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Health risk assessment of indoor air quality and its association with sick building syndrome symptoms among workers

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ABSTRACT

Background: Poor indoor air quality can harm human health. A closed indoor work environment and an inadequate ventilation system can increase the risk of sick building syndrome symptoms. This study aims to analyze the most significant risk factors with symptoms of sick building syndrome in workers at PT X. **Methods:** The study used a cross-sectional study design, and the data was processed with the chi-square test and multiple logistic regression tests with a sample of all production area workers at PT X. A total of 91 workers included in this study. Carbon monoxide, temperature, humidity, PM10 and formaldehyde were measured using a particle counter and wind speed was measured using an anemometer. Measurements were taken at 17 different points. **Findings:** The results showed that 85 out of 91 workers (93.4%) experienced symptoms of sick building syndrome. There is a relationship between temperature (p-value=0.013) and wind speed (p-value=0.031) symptoms of sick building syndrome. The most dominant variable is the formaldehyde (POR=0.457). **Conclusion:** It is concluded that the variables associated with symptoms of sick building syndrome are temperature and wind speed, with formaldehyde being the most dominant. The company is advised to monitor indoor air quality regularly and improve the ventilation system at the production area. **Novelty/Originality of this Study:** This study provides valuable insights into the relationship between environmental factors such as temperature, wind speed, and formaldehyde with sick building syndrome symptoms in a production environment, highlighting the need for regular indoor air quality monitoring and improved ventilation systems to safeguard worker health.

KEYWORDS: indoor air quality, sick building syndrome, workers.

1. Introduction

Sick Building Syndrome is a group of symptoms that affect building occupants while they are inside the building, and these symptoms disappear when they leave the building (EPA, 2023). Sick Building Syndrome has varying symptoms in the respiratory system, eyes, skin, throat, as well as general symptoms such as dizziness and difficulty concentrating (Molina et al., 1989). The typical symptoms of Sick Building Syndrome (SBS) include dizziness, eye irritation (itchy, watery, and red eyes), nose irritation (runny nose and sneezing), dry throat, dry cough, dry or itchy skin, nausea, difficulty concentrating, fatigue, and sensitivity to odors (Smajlović et al., 2019).

Indoor air quality is a crucial aspect because most people spend approximately 90% of their time indoors, either at home or at work (Tran et al., 2020). Indoor pollutant levels can

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be 2 to 5 times higher than outdoor pollutant levels, and potentially 100 times worse (IQAIR, 2018). The concentration of indoor pollutants has increased in recent decades due to several factors such as inadequate ventilation systems for air exchange and the increased use of synthetic building materials, furniture, pesticides, personal cleaning products, and household cleaners (United States Environmental Protection Agency, 2023). Individuals in spaces with air conditioning (AC), exposed to gases for long periods, or workers exposed to particulate matter in industries are at higher risk of developing Sick Building Syndrome due to poor indoor air quality (Gopalakrishnan et al., 2021).

SBS is caused by several factors, such as the building's location, work climate, building materials, humidity, contaminant sources, occupant activities, and inadequate ventilation systems that prevent proper air exchange, leading to SBS in building occupants (Nag, 2019). Individual characteristics (such as age, gender, psychological status, and length of employment) may contribute to the symptoms of SBS (Karlina et al., 2021). Sick Building Syndrome has a significant impact on companies and employees, both in terms of health and productivity. A decrease in productivity can occur because employees who often feel unwell tend to be less focused and productive in their work. Additionally, employee absenteeism can increase, affecting the company's operations (Ganji et al., 2023).

PT X is a company engaged in soap production and household cleaning products, located in North Jakarta, Special Capital Region of Jakarta. Based on a preliminary study, the air quality in the factory is quite poor due to inadequate ventilation. This affects the indoor air quality, especially since workers spend long hours indoors. Such conditions put workers at risk of health issues, including SBS symptoms. Based on preliminary study results regarding SBS symptoms experienced by workers at PT X, it was found that 87.5% of 8 sampled workers reported experiencing Sick Building Syndrome symptoms in the last three months. The symptoms most commonly reported were fatigue, drowsiness, dry/scratchy throat, dry skin, eye irritation, poor concentration, and a runny nose. These symptoms were felt while working in air-conditioned rooms, and gradually disappeared after leaving the room.

