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# Assessing indoor air quality and its impact on sick building syndrome symptoms in an industrial work environment

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## ABSTRACT
**Introduction:** Poor indoor quality is known to adversely affect human health, especially in enclosed workspaces with inadequate ventilation. Such conditions can increase the likelihood of workers experiencing symptoms of Sick Building Syndrome (SBS). This study was conducted to examine the environmental risk factors that have the most influence on SBS symptoms in workers at PT X. **Methods:** The cross-sectional research design used included 91 workers in the PT X production area. Environmental measurements included carbon monoxide levels, temperature, humidity, PM10, and formaldehyde using a particle counter, and wind speed measurements using an anemometer. Data were collected from 17 predetermined points and analyzed using the chi-square test and multiple logistic regression. **Findings:** The results showed that 93.4% of participants (85 out of 91 workers) reported experiencing symptoms consistent with SBS. Statistical analysis showed a significant association between SBS symptoms and temperature (p=0.013) and wind speed (p=0.031). Among these variables, formaldehyde emerged as the most influential factor, with a Prevalence Odds Ratio (POR) of 0.457. **Conclusion:** The study concluded that temperature and wind speed were significantly associated with SBS symptoms, with formaldehyde as the dominant causal factor. It is recommended that companies implement regular indoor air quality monitoring and improve ventilation systems, especially in production areas, to reduce health risks for workers. **Novelty/Originality:** The novelty of this research lies in its specific and quantitative investigation of environmental risk factors influencing Sick Building Syndrome (SBS) in a real industrial workplace setting—namely, the production area of PT X.

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

## 1. Introduction

Air is one of the essential components of our needs as living beings. Most people are aware that only outdoor air pollution can affect their health, but poor indoor air conditions can also have significant health impacts. Outdoor air pollution can enter indoor spaces through ventilation, wall cracks, and gaps in doors and windows (EPA, 2023). This can affect indoor air quality.

Approximately 2.4 billion people worldwide cook over open flames or use stoves fueled by kerosene, biomass (wood, animal dung, and agricultural waste), and coal, which negatively impacts indoor air quality (WHO, 2022). In 2020, household air pollution was estimated to be responsible for 3.2 million deaths annually (WHO, 2022). In a hospital in South Jakarta, 31 people reported symptoms of Sick Building Syndrome (Ridwan et al., 2018).

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Sick Building Syndrome (SBS) is a collection of symptoms that affect building occupants while they are inside the building, with these symptoms disappearing once they leave (EPA, 2023). SBS presents various symptoms affecting the respiratory tract, eyes, skin, throat, and general conditions such as dizziness and difficulty concentrating (Molina et al., 1989). Typical symptoms of SBS include dizziness, eye irritation (itchy, watery, and red eyes), nasal 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 conditions are crucial because most people spend approximately 90% of their time indoors, either at home or at work (Van Tran et al., 2020). Indoor pollutant levels can be two to five times higher than outdoor levels and, in some cases, up to 100 times worse (IQAIR, 2018). Indoor pollutant concentrations have increased over the past few decades due to several factors, such as inadequate ventilation systems that fail to facilitate proper air exchange and the increased use of synthetic building materials, furniture, pesticides, personal care products, and household cleaners (United States Environmental Protection Agency, 2023). Individuals who stay in air-conditioned (AC) rooms for extended periods, those exposed to gases over long durations, and workers in industries with high particulate matter exposure are at a greater risk of developing Sick Building Syndrome due to poor indoor air quality (Gopalakrishnan et al., 2021).

Sick Building Syndrome (SBS) is caused by several factors, including building location, workplace climate, building materials, humidity, sources of contaminants, occupant activities, and inadequate ventilation systems, which prevent proper air exchange and contribute to SBS among building occupants (Nag, 2019). Individual characteristics such as age, gender, psychological status, and work duration may also contribute to SBS symptoms (Karlina et., 2021).

