, and lighting. Additionally, these measurements enhanced the reliability of the data through control measurements. These scenarios exhibited more significant variability and potential trends in specific variables, necessitating additional measurements. Conversely, in other scenarios (e.g., Scenario 2 and Scenario 5), 8 measurements were deemed sufficient, as these scenarios demonstrated less variability and met the experimental requirements. This approach ensured data accuracy and an adaptive methodology tailored to the specific needs of each scenario.

Table 1. Comparison of Formaldehyde Measurements in Different Scenarios

ANOVA					
Formaldehyde	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.214	4	.053	21.218	<.001
Within Groups	.096	38	.003		
Total	.310	42			

Duncan[a,b]				
Scenario	N	Subset for alpha = 0.05		
		1	2	3
Scenario 5	8	.073		
Scenario 2	8	.081		
Scenario 1	9		.157	
Scenario 4	9			.212
Scenario 3	9			.254
Sig.		0.759	1.000	0.090

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 8.571
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed

One-way ANOVA revealed a significant difference in formaldehyde levels, as indicated by an F value of 21.218 and a p-value of less than 0.001. This significant difference, with a confidence level of 95%, indicates substantial variation between at least one of the five situations and the others. Scenarios 5 and 2 had the lowest formaldehyde levels, whereas Scenarios 3 and 4 had the highest formaldehyde levels. Scenario 1 exhibits a moderate formaldehyde concentration. Table 2 compares the TVOC measurements under different scenarios.

Table 2 presents TVOC levels for different scenarios, which have significant implications. It shows that Scenario 1 had the highest average TVOC level, at 0.0022. Scenarios 3 and 4, with TVOC = 0.0018, were ranked second. Conversely, Scenarios 5 and 2 have the lowest average TVOC levels of 0.0008 and 0.0009, respectively. Table 3 compares the PM10 measurements under different scenarios.

Table 2. Comparison of TVOC Measurements in Different Scenarios

ANOVA					
TVOC	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.000	4	0.000	3.514	0.015
Within Groups	0.000	38	0.000		
Total	0.000	42			

Duncan[a.b]			
Scenario	N	Subset for alpha = 0.05	
		1	2
Scenario 5	8	0.0008	
Scenario 2	8	0.0009	
Scenario 3	9	0.0018	0.0018
Scenario 4	9	0.0018	0.0018
Scenario 1	9		0.0022
Sig.		0.054	0.387

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 8.571.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 3. Comparison of PM10 Measurements in Different Scenarios

ANOVA					
PM10	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4934.859	4	1233.715	46.068	<0.001
Within Groups	1017.653	38	26.780		
Total	5952.512	42			

Duncan[a.b]				
Scenario	N	Subset for alpha = 0.05		
		1	2	3
Scenario 4	8	14.888		
Scenario 2	8	16.625		
Scenario 3	9	20.111	20.111	
Scenario 5	9		22.500	
Scenario 1	9			44.000
Sig.		0.054	0.345	1.000

Means of groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 8.571.
b. Group sizes are unequal. The harmonic mean of the group sizes was used. Type I error levels are not guaranteed.

The PM10 values were determined, and the scenarios were ranked based on the data presented in Table 3. The highest PM10 levels were found in Scenario 1, with an average of 44.000. The second highest levels were observed in Scenario 5, with an average of 22.500. The third highest levels were observed in Scenarios 3 and 2, with averages of 20.111 and 16.625, respectively. The lowest PM10 levels were recorded in Scenario 4, with an average of 14.888. Table 4 compares the PM2.5 values for different scenarios.

Table 4. Comparison of PM2.5 Measurements in Different Scenarios

ANOVA						
PM2.5	Sum of Squares		df	Mean	F	Sig.
Between Groups	3637.099		4	909.275	46.735	<0.001
Within Groups	739.319		38	19.456		
Total	4376.419		42			
Duncan[a.b]						
Scenario	N	Subset for alpha = 0.05				
		1	2	3	4	
Scenario 4	8	13.777				
Scenario 2	8	16.000	16.000			
Scenario 3	9		18.666	18.666		
Scenario 5	9			21.125		
Scenario 1	9				39.111	
Sig.		0.304	0.218	0.256	1.000	

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 8.571.
b. The group sizes are unequal. The harmonic mean of the group sizes is used.
Type I error levels are not guaranteed.