1.1 Theory

SBS is a condition in which occupants of a room or building experience acute health issues related to the amount of time spent in that space (Aurora, 2021). SBS is a collection of health disturbances experienced by people within a building, which may be related to the duration of time spent inside the building (Karlina et al., 2021). The acute health effects and discomfort of SBS appear when a person spends a certain amount of time or duration inside a building, but the causes of SBS are difficult to identify clearly (Marmot et al., 2006). Based on the explanations above, it can be concluded that SBS is a condition in which a set of complaints/symptoms arise without a clearly identifiable cause or disease, related to factors such as the duration of time a person spends indoors, poor air quality, and individual factors.

SBS can be identified when building occupants experience a series of common symptoms that cause discomfort and a sense of being unwell. The symptoms of Sick Building Syndrome tend to worsen with the duration of time a person spends in the building, and when the person is away from the building (WHO – CEPIS, 2008). Sick Building Syndrome/SBS can have a significant impact on employee absenteeism due to illness and productivity at the workplace. SBS refers to a series of symptoms experienced by individuals working or living inside a building, which is often associated with poor indoor air quality. These symptoms can include headaches, eye irritation, respiratory issues, fatigue, and other discomforts.

In addition, Indoor Air Quality (IAQ) is a key factor that plays a role in the incidence of SBS. SBS refers to a set of health symptoms that appear in building occupants, and IAQ is one of the main triggers. Disruptions in indoor air quality can involve various elements, such as air pollutant levels, inadequate ventilation or microbial contamination. Therefore, understanding the link between IAQ and SBS is crucial to identify and address potential health risks that may arise in the work environment.

IAQ is a condition that describes the air quality in a closed indoor environment based on thermal, comfort (temperature and humidity) and pollutant concentrations (Güneş et al., 2022). Indoor Air Quality is what describes the air quality of the space inside an appropriate building based on the activities and comfort of the building occupants (Rahmawati et al., 2022). Healthy IAQ is defined by indoor air conditions that do not contain harmful substances and do not cause discomfort in at least 80% of workers in the workplace. Based on some of the definitions above, it can be concluded that Indoor Air Quality is an indoor air condition that is influenced by various factors.

2. Methods

The variables studied consist of independent (explanatory) variables, which include carbon monoxide, temperature, humidity, PM10, formaldehyde, wind speed (Indoor Air Quality), and individual factors such as age, gender, and length of employment (Figure 1). The dependent variable is the Sick Building Syndrome symptoms. Environmental factors include physical, biological, and chemical factors. This study is a quantitative research with a cross-sectional design, as it can describe the conditions and characteristics of the research population and can be applied to large populations. This design was chosen because the research is conducted at a single point in time, and the outcomes are issues that are commonly found. Additionally, the use of a cross-sectional study design is due to the relevance of Sick Building Syndrome as a case within the population. The population of this study consists of workers at PT X, who work in the production area, totaling 91 workers. Additionally, 17 points were selected for measuring the independent variables.

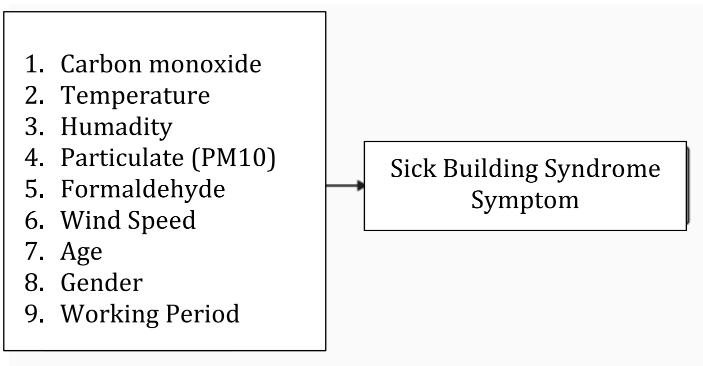

Fig. 1. Conceptual framework

The research was conducted from October to December 2023. The study will be carried out on workers at PT X, located in North Jakarta, Special Capital Region of Jakarta. The data collection method used in this study is primary data. Primary data are the data collected through questionnaires filled out by workers regarding Sick Building Syndrome symptoms, age, gender, length of employment, as well as direct observations by the researcher, including measurements of carbon monoxide, temperature, humidity, PM10, formaldehyde, and wind speed. This analysis aims to provide an overview of the characteristics of the independent variables. The analysis will produce the distribution and percentage of workers at PT X. A univariate analysis will also be used to examine the relationship between the independent and dependent variables, specifically Sick Building Syndrome symptoms.