SBS has a significant impact on both companies and workers, affecting health and productivity. A decline in productivity can occur because workers who frequently feel unwell tend to be less focused and efficient in their tasks. Additionally, increased worker absenteeism can disrupt company operations (Ganji et al., 2023). PT X is a company engaged in the production of soap and household cleaning products, located in North Jakarta, Special Capital Region of Jakarta. Based on a preliminary study, the factory's indoor air quality is quite poor due to a lack of ventilation. This affects indoor air quality, especially since workers spend long hours inside the building. Such conditions put workers at risk of developing health issues, including SBS symptoms. A preliminary study on SBS symptoms among workers at PT X found that 87.5% of the eight interviewed workers reported experiencing Sick Building Syndrome symptoms in the past three months. The most commonly reported symptoms included fatigue, drowsiness, dry/sore throat, dry skin, eye irritation, poor concentration, and a runny nose. These symptoms were experienced while working in air-conditioned rooms and gradually disappeared after leaving the workplace. Thus, this study aims to examine the "Analysis of Indoor Air Quality on Symptoms of Sick Building Syndrome Among Workers at PT X in 2023."

## 2. Methods

This research is a quantitative study with a cross-sectional design, as it can describe the condition and characteristics of the study population and can be applied to large populations. This design was chosen because the study was conducted at a single point in time and the outcome involves a commonly found issue. Additionally, the use of a cross-sectional study design is justified as Sick Building Syndrome is a relevant case within the population. The dependent variable is the symptoms of Sick Building Syndrome, while the independent variables include carbon monoxide levels, temperature, humidity, PM10, formaldehyde, wind speed, age, gender, and work duration.

## 3. Result and Discussion

*3.1 Description of the Research Location*

PT X is a company engaged in soap production. It was established in 2002. The soap production area consists of three production lines, each containing several workstations, including a mixing machine area (for blending raw materials), a refinery (for transforming raw materials into thin sheets), a plodder (for shaping raw materials into solid blocks), a cutting station (for slicing soap into smaller pieces), a stamper (for molding soap into predetermined sizes), a cartoning station (for packaging and sorting soap), and a sealer (for arranging and sealing soap cartons).

The production area also includes several supporting rooms essential for the manufacturing process, such as the production office (which houses production administration, occupational health and safety (OHS) personnel, and engineering staff), the quality control room (for physical quality inspection of the soap), and the additive room (for weighing and storing soap additives).

The company is in an industrial area with high activity levels. Additionally, air pollution caused by heavy vehicle traffic, such as large trucks and container trucks, affects the air quality around the company. The production area is enclosed and equipped with air conditioning (AC), fans, and exhaust fans. However, exhaust fans and fans are only installed in certain areas, such as the mixing area. The use of fans in the mixing area can cause dust from raw materials to become airborne.

This study measures air quality in 17 areas, including the production office, Line 1 & 2 mixing areas, Line 1 refiner machine area, Line 1 plodder, cutter, and stamper area, Line 1 cartoning machine area, Line 2 refiner machine area, Line 2 plodder, cutter, and stamper area, Line 2 cartoning machine area, Line 1 & 2 sealer area, Line 3 mixing area, Line 3 refiner machine area, Line 3 plodder, cutter, and stamper area, Line 3 cartoning machine area, Line 3 sealer area, the additive weighing room, the additive dispensing room, and the QC line area.

*3.2 Univariate Analysis*

The univariate analysis in this study aims to determine the distribution and frequency of data from independent variables (such as carbon monoxide, temperature, humidity, PM10, formaldehyde, wind speed, age, gender, and length of work) and the dependent variable, namely Sick Building Syndrome (SBS) symptoms. This study involved 91 respondents, all of whom were workers in the production area of PT X. Based on Table 1, of the 91 respondents, 85 people (93.4%) reported experiencing SBS symptoms.