The data presented in Table 4 are the results of a thorough research, showing that Scenario 1 had the highest average PM2.5 level (39.1), while Scenario 5 had the second highest average level at 21.1. Scenarios 3 and 2 obtained the third highest rankings, with PM2.5 levels of 18.7 and 16.0, respectively. The lowest average PM2.5 level was observed in Scenario 4, measuring 13.8. Table 5 compares the humidity measurements for different scenarios. According to the Duncan test results presented in Table 5, the scenarios can be ranked in the following order: Scenario 1 had the highest mean value of 54.9, followed by Scenario 3, which had a mean value of 50.6.

Table 5. Comparison of Humidity Measurements in Different Scenarios

ANOVA						
Humidity	Sum of Squares		df	Mean Square	F	Sig.
Between Groups	761.402		4	190.350	28.174	<0.001
Within Groups	256.739		38	6.756		
Total	1018.140		46			
Duncan[a.b]						
Scenario	N	Subset for alpha = 0.05				
		1	2	3	4	
Scenario 5	8	42.575				
Scenario 2	8		45.475			
Scenario 4	9			49.211		
Scenario 3	9			50.633		
Scenario 1	9				54.866	
Sig.		1.000	1.000	0.264	1.000	

Means for groups in homogeneous subsets are displayed. a. Uses Harmonic Mean Sample Size = 8.571. b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Scenario 4 took the third place with a mean value of 49.2, while Scenario 2 followed with the fourth highest mean value of 45.5. Finally, Scenario 5 has the lowest mean value of 42.6. Table 6 compares the temperature measurements.

Table 6 indicates that the data objectively show that Scenario 5 had the highest average temperature level (21.4), followed by Scenario 4 with the second highest value (20.3). Scenarios 2 and 3 both obtained an average of 19.5, which ranks them third. Scenario 1 had the lowest average temperature of 18.8 °C. Table 7 compares the airflow measurements for different scenarios.

Table 6. Comparison of Temperature Measurements in Different Scenarios

ANOVA					
Temp.	Sum of Squares	df	Mean	F	Sig.
Between Groups	32.017	4	8.004	7.041	<0.001
Within Groups	43.201	38	1.137		
Total	75.218	42			

Duncan^{a,b}				
Scenario	N	Subset for alpha = 0.05		
		1	2	3
Scenario 1	8	18.788		
Scenario 3	8	19.511	19.511	
Scenario 2	9	19.512	19.512	
Scenario 4	9		20.277	
Scenario 5	9			21.362
Sig.		0.193	0.168	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 8.571.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 7. Comparison of Airflow Measurements in Different Scenarios

ANOVA					
Air Flow	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.030	4	0.258	0.532	0.713
Within Groups	18.400	38	0.484		
Total	19.431	42			

The ANOVA revealed no statistically significant differences between the airflow levels and the groups (F = 0.532, p = 0.713). Therefore, the Duncan test was not executed. The illumination measurements for multiple scenarios are presented in Table 8.

According to Table 8, the mean values followed a clear hierarchy: Scenario 2 had the highest mean value (770), followed by Scenario 4 (388), Scenario 1 (353), Scenario 3 (338), and Scenario 5 (262). At the specified significance level ($\alpha = 0.05$), a statistically significant difference was found only between Scenarios 2 and 4 ($p = 0.058$), while the differences between the other scenarios were not significant ($p > 0.05$).