This analysis is useful for understanding the relationship between independent and dependent variables. The relationship between these two categorical variables can be tested using the chi-square test. The confidence level is 95%, with the assumption that the data analyzed are categorical. If the statistical test results show a p value ≤ 0.05, it means that there is a significant relationship between the independent variable and the dependent variable, and vice versa. Multivariate analysis is an advanced analysis from the bivariate analysis. This analysis is used to identify which independent variable most influences the dependent variable. In this study, multivariate analysis will be conducted using multiple logistic regression, which is a predictive analysis model aimed at studying the relationships between several variables and attempting to identify the relationships between independent variables.

3. Results and Discussion

3.1 Univariate analysis

Univariate analysis aims to determine the distribution and frequency of data for the independent variables (carbon monoxide, temperature, humidity, PM10, formaldehyde, wind speed, age, gender, and length of employment) and the dependent variable of the study, which is the symptoms of Sick Building Syndrome. The respondents obtained in this study were 91 respondents, who are workers in the production area of PT X. This table shows the frequency distribution of SBS symptoms among PT X workers. Of the 91 workers surveyed, 85 (93.4%) experienced SBS symptoms, while only 6 (6.6%) did not (Table 1). This data indicates that the majority of workers at PT X experience the impact of their work environment, potentially due to indoor air quality factors or building conditions that are less supportive of health.

Table 1. Frequency distribution of sick building syndrome symptoms among workers at PT X.

Sick building syndrome sypmtom	Amount of worker (n)	Percentage (%)
Yes	85	93.4
No	6	6.6
Total	91	100

Furthermore, Table 2 presents the frequency distribution of indoor air quality at PT X based on several environmental variables. The results show that all air samples (100%) contain carbon monoxide that does not meet the standard. In addition, most workers are exposed to temperature (80.2%) and humidity (93.4%) that do not meet the standard. PM_{10} particles showed a better compliance rate, with 63.7% meeting the standard. Meanwhile, formaldehyde did not meet the standard in 60.4% of cases, and wind speed was relatively more balanced with 54.9% meeting the standard. This data indicates a potential health risk due to suboptimal air quality at PT X.

Table 2. Frequency distribution of indoor air quality at PT X.

Variable	Amount (n)	Percentage (%)
Carbon monoxide		
According to standard	0	0
Not according to standard	91	100
Temperature		
Not according to standard	73	80.2
According to standard	18	19.8
Humidity		
Not according to standard	85	93.4
According to standard	6	6.6
PM_{10}		
Not according to standard	33	36.3
According to standard	58	63.7
Formaldehyde		
Not according to standard	55	60.4
According to standard	36	39.6
Wind speed		
Not according to standard	41	45.1
According to standard	50	54.9

Table 3 illustrates the frequency distribution of individual characteristics of workers at PT X based on age, gender, and length of service. The majority of workers (63.7%) are ≤33 years old, while the other 36.3% are more than 33 years old. In terms of gender, the majority of workers are male (67%), while only 33% are female. Based on length of service, workers with more than 8 years of experience were slightly more numerous (51.6%) than those with ≤8 years of service (48.4%). This data provides an overview of workers' demographics, which can be an important factor in further analysis of their working conditions and welfare.

Table 3. Frequency distribution of the characteristic of at individual worker at PT X

Variable	Amount (n)	Percentage (%)
Age		
> 33 years	33	36.3
≤ 33 years	58	63.7
Gender		
Woman	30	33
Man	61	67
Working period		
> 8 years	47	51.6
≤ 8 years	44	48.4

3.2 Bivariate analysis

Bivariate analysis is conducted between the dependent and independent variables (Indoor Air Quality), namely temperature, humidity, PM10, formaldehyde, and wind speed. This is done to examine the relationship between each independent variable of Indoor Air Quality and the dependent variable. This table presents the results of bivariate analysis between SBS symptoms as the dependent variable and indoor air quality as the independent variable, which includes temperature, humidity, PM_{10}, formaldehyde, and wind speed. This analysis aimed to evaluate the relationship between each air quality variable and the incidence of SBS in workers. The results showed that some variables, such as temperature and wind speed, had a significant association with the incidence of SBS, as indicated by a P-value below 0.05. Meanwhile, humidity, PM_{10}, and formaldehyde did not show a significant relationship with the incidence of SBS. These findings may provide insights into environmental factors that could potentially affect the health of workers in buildings.