Most workers were in rooms with carbon monoxide levels that were still within safe limits, namely all 91 people (100%). For room temperature, 73 people (80.2%) worked in areas where the temperature did not meet the standard. As for PM10, most workers, namely 58 people (63.7%) worked in places with PM10 levels that still met the standard. Meanwhile, for formaldehyde, 55 people (60.4%) were in rooms with levels that exceeded the standard. Finally, 50 people (54.9%) worked in rooms with wind speeds that met the standard. From the distribution of individual characteristics shown in Table 3, the largest age group was workers aged 33 years and below, as many as 58 people (63.7%). Most of the respondents were also male, as many as 61 people (67%). ased on length of service, the majority had worked for more than eight years, as many as 47 people (51.6%).

*3.3 Bivariat Analysis*

Bivariate analysis was conducted between the dependent variable (Sick Building Syndrome symptoms) and the independent variables (Indoor Air Quality), which include temperature, humidity, PM10, formaldehyde, and wind speed. This analysis aims to examine the relationship between each Indoor Air Quality independent variable and the dependent variable.

Based on the bivariate analysis results, the highest proportion was observed among workers in rooms with non-standard temperatures, where 71 out of 91 workers (97.3%) experienced Sick Building Syndrome (SBS) symptoms. This was higher than the proportion of workers in rooms with standard temperatures. The chi-square test result showed a p-value of 0.013 (<0.05), indicating a significant relationship between temperature and Sick Building Syndrome symptoms at PT X.

The highest proportion was observed among workers in rooms with non-standard humidity levels, where 79 out of 91 workers (92.9%) experienced SBS symptoms. This was higher than the proportion of workers in rooms with standard humidity levels. The chi-square test result showed a p-value of 1.000 (>0.05), indicating no significant relationship between humidity and Sick Building Syndrome symptoms at PT X.

The highest proportion was found among workers in rooms with standard PM10 levels, where 53 out of 91 workers (91.4%) experienced SBS symptoms. This was higher than the proportion of workers in rooms with non-standard PM10 levels. The chi-square test result showed a p-value of 0.411 (>0.05), indicating no significant relationship between PM10 and Sick Building Syndrome symptoms at PT X.

The highest proportion was observed among workers in rooms with non-standard formaldehyde levels, where 53 out of 91 workers (96.4%) experienced SBS symptoms. This was higher than the proportion of workers in rooms with standard formaldehyde levels. The chi-square test result showed a p-value of 0.209 (>0.05), indicating no significant relationship between formaldehyde and Sick Building Syndrome symptoms at PT X.

The highest proportion was found among workers in rooms with standard wind speed, where 44 out of 91 workers (88%) experienced SBS symptoms. This was higher than the proportion of workers in rooms with non-standard wind speed, where all 41 workers (100%) experienced SBS symptoms. The chi-square test result showed a p-value of 0.031 (<0.05), indicating a significant relationship between wind speed and Sick Building Syndrome symptoms at PT X.

### *3.4 Multivariat Analysis*

Multivariate analysis aims to identify the most dominant independent variable influencing the dependent variable. In this study, multivariate analysis was conducted using multiple logistic regression. Bivariate selection was performed using the chi-square test to examine all independent variables, including carbon monoxide, temperature, humidity, PM10, formaldehyde, wind speed, age, gender, and work tenure. Variables with a p-value >0.25 could not proceed to the multivariate test, as they did not meet the requirements for further modeling.

The results of the bivariate selection indicate that five variables were included in the multivariate analysis model: temperature, formaldehyde, wind speed, gender, and work duration, as they had a p-value < 0.25. Meanwhile, the variables age, humidity, PM10, and carbon monoxide were excluded from the multivariate analysis model because they had a p-value > 0.25.