Table 8. Comparison of Lighting Measurements for Different Scenarios

ANOVA					
Lights	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1291315.044	4	322828.761	38.739	<0.001
Within Groups	316667.375	38	8333.352		
Total	1607982.49	42			

Duncan[a,b]				
Scenario	N	Subset for alpha = 0.05		
		1	2	3
Scenario 5	8	262.25		
Scenario 3	8	338.00	338.00	
Scenario 1	9	353.00	353.00	
Scenario 4	9		387.67	
Scenario 2	9			770.38
Sig.		0.058	0.296	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 8.571.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

The formaldehyde measurements showed the lowest concentrations in Scenarios 5 and 2, depending on the various scenario. A key finding of this research was that wooden toys are likely to absorb formaldehyde, a significant discovery that could have implications for children's health. Wooden toys have the potential to absorb formaldehyde due to the chemical composition of wood, which includes cellulose, hemicellulose, and lignin. These components can chemically react with formaldehyde, binding it within the wood structure. Additionally, the porous nature of wood facilitates the physical absorption of formaldehyde molecules. Studies suggest that lignin, a major component of wood, can engage in chemical interactions with aldehydes, including formaldehyde, reducing its concentration in the surrounding air. The moisture content and specific species of wood further influence its capacity for formaldehyde absorption, as these factors affect the reactivity and porosity of the material (Salem and Böhm 2013).

According to the data, a significant increase in formaldehyde levels was observed in Scenario 3. The formaldehyde concentration, initially measured at 0.12 ppm in the first hour, showed a continuous rise throughout the observation period, reaching 0.36 ppm by the eighth hour. In contrast, formaldehyde levels in the other scenarios remained relatively stable. TVOC measurements, on the other hand, were consistently very low across all scenarios and did not exhibit any notable upward trend. The occasional observation of zero values suggests that TVOC levels were well-controlled or that sources of volatile organic compounds in the environment were limited.

A cross-scenario evaluation indicates that the increase in formaldehyde levels in Scenario 3 can be assessed independently of temperature variations. While formaldehyde levels exhibited a consistent rise in this scenario, temperature values remained within a stable range (19.4 to 20.3°C). This stability suggests that the formaldehyde increase in Scenario 3 was not influenced by temperature changes.

The second group comprises Scenario 1, which represents the complete classroom. The third group consists of Scenarios 4 and 3. The use of wooden toys, in addition to plastic ones, may have somewhat diminished the presence of formaldehyde. Arar and Jung (2021) found that formaldehyde levels in kindergarten facilities in the UAE were generally low, but there was a localized increase in certain regions. Abu Mansor *et al.* (2020) examined formaldehyde levels in nurseries in Malaysia and found that the concentrations generally ranged between 0.03 and 0.1 ppm, indicating some health risks. Almeida *et al.* (2011) found that formaldehyde levels in primary schools in Lisbon were between 0.01 and 0.08 ppm and that these levels can negatively affect children's health. Deng *et al.* (2015) examined formaldehyde levels in primary schools in China and found that the concentrations were generally below 0.05 ppm.

The highest TVOC values were found in Scenario 1, followed by Scenarios 3 and 4, with a small difference. The lowest values were found in Scenarios 5 and 2. The lowest TVOC values for Scenario 5 with wooden toys indicate that wood, as an organic material, does not contribute to the generation of volatile organic compounds. Bayati *et al.* (2021) conducted a comprehensive study on the potential effects of VOC levels on children's health in day care centers in the USA. Their findings indicated that VOC levels could increase the risk of respiratory disorders, underscoring the need for further research and immediate action. Sousa *et al.* (2012) found that the VOC levels in kindergarten facilities in Porto could negatively affect children's health.

In Scenario 1, PM10 levels ranged between 50 to 52 µg/m³ and PM2.5 levels ranged between 40 to 46 µg/m³, indicating that PM levels were higher in the original classroom layout than in the other scenarios. Furniture and other household items in the classroom increase airborne particulate matter concentrations. In Scenario 2, PM levels were lowest, indicating that furniture and toys contribute significantly to the release of particulate matter. In Scenario 3, PM levels were higher than those in the scenarios with wooden toys, indicating that plastic toys contribute more to particulate matter emissions. In Scenario 4, PM levels were lower than those in the scenario with a high concentration of plastic toys, indicating that wooden toys can reduce the release of particulate matter. In Scenario 5, the PM2.5 level was low, but the PM10 level varied. Wooden toys can reduce particulate matter release, but other factors also influence PM10 levels. Basińska *et al.* (2021), in their study of nurseries, found that PM10 concentrations were below 50 µg/m³ in all nursery rooms, but PM2.5 concentrations (> 25 µg/m³) were high. This finding is similar to the results in Scenario 1 and highlights the potential impact of IAQ on children's health. This research is crucial for understanding and improving indoor air quality in classrooms, and its implications are significant for educators, parents, and researchers.