Table 4. The result of bivariate analysis

Variable	SBS symptom						p-value	POR (95% CI)
	Yes		No		Total			
	N	%	N	%	N	%		
Temparature								
Not according to standard	71	97.3	2	2.7	73	100	0.013	10.143
According to standard	14	77.8	4	22.2	18	100		(1.691–60.843)
Humidity								
Not according to standard	79	92.9	6	7.1	85	100	1.000	0.929
According to standard	6	100	0	0	6	100		(0.877–0.985)
PM_{10}								
Not according to standard	32	97	1	3	33	100	0.411	3.019
According to standard	53	91.4	5	8.6	58	100		(0.337–27.012)
Formaldehyde								
Not according to standard	53	96.4	2	3.6	55	100	0.209	3.313
According to standard	32	88.9	4	11.1	36	100		(0.574–19.123)
Wind speed								
Not according to standard	41	100	0	0	41	100	0.031	1.36
According to standard	44	88	6	12	50	100		(1.026–1.259)

The relationship between various environmental factors and SBS in workers at PT X was analyzed using bivariate analysis. The results showed that temperature had a significant relationship with SBS, where 71 out of 91 workers (97.3%) in rooms with non-standard temperatures experienced SBS symptoms more often than workers in rooms with standard temperatures. The chi-square test yielded a p-value of 0.013 (<0.05), confirming a statistically significant relationship between temperature and SBS symptoms (Table 4).

However, humidity showed no significant correlation with SBS. Although 79 out of 91 workers (92.9%) in rooms with nonstandard humidity levels experienced SBS symptoms more frequently, the chi-square test results (p-value=1.000>0.05) showed no statistically significant association. Similarly, PM10 levels were not significantly associated with SBS, as 53 out of 91 workers (91.4%) in rooms with standard PM10 levels experienced SBS, but the chi-square test results (p-value=0.411>0.05) did not confirm a significant correlation. Likewise, formaldehyde concentration did not show a significant association with SBS, although 53 out of 91 workers (96.4%) in rooms with nonstandard formaldehyde levels experienced symptoms. The chi-square test result (p-value=0.209>0.05) showed no statistical significance. On the other hand, wind speed showed a significant correlation with SBS. Among the workers, 44 out of 91 (88%) in rooms with standard wind speed experienced SBS, while all 41 workers (100%) in rooms with nonstandard wind speed reported symptoms. The chi-square test yielded a p-value of 0.031 (<0.05), indicating a significant association between wind speed and SBS symptoms at PT X (Table 4). These findings suggest that temperature and wind speed play an important role in influencing SBS symptoms, while humidity, PM10 level, and formaldehyde concentration showed no statistically significant impact.

3.3 Multivariate analysis

Multivariate analysis aims to identify the independent variable that has the most dominant influence on the dependent variable. In this study, multivariate analysis is performed using multiple logistic regression. Bivariate selection is done using the chi-square test to examine all the independent variables, namely carbon monoxide, temperature, humidity, PM10, formaldehyde, wind speed, age, gender, and length of employment. Variables with a p-value>0.25 cannot be included in the multivariate test because they do not meet the requirements for further modeling.

Table 5. The result of bivariat selection test

Variable	SBS symptom						*p-value*	POR (95% CI)	Explanation
	Yes		No		Total				
	N	%	N	%	N	%			
Temparature									
Not according to standard	71	97.3	2	2.7	73	100	0.013	10.143	Including
According to standard	14	77.8	4	22.2	18	100		(1.691–60.843)	modeling
Humidity									
Not according to standard	79	92.9	6	7.1	85	100	1.000	0.929	Excluding
According to standard	6	100	0	0	6	100		(0.877–0.985)	modeling
PM_{10}									
Not according to standard	32	97	1	3	33	100	0.411	3.019	Excluding
According to standard	53	91.4	5	8.6	58	100		(0.337–27.012)	modeling
Formaldehyde									
Not according to standard	53	96.4	2	3.6	55	100	0.209	3.313	Including
According to standard	32	88.9	4	11.1	36	100		(0.574–19.123)	modeling
Wind speed									
Not according to standard	41	100	0	0	41	100	0.031	1.36	Including
According to standard	44	88	6	12	50	100		(1.026–1.259)	modeling
Age									
> 33 years	32	97	1	3	33	100	0.411	3.019	Excluding
≤ 33 years	53	91.4	5	8.6	58	100		(0.337–27.012)	modeling
Gender									
Woman	30	100	0	0	30	100	0.172	1.109	Including
Man	55	90.2	6	9.8	61	100		(1.021–1.025)	modeling

Working period									
> 8 years	46	97.9	1	2.1	47	100	0.103	5.897	Including
≤ 8 years	39	88.6	5	11.4	44	100		(0.661–52.643)	modeling