The candidate variables for multivariate modeling with a p-value < 0.25 were analyzed together, followed by the stepwise elimination of variables with a p-value > 0.05, starting with the highest p-value among them. After each elimination, the Prevalence Odds Ratio (POR) was recalculated. If there was a change in POR greater than 10%, the eliminated variable had to be reintroduced into the model, and the elimination process continued with the next variable with the highest p-value. However, if no POR change exceeded 10%, the analysis could proceed. The following presents the results of the initial modeling:

Table 1. First logistic regression modeling

| Variable | B | P-Value | POR | 95% CI |
|---|---|---|---|---|
| Temperature | -1.094 | 1 | 0.335 | 0 |
| Formaldehyde | -0.682 | 1 | 0.506 | 0 |
| Wind Speed | -18.616 | 0.997 | 0 | 0 |
| Gender | -18.635 | 0.998 | 0 | 0 |
| Work Tenure | -0.541 | 0.660 | 0.582 | 6.454 |

Based on Table 1, the independent variable with the highest p-value, formaldehyde (p-value = 1), is eliminated. In the next modeling stage, the formaldehyde variable is removed.

Table 2. Second logistic regression modeling

| | B | P-Value | POR | 95% CI |
|---|---|---|---|---|
| Temperature | -1.775 | 0.069 | 0.169 | 0.025–1.150 |
| Formaldehyde | -18.570 | 0.997 | 0 | 0 |
| Wind Speed | -18.373 | 0.998 | 0 | 0 |
| Gender | -0.541 | 0.660 | 0.582 | 0.053–6.454 |

In the second modeling, the independent variable formaldehyde has been excluded. Next, the calculation of the change in the Prevalence Odds Ratio (POR) value between before and after the exclusion of the formaldehyde variable is conducted.

Table 3 Calculation of por change without formaldehyde

| Variable | Old POR | New POR | POR Change |
|---|---|---|---|
| Temperature | 0.335 | 0.169 | 49.55% |
| Formaldehyde | 0 | 0 | 0% |
| Wind Speed | 0 | 0 | 0% |
| Gender | 0.582 | 0.582 | 0% |

Based on Table 3, there is a POR change of more than 10% in the temperature variable. Therefore, the formaldehyde variable is reintroduced into the model. For the third modeling stage, the temperature variable should be removed (based on the table before formaldehyde was excluded).

Table 4. Third logistic regression modeling without temperature

| Variable | B | P-Value | POR | 95% CI |
|---|---|---|---|---|
| Temperature | -18.745 | 0.997 | 0 | 0 |
| Formaldehyde | -18.373 | 0.998 | 0 | 0 |
| Wind Speed | -0.541 | 0.660 | 0.582 | 0.053–6.454 |
| Formaldehyde | -1.775 | 0.069 | 0.169 | 0.025–1. 150 |

In the third modeling, the independent variable temperature has been removed. Next, the calculation of changes in the Prevalence Odds Ratio (POR) will be conducted to compare the values before and after the removal of the temperature variable.

Table 5. Calculation of POR changes without temperature

| Variable | Old POR | New POR | POR Change |
|---|---|---|---|
| Wind Speed | 0 | 0 | 0% |
| Gender | 0 | 0 | 0% |
| Work Tenure | 0.582 | 0.582 | 0% |
| Formaldehyde | 0.506 | 0.169 | 66% |

Based on Table 5, there is a change in the POR value of more than 10% for the formaldehyde variable. Therefore, the temperature variable is reintroduced into the model. In the next step, for the fourth modeling, the independent variable gender is removed as it has the highest p-value after the temperature variable.

Table 6. Logistic regression model – fourth model without gender

| Variable | B | *P-Value* | POR | 95% CI |
|---|---|---|---|---|
| Wind Speed | -18.503 | 0.997 | 0 | 0 |
| Work Tenure | -1.380 | 0.245 | 0.252 | 0.025–2.577 |
| Formaldehyde | -17.237 | 0.998 | 30608080.42 | 0 |
| Temperature | -18.834 | 0.998 | 0 | 0 |

In the fourth modeling, the independent variable gender has been removed. Next, the calculation of the change in the Prevalence Odds Ratio (POR) value between before and after the removal of the gender variable is performed.