The lowest humidity measurements were observed in Scenario 5 (with only wooden toys and materials). This finding has practical implications, indicating that wood, as an organic material, continues to exchange moisture, which can affect the overall humidity in indoor environments. The highest temperature measurement value was also found in Scenario 5, which can be explained by the natural structure of wood, which has a warm texture. This finding is relevant for designing indoor spaces because it indicates that the selection of materials can affect the ambient temperature. In comparison, Yun *et al.* (2014) evaluated the thermal comfort of kindergarten children in naturally ventilated classrooms in Seoul, Korea and found that the average temperature was lower than that in this study in Ayancık, Sinop (Yun *et al*.: 17.9 °C, this study: 20.6 °C). These differences may be due to different climatic conditions or ventilation and heating systems. The mean humidity values in the study by Yun *et al*. (2014) were higher than those in this study, while airflow velocities varied within a narrower range (Yun *et al.*: maximum 4.5 m/s, this study: maximum 5.01 m/s). The mean airflow velocities were found to be close to each other.

Based on the lighting measurements for the different scenarios, Scenario 1 had the highest minimum and maximum illumination levels, indicating that the classroom is well lit and visual comfort is ensured. This is in line with the recommended lighting levels for a typical classroom. Scenario 2 had the lowest minimum and maximum illumination levels, indicating that the classroom was poorly lit and potentially fell below the recommended levels. Scenario 3 had moderate lighting levels that meet the standard requirements. Scenario 4 provided adequate and balanced lighting to meet the lighting requirements of the environment with various types of toys. Scenario 5 had the highest illumination levels, indicating that the environment with wooden toys was the best-lit environment. Overall, Scenario 1 and Scenario 5 had the highest illumination levels, and Scenario 2 had the lowest. Observing changes in lighting levels is important for ensuring optimal lighting conditions for children. It should be kept in mind that lighting varies depending on the time of day, season, and weather. Although the minimum illumination levels were higher in this study, the maximum illumination levels were higher in Gulbinas and Petuhova (2019) study. The average illumination levels were similar in both studies, indicating that both studies have similar goals to improve the quality of lighting in educational environments.

CONCLUSION

1. This study's findings were significant with respect to improving IAQ in kindergarten environments and establishing a foundation for future research. Careful design and material selection are crucial for protecting children's health and supporting their development.
2. Wood materials offer a practical solution to reducing formaldehyde and TVOC emissions and lowering particulate levels. They have the potential to enhance children's health and visual comfort.
3. Optimizing natural and artificial ventilation and selecting toys and furniture from materials that minimize formaldehyde and TVOC emissions can improve IAQ and reduce children's exposure to harmful substances.
4. This study has revealed significant results regarding the IAQ of kindergarten classrooms by evaluating parameters such as formaldehyde, TVOC, PM10, PM2.5, humidity, temperature, air flow rate, and lighting levels. These findings emphasize that the materials and arrangements used in kindergarten facilities have a significant impact on indoor air quality.
5. The study evaluated the chemical emissions of plastic toys and the health benefits of wooden toys. Other pollutants, such as PM10 and PM2.5, indoor temperature, humidity, airflow rate, and lighting levels, have also been analyzed.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude to the management and staff of Sinop Ayancık Zübeyde Hanım Kindergarten, T.C. Ministry of National Education, for their support in realizing this study.

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Article submitted: September 19, 2024; Peer review completed: November 15, 2024; Revised version received and accepted: November 17, 2024; Published: December 5, 2024.
DOI: 10.15376/biores.20.1.1088-1109