The results of the bivariate selection indicate that five variables—temperature, formaldehyde, wind speed, gender, and work duration—were included in the multivariate modeling, as they had p-values < 0.25. Meanwhile, the variables of age, humidity, PM10, and carbon monoxide were excluded from the multivariate test modeling because their p-values exceeded 0.25. In the multiple logistic regression modeling, candidate variables with p-values < 0.25 were analyzed together, followed by the stepwise elimination of variables with p-values > 0.05, starting with the highest p-value among them. After each elimination, the change in the Prevalence Odds Ratio (POR) was calculated. If eliminating a variable resulted in a POR change of more than 10%, the eliminated variable was reintroduced into the model, and the process continued with the next variable that had the highest p-value (Table 5). However, if the POR change was less than 10%, the analysis proceeded without reintroducing the eliminated variable.

Table 6. The result of final logistic regression modeling

Variable	SBS symptom				Unadjusted		Adjusted	
	Yes		No					
	N	%	N	%	POR (95% CI)	p-value	POR (95% CI)	p-value
Formaldehyde								
Not according to standard	53	96.4	2	3.6	3.313	0.209	0.457	1
According to standard	32	88.9	4	11.1	(0.574-19.123)		(0)	
Temparature								
Not according to standard	71	97.3	2	2.7	10.143	0.013	0.348	1
According to standard	14	77.8	4	22.2	(1.691–60.843)		(0)	
Wind speed								
Not according to standard	41	100	0	0	1.36	0.031	0	0.997
According to standard	44	88	6	12	(1.026–1.259)		(0)	
Gender								
Woman	30	100	0	0	1.109	0.172	0	0.998
Man	55	90.2	6	9.8	(1.021–1.025)		(0)	
Working period								
> 8 years	46	97.9	1	2.1	5.897	0.103		
≤ 8 years	39	88.6	5	11.4	(0.661–52.643)			
Age								
> 33 years	32	97	1	3	3.019	0.411		
≤ 33 years	53	91.4	5	8.6	(0.337–27.012)			
Humidity								
Not according to standard	79	92.9	6	7.1	0.929	1		
According to standard	6	100	0	0	(0.877–0.985)			
PM_{10}								
Not according to standard	32	97	1	3	3.019	0.411		
According to standard	53	91.4	5	8.6	(0.337–27.012)			

Based on the multivariate analysis using the multiple logistic regression model, the most dominant variable associated with Sick Building Syndrome symptoms among workers at PT X was formaldehyde. The Prevalence Odds Ratio (POR) for formaldehyde was 0.457, indicating that this variable had the strongest association with SBS symptoms (Table 6). This conclusion was also supported by substantial justification, reinforcing the significance of formaldehyde as the key factor in this study.

3.4 Discussion

SBS is a condition in which occupants of a room or building experience acute health problems related to the amount of time spent in the space (Aurora, 2021). The production area is a hazardous zone with various types of hazards that affect the safety and health of factory workers. One factor that can impact worker health is IAQ. Work areas with poor Indoor Air Quality that do not meet the standards will negatively affect the health and comfort of workers.

According to the research results from 91 respondents, 85 respondents experienced Sick Building Syndrome symptoms. Although there is no single cause for Sick Building Syndrome, poor indoor air quality is one of the main factors. According to Aziz et al. (2023), physical parameters such as humidity and temperature, and chemical pollutants such as carbon monoxide, formaldehyde, total volatile organic compounds, PM2.5, and PM10, are significantly related to the occurrence of Sick Building Syndrome in the work environment.

The standard carbon monoxide level in indoor spaces is less than 10 ppm. Indoor carbon monoxide mainly comes from combustion activities such as cooking or heating the space (WHO, 1999). Based on Table 6, all workers were in rooms with carbon monoxide levels within the standard. This is because there is no combustion process in the production process, nor are there any production processes that generate carbon monoxide. Meanwhile, the standard room temperature in industrial settings is between 23°C and 26°C. Based on Table 6, more workers were in rooms with temperatures outside the standard. Some production areas, such as the mixing area, refinery machines, and the sealer area, had high temperatures. This is because these areas are not equipped with air conditioning and only use fans and exhaust fans. In both high or low-temperature conditions, the body can feel more fatigued than usual and experience health disturbances, one of which is SBS symptoms (Hanifah, Rahman, and Tualeka, 2020).