Table 7. Calculation of POR changes without gender

| Variable | Old POR | New POR | POR Change |
|---|---|---|---|
| Wind Speed | 0 | 0 | 0% |
| Work Tenure | 0.582 | 0.252 | 56% |
| Formaldehyde | 0.506 | 30608080.42 | -66% |
| Temperature | 0.335 | 0 | 100% |

Based on Table 7, there is a POR change of more than 10% in the variables of work duration and temperature. Therefore, the gender variable is reintroduced into the model. In the fifth modeling stage, the wind speed variable is removed as it has the highest p-value after the gender variable.

Table 8. Logistic regression model fifth without wind speed

| Variable | B | *P-Value* | POR | 95% CI |
|---|---|---|---|---|
| Work Tenure | -0.785 | 0.506 | 0.456 | 0.045–4.621 |
| Formaldehyde | -15.505 | 0.998 | 5416491.219 | 0 |
| Temperature | -17.551 | 0.998 | 0 | 0 |
| Gender | -17.780 | 0.998 | 0 | 0 |

In the fifth modeling stage, the independent variable wind speed has been removed. Next, the percentage change in the POR (Prevalence Odds Ratio) values will be calculated to compare the values before and after the removal of the wind speed variable.

Table 9. Calculation of changes in POR values without wind speed

| Variable | Old POR | New POR | POR Change |
|---|---|---|---|
| Work Tenure | 0,582 | 0,456 | 21% |
| Formaldehyde | 0,506 | 5416491,219 | -107% |
| Temperature | 0,335 | 0 | 100% |
| Gender | 0 | 0 | 0 |

Based on the calculation of changes in POR values, there was a change of more than 10% in the variable's temperature and work duration, indicating that the wind speed variable should be reintroduced into the model. In the next modeling stage, the work duration variable was removed as it had the highest p-value after the wind speed variable.

Table 10. Logistic regression modeling sixth without work duration

| Variable | B | P-Value | POR | 95% CI |
|---|---|---|---|---|
| Formaldehyde | -0.784 | 1 | 0.457 | 0 |
| Temperature | -1.054 | 1 | 0.348 | 0 |
| Gender | -19.011 | 0.998 | 0 | 0 |
| Wind Speed | -18.692 | 0.997 | 0 | 0 |

In the sixth modeling, the independent variable work duration has been removed. Next, the calculation of changes in POR values will be conducted before and after the removal of the work duration variable.

Table 11. Calculation of changes in POR values without work duration

| Variable | Old POR | New POR | POR Change |
|---|---|---|---|
| Formaldehyde | 0.506 | 0.457 | 9.6% |
| Temperature | 0.335 | 0.348 | -3.8% |
| Gender | 0 | 0 | 0% |
| Wind Speed | 0 | 0 | 0% |

The multivariate modeling has concluded because all variables with a p-value > 0.05 have been eliminated, and the calculation of POR changes > 10% has been conducted, showing that no variables have a POR change greater than 10%. Therefore, the final modeling table represents the results of multivariate modeling. The final model results identify the most dominant variable, which is the variable with the highest POR value and exponent (B). The Prevalence Odds Ratio (POR) is used to determine the extent to which the independent variable influences the dependent variable. Based on the multivariate analysis using the multiple logistic regression model, the dominant variable identified is formaldehyde. The Prevalence Odds Ratio (POR) for the formaldehyde variable is 0.457. It can be concluded that formaldehyde is the most dominant variable associated with Sick Building Syndrome symptoms among workers at PT X. This result is also supported by substantial justification.

### *3.5 Univariat*

Sick Building Syndrome is a condition in which occupants of a room or building experience acute health problems related to the amount of time spent in that space (Aurora, 2021). The production area is a hazardous zone that contains various risks affecting the safety and health of factory workers. One of the factors that can influence workers' health is Indoor Air Quality (IAQ). A workspace with Indoor Air Quality that does not meet the standards can negatively impact workers' health and comfort.

According to the study results from 91 respondents, 85 respondents experienced symptoms of Sick Building Syndrome. Although there is no single cause of Sick Building Syndrome, indoor air quality is one of the main contributing factors. According to Aziz et al. (2023), physical parameters such as humidity and temperature, as well as chemical pollutants such as carbon monoxide, formaldehyde, total volatile organic compounds, PM2.5, and PM10, have a significant relationship with the occurrence of Sick Building Syndrome in the workplace.

According to Occupational Safety and Health (2010), the standard level of carbon monoxide indoors is less than 10 ppm. Indoor carbon monoxide mainly originates from combustion activities such as cooking or heating (World Health Organization, 1999). Based on Table 6, all workers were in rooms where the carbon monoxide levels met the standard. This is because the production process does not involve combustion or any activities that generate carbon monoxide.

According to Occupational Safety and Health (2010), the standard room temperature in the industry is 23°C – 26°C. Based on Table 6, most workers were in rooms with temperatures that did not meet the standard. Several production areas, such as the mixing area, refinery machines, and sealer area, had high temperatures. This is because these areas are not covered by air conditioning facilities and only use fans and exhaust systems. In both high and low temperatures, the body can become fatigued more quickly than usual and experience health disturbances, including SBS complaints (Hanifah et al., 2020).

According to Occupational Safety and Health (2010), the standard humidity level in the industry is 40% – 70%. Based on Table 6, most workers were in rooms where the humidity level did not meet the standard. The humidity in the production area tends to exceed 70%. This is due to inadequate ventilation systems in the production area, leading to 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 those in areas with humidity levels below 70%.

According to Occupational Safety and Health (2010), the standard level of PM10 in industrial rooms is less than 0.15 mg/m3. Based on Table 6, most workers were in areas where the PM10 levels met the standard. This is because the production area is an enclosed space. However, PM10 levels exceeded the standard in some areas where activities generate airborne particulate dust, such as the mixing and sealer areas.

According to Occupational Safety and Health (2010), the standard formaldehyde level in industrial rooms is less than 0.1 ppm. Based on Table 6, most workers were in rooms where formaldehyde levels did not meet the standard. Formaldehyde is an indoor air pollutant originating from building materials that can cause health disturbances among building occupants (Zaelani, 2015). In the production area of PT X, formaldehyde originates from certain chemicals used in soap production, such as additives and perfume ingredients, which emit a strong odor. Additionally, some types of cardboard packaging release strong adhesive or glue smells, affecting workers' comfort and health.

According to Occupational Safety and Health (2010), the standard wind speed in industrial rooms is 0.15 – 0.50 m/s. Based on Table 6, some workers were in rooms where wind speed met the standard. Wind speed plays an essential role in many factors, including air pollution (Deng et al., 2020). Therefore, maintaining wind speed in the production area is crucial, as it affects workers' comfort and productivity.

The univariate analysis results show that there were more workers aged over 33 years than those under 33 years. This is because younger workers are often considered to have better energy and physical strength for tasks involving physical labor in the production area. Additionally, the workforce at PT X was predominantly male. The majority of male workers were assigned to operate production machinery. Regarding work tenure, most workers had been employed for more than eight years. This is due to the limited rotation of workers in the production area, as production workers need experience in their respective fields.

### *3.6 Bivariat*

Based on the bivariate analysis test using chi-square, it was found that there is a statistically significant relationship between temperature variables and Sick Building Syndrome symptoms among workers at PT X. Bardi et al. (2021) also stated that there is a relationship between room temperature and Sick Building Syndrome (SBS) symptoms. According to the study results, the temperature in the production area tends to be hot, exceeding 27°C. This high temperature can cause fatigue, discomfort, and concentration disturbances in workers. A temperature that does not meet normal standards will affect workers' performance, which can impact the efficiency and productivity of each worker (ILO, 2013). Temperature can influence workers' focus and work quality (Hanifah et al., 2020). This is because workers' discomfort can disrupt concentration, affecting their ability to carry out tasks. Additionally, workers who cannot work comfortably may experience a decrease in productivity. In both high and low temperatures, the body can feel more easily fatigued than usual and experience health issues, including SBS complaints (Hanifah., 2020). Excessively 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 environments with temperatures exceeding 25.50°C have a 4.386 times greater likelihood of experiencing SBS symptoms compared to those working in rooms with standard-compliant temperatures. In the production area, especially in the mixing area, temperatures exceed 30°C, increasing the likelihood of workers experiencing Sick Building Syndrome symptoms.

Based on the bivariate analysis test using chi-square, no statistically significant relationship was found between humidity variables and Sick Building Syndrome symptoms among workers at PT X. According to Occupational Safety and Health (2010), the industrial humidity standard is 40% – 70%. The study results indicate that most room humidity levels do not meet the standard. A study by Saffanah & Pulungan (2017) found no significant relationship between humidity variables and Sick Building Syndrome symptoms. This finding is supported by Hanifah et al. (2020), who also found no meaningful relationship between humidity and Sick Building Syndrome symptoms. Although the statistical test did not indicate a relationship between humidity and Sick Building Syndrome symptoms, a greater number of workers in environments with non-standard humidity levels experienced Sick Building Syndrome symptoms. This may be due to workers having adapted to high humidity over time. The human body has the ability to adapt to certain conditions, although this adaptability varies among individuals. The production area at PT X tends to have humidity levels exceeding 70%. According to a study by Nopiyanti et al. (2019), workers in areas with humidity levels above 70% are four times more likely to experience SBS symptoms compared to those in areas with normal humidity levels.

Based on the bivariate analysis test using chi-square, no statistically significant relationship was found between the PM10 variable and Sick Building Syndrome symptoms among workers at PT X. A study conducted by Franswijaya & Kusnoputranto (2013) also stated that there is no meaningful relationship between the PM10 variable and Sick Building Syndrome symptoms. PM10 stands for Particulate Matter 10, which refers to airborne particles with a diameter of 10 micrometers or smaller. These particles consist of various substances such as dust, pollen, metals, and other chemicals. PM10 can remain suspended in the air and be inhaled by humans, posing potential health risks (Salvador & Salvador, 2012). According to the study results, the mixing area at PT X has the highest PM10 levels due to the use of powdered raw materials for soap production and inadequate ventilation. The presence of fans causes the powder to spread throughout the mixing area. Non-standard PM10 levels can lead to eye, nose, and throat irritation. Larger particles that enter the nose or throat are filtered by the body's natural defense system, while very fine particles that reach the respiratory system can be absorbed into the bloodstream or cause lung disorders (Environmental Protection UK, 2022). The bivariate analysis showed no relationship between PM10 levels and Sick Building Syndrome symptoms. This is likely because workers in the mixing area, where PM10 levels are highest, use respiratory masks, preventing significant health effects.

Based on the bivariate analysis test using chi-square, no statistically significant relationship was found between the formaldehyde variable and Sick Building Syndrome symptoms among workers at PT X. Guo et al. (2013) also stated that there is no meaningful relationship between the formaldehyde variable and Sick Building Syndrome symptoms. Formaldehyde is an indoor air pollutant originating from building materials, which has the potential to cause health issues for building occupants (Zaelani, 2015). Sources of formaldehyde in indoor environments include construction materials, insulation, finishing materials, combustion appliances, tobacco smoke, chemicals, and various products (Australian Building Codes Board, 2021). The statistical test indicated no relationship between formaldehyde levels and Sick Building Syndrome symptoms. This is because some areas have low or standard-compliant formaldehyde concentrations, which are not high enough to trigger Sick Building Syndrome symptoms. However, the mixing area has high formaldehyde concentrations due to the use of soap raw materials containing fragrances, colorants, and other additives. Formaldehyde exposure can cause irritation of the respiratory system, eyes, and throat, as well as dizziness. Exposure to formaldehyde at levels of 0.05–0.5 ppm has the potential to cause eye irritation and respiratory system irritation (Zaelani, 2015).

Based on the bivariate analysis test using chi-square, a statistically significant relationship was found between wind speed and Sick Building Syndrome symptoms among workers at PT X. Saffanah & Pulungan (2017) also stated that there is a relationship between airflow speed and the occurrence of Sick Building Syndrome (SBS) among employees at the Health Human Resources Development Agency of Indonesia. Wind speed refers to the rate at which air moves horizontally past a specific point (Deng et al., 2020). Non-standard wind speed can affect workers' comfort. Excessively high wind speeds can cause workers to feel cold in low-temperature environments, while low wind speeds in high-temperature environments can make workers feel uncomfortable and sweaty. The study results indicate that wind speed in the production area tends to be low. This suggests that air circulation within the production area is poor. Poor air circulation can lead to the accumulation of airborne pollutants, such as dust, odors, and chemical compounds, which can negatively impact workers' health and the work environment. Low wind speed may be caused by inadequate ventilation or a lack of fresh air circulation (Savanti et al., 2019). Poor ventilation can lead to the buildup of carbon dioxide and high humidity levels. High humidity levels can promote mold and bacterial growth, posing risks to workers' health and comfort.

### *3.7 Multivariat*

The final model of multivariate analysis indicates that formaldehyde levels within the standard limits have a 0.46 lower risk of causing Sick Building Syndrome (SBS) symptoms compared to levels that exceed the standard. Formaldehyde can trigger Sick Building Syndrome (SBS) when exposure occurs at concentrations that exceed standard limits (Seguel et al., 2017). High indoor formaldehyde concentrations can cause irritation of the respiratory tract, eyes, and throat, as well as symptoms such as headaches, fatigue, and other health problems associated with SBS. Additionally, formaldehyde is a volatile organic compound that can release significant gas emissions from building materials and chemicals (Alwi et al., 2021). This factor can further degrade indoor air quality, making it one of the primary causes of SBS.

The production area serves as the core location for the soap manufacturing process. Workers in the production area typically work for 7–8 hours per day, spending their entire work shift in an indoor production space with inadequate air circulation. The air conditioning (AC) system does not adequately cover the entire production area, prompting the company to install several fans at various points. However, these fans do not provide fresh air or expel indoor air to facilitate proper air exchange. Some sections, such as the mixing area, do not have air conditioning, and using fans in the mixing area would cause airborne dispersion of powdered raw materials. This situation illustrates 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 substances may contain formaldehyde or produce it as a byproduct of the soap manufacturing process, particularly during heating. Additionally, formaldehyde can be released from cardboard packaging made from paper and wood (Alwi et al., 2021). High indoor formaldehyde levels can also be influenced by elevated room temperatures (Australian Building Codes Board, 2021). Measurements in the production area indicate the highest formaldehyde concentration at 0.37 ppm, significantly exceeding the standard limit of 0.1 ppm. Research findings show that the production area's temperature tends to be high, often exceeding 27°C, with the mixing area reaching over 33°C. High temperatures contribute to increased formaldehyde levels in the air (Alwi et al., 2021).

Formaldehyde exposure can cause irritation to the respiratory system, eyes, throat, and dizziness. Exposure levels ranging from 0.05–0.5 ppm have the potential to cause eye and respiratory tract irritation (Zaelani, 2015). A study on production area workers in Malaysia found that formaldehyde exposure contributes to fatigue and hoarseness (Alwi et al., 2021). The World Health Organization (WHO) also states that high formaldehyde concentrations