Meanwhile, the standard humidity level in industrial settings is between 40% and 70%. Based on Table 6, more workers were exposed to humidity levels outside the standard. Humidity in the production area tends to exceed 70%. This is due to the inadequate ventilation system in the production area, which results in poor air circulation. According to Nopiyanti et al. (2019), workers in areas with humidity levels above 70% are four times more likely to experience SBS compared to workers in areas with humidity levels below 70%.

The standard PM10 level in industrial spaces is less than 0.15 mg/m^3. Based on Table 6, more workers were exposed to PM10 levels within the standard. This is because the production area is a closed space, and PM10 levels above the standard were only found in certain areas where activities generated airborne particulate dust, such as the mixing and sealer areas.

The standard formaldehyde level in indoor industrial spaces is less than 0.1 ppm. Based on Table 6, more workers were exposed to formaldehyde levels exceeding the standard. Formaldehyde is an indoor air pollutant that comes from building materials and can potentially cause health problems for building occupants. In the production area at PT X, formaldehyde comes from several chemicals used in soap production, such as additives and fragrances with strong odors. Additionally, some types of cardboard emit a strong glue or adhesive odor, which disrupts the comfort and health of workers.

Based on Table 6, most workers were in rooms with wind speeds within the standard (between 0.15 – 0.50 m/s). Wind speed plays an important role in various factors, including air pollution (Deng et al., 2020). Therefore, maintaining the correct wind speed in the production area is essential as it affects worker comfort and productivity. The univariate analysis revealed that more workers were over 33 years old than those under 33. This is because younger workers are often considered to have better energy and physical strength for tasks involving physical labor in production areas. It was also found that male workers dominate the workforce at PT X. This is because machine operator roles in production are primarily filled by male workers. Regarding length of service, more workers had more than 8 years of experience. This is due to the infrequent rotation of workers in the production area, where experienced workers are needed for specialized tasks.

3.4.1 Relationship between temperature and sick building syndrome symptoms

Based on bivariate analysis using the chi-square test, it shows that there is a statistically significant relationship between the temperature variable and Sick Building Syndrome symptoms in workers at PT X. Bardi et al. (2021) also state that there is a relationship between room temperature and SBS symptoms. According to the research results, the room temperature in the production area tends to be hot, with temperatures above 27°C. High temperatures can cause fatigue, discomfort, and concentration disturbances in workers.

Temperature outside the normal standard can affect worker performance. This factor can impact the efficiency and productivity of each worker (ILO, 2013). Temperature can influence the level of focus and work quality (Hanifah et el., 2020). This is because worker discomfort can interfere with concentration, affecting their performance in carrying out tasks. Additionally, workers who cannot work comfortably may experience a decrease in productivity. In high or very low-temperature conditions, the body can feel more fatigued than usual and experience health disturbances, one of which is SBS symptoms (Hanifah et al., 2020). Extremely high temperatures can cause dehydration if workers do not drink enough water, which can affect their health.

According to Ridwan et al. (2018), respondents working in rooms with temperatures above 25.50°C (i.e., not meeting the standards) are 4.386 times more likely to experience SBS symptoms compared to respondents working in rooms with acceptable temperatures. The temperature in the production area, especially in the mixing area, is above 30°C, which increases the likelihood of workers experiencing Sick Building Syndrome symptoms.

3.4.2 Relationship between humidity and sick building syndrome symptoms

Based on bivariate analysis using the chi-square test, it shows that there is no statistically significant relationship between the humidity variable and Sick Building Syndrome symptoms in workers at PT X. The standard humidity level in industrial settings is 40% – 70%. The research results show that a greater number of rooms had humidity levels outside the standard. A study by Saffanah & Pulungan (2017) indicates that there is no significant relationship between humidity and Sick Building Syndrome symptoms. This is supported by research from Hanifah et al. (2020), which also found no significant relationship between humidity and SBS symptoms.

Although statistical tests show no relationship between humidity and Sick Building Syndrome symptoms, more workers with non-standard humidity levels experienced SBS symptoms. This could be because workers are accustomed to high humidity levels and may have adapted to the conditions. The human body has the ability to adapt to certain conditions, although this ability to adapt varies between individuals. The production area at PT X tends to have humidity levels above 70%. According to Nopiyanti et al. (2019), workers in areas with humidity levels above 70% are four times more likely to experience SBS symptoms compared to workers in areas with normal humidity.

3.4.3 Relationship between PM10 and sick building syndrome symptoms

Based on bivariate analysis using the chi-square test, it shows that there is no statistically significant relationship between the PM10 variable and Sick Building Syndrome symptoms in workers at PT X. Research by Lestari (2024) also found no significant relationship between PM10 and Sick Building Syndrome symptoms. PM10 stands for Particulate Matter 10, which refers to airborne particles with a diameter of 10 micrometers or less. These particles consist of various substances such as dust, pollen, metals, and other chemicals. PM10 can remain in the air and be inhaled by humans, potentially affecting human health.

Based on the research results, the mixing area at PT X has the highest PM10 levels due to the use of powdered soap ingredients and inadequate ventilation. Fans cause powder particles from raw materials to become airborne in the mixing area. Non-standard PM10 levels can lead to irritation of the eyes, nose, and throat, while larger particles that enter the nose or throat are filtered by the body's natural defense system. Very fine particles can enter the respiratory system, potentially being absorbed into the bloodstream or causing lung problems (Environmental Protection UK, 2022). However, the bivariate analysis showed no relationship between PM10 and SBS symptoms because workers in the mixing area, who were exposed to the highest PM10 levels, were using respirator masks, which reduced the exposure's impact.

3.4.4 Relationship between formaldehyde and sick building syndrome symptoms

Based on bivariate analysis using the chi-square test, it shows that there is no statistically significant relationship between the formaldehyde variable and Sick Building Syndrome symptoms in workers at PT X. Guo et al. (2013) also state that there is no significant relationship between formaldehyde and Sick Building Syndrome symptoms. Formaldehyde is an indoor air pollutant that comes from building materials and can potentially cause health problems for building occupants. Sources of formaldehyde in indoor spaces include construction materials, insulation materials, finishes, combustion equipment, tobacco smoke, chemicals, and various other products (Australian Building Codes Board, 2021).

Based on the statistical test, there is no relationship between formaldehyde and Sick Building Syndrome symptoms. This is because some areas have low formaldehyde concentrations or levels within the standard, which are not high enough to cause SBS symptoms. The mixing area has high formaldehyde concentrations due to the use of soap raw materials that contain fragrances, dyes, and other additives. Exposure to formaldehyde can cause irritation to the respiratory system, eyes, and throat, and dizziness. Exposure to formaldehyde in the range of 0.05–0.5 ppm can cause eye irritation and irritation to the respiratory system.

3.4.5 Relationship between wind speed and sick building syndrome symptoms

Based on bivariate analysis using the chi-square test, it shows that there is a statistically significant relationship between the wind speed variable and Sick Building Syndrome symptoms in workers at PT X. Saffanah & Pulungan (2017) also state that there is a relationship between airflow speed and SBS occurrence in employees at the Indonesian Ministry of Health's PPSDM. Wind speed refers to the horizontal movement of air passing through a specific point (Deng et al., 2020). Wind speeds that do not meet standards can affect worker comfort. Wind speeds that are too high can cause workers to feel cold, especially if the workspace has low temperatures. Conversely, low wind speeds at high temperatures will make workers feel uncomfortable and sweaty.

Based on the research results, wind speed in the production area tends to be low, indicating poor air circulation in the area. Poor air circulation can cause pollutants to accumulate in the air. Pollutants such as dust, odors, and chemical compounds can negatively impact the health and comfort of workers. Low wind speeds may be caused by inadequate ventilation or a lack of fresh air supply (Savanti et al., 2019). Lack of ventilation can lead to an accumulation of carbon dioxide levels and high humidity, which can encourage the growth of mold and bacteria, posing a health risk to workers.

3.4.6 Interpretation of multivariate results

Based on the final model from multivariate analysis, it shows that rooms with formaldehyde levels meeting the standards are 0.46 times less likely to experience SBS symptoms compared to those with non-compliant formaldehyde levels. Formaldehyde can trigger SBS symptoms when exposure occurs at concentrations that exceed the standard limits (Seguel et al., 2017). High concentrations of formaldehyde in indoor environments can cause irritation to the respiratory system, eyes, and throat, and can lead to symptoms such as headaches, fatigue, and other health problems commonly associated with SBS. Additionally, formaldehyde is a volatile organic compound, meaning it can emit significant amounts of gas from building materials and chemicals (Syahzanan et al., 2021). This factor contributes to worsening indoor air quality and is considered one of the main causes of SBS.

The production area is the core area for soap manufacturing, where workers typically spend 7-8 hours per day. These workers work in spaces with inadequate air circulation. While air conditioning (AC) is available, it does not cover the entire production area, so the company installs fans in various spots. However, fans do not introduce fresh air or exhaust indoor air, so air exchange does not occur effectively. For example, the mixing area does not have AC, and the use of fans in this area causes soap powder materials to become airborne. This highlights that the ventilation system in the production area is insufficient.

In the production area, formaldehyde may originate from soap raw materials, colorants, additives, and fragrances. These materials may contain formaldehyde, or formaldehyde may be generated as a byproduct during the heating process in soap production. Additionally, formaldehyde can come from cardboard, which is made from paper and wood (Syahzanan et al., 2021). Elevated formaldehyde levels in rooms can also be influenced by high room temperatures (Australian Building Codes Board, 2021). The highest formaldehyde concentration measured in the production area was 0.37 ppm, significantly higher than the standard limit of 0.1 ppm. The research also found that the temperature in the production area tended to be high, exceeding 27°C, with the highest temperature in the mixing area reaching above 33°C. High temperatures contribute to increased formaldehyde concentrations in indoor spaces (Syahzanan et al., 2021).

Formaldehyde exposure can cause irritation in the respiratory system, eyes, and throat, as well as dizziness. Exposure to formaldehyde concentrations ranging from 0.05 to 0.5 ppm has the potential to cause eye and respiratory irritation. A study conducted on workers in Malaysia's production area found that formaldehyde exposure contributed to fatigue and throat irritation in workers (Syahzanan et al., 2021). The WHO has also stated that high formaldehyde levels can cause acute effects, including discomfort from odor, irritation in the upper respiratory tract and eyes, lung effects, and even eczema (WHO, 2010). Additionally, there is a strong link between formaldehyde and allergies, asthma, and respiratory issues (Australian Building Codes Board, 2021). These health effects are part of the common symptoms associated with Sick Building Syndrome.

Formaldehyde can also be carcinogenic to humans. Long-term exposure to formaldehyde can increase the risk of nasopharyngeal cancer and leukemia (Protano et al., 2022). Therefore, controlling formaldehyde exposure is essential for protecting human health. The company must ensure that formaldehyde concentrations inside the production area remain within the standard limit of 0.1 ppm, reducing the associated health risks. To achieve this, regular monitoring of formaldehyde levels in the production area is necessary. Additionally, routine health checks for workers should be conducted to detect any health issues that might arise from workplace exposure.

Formaldehyde is one of the 20 most widely produced industrial chemicals (Dan et al., 2020). Formaldehyde can enter the body through inhalation, ingestion, or skin contact (Tesfaye et al., 2021). According to Reingruber & Pontel (2018), the human body can be exposed to formaldehyde by inhaling or ingesting products containing formaldehyde, which can then be metabolized into formaldehyde. The different routes of exposure can lead to varying health effects.

The effects of formaldehyde exposure may vary from person to person. Several factors can influence an individual's response to formaldehyde exposure, including age, duration or intensity of exposure, and individual sensitivity. Children and the elderly are particularly vulnerable to formaldehyde exposure because children's immune systems are not fully developed, and older adults experience a decline in immune function (National Center for Environmental Health, 2016). Long-term exposure to higher concentrations of formaldehyde can increase the risk of adverse health effects (Reingruber & Pontel, 2018). Some individuals may be more susceptible to formaldehyde due to genetic factors, existing health conditions, and individual sensitivities to certain chemicals (National Center for Environmental Health, 2016).

4. Conclusions

Based on the research results regarding the analysis of IAQ and its relation to SBS symptoms among workers at PT X in 2023, the findings are as follows. 93.4% of workers at PT X experienced Sick Building Syndrome symptoms. 100% of the areas met the carbon monoxide concentration standards. 80.2% of the areas had temperatures not meeting the standard. 93.4% of the areas had humidity levels that did not meet the standard. 63.7% of the areas had PM10 concentrations that met the standard. Furthermore, 60.4% of the areas had formaldehyde concentrations that did not meet the standard. 54.9% of the areas had wind speed that met the standard.

The demographic characteristics of the workers at PT X showed that 63% were under 33 years of age. In terms of gender, 67% were male. Additionally, most workers had been employed for more than 8 years. A significant relationship was found between temperature and SBS symptoms in workers at PT X in 2023 ($p=0.013$). No significant relationship was found between humidity and SBS symptoms ($p=1.000$). There was no significant relationship between PM10 levels and SBS symptoms ($p=0.411$). No significant relationship was found between formaldehyde and SBS symptoms ($p=0.209$). A significant relationship was found between wind speed and SBS symptoms in workers at PT X in 2023 ($p=0.031$). The most dominant variable related to SBS symptoms was formaldehyde, with a POR (Prevalence Odds Ratio) of 0.457.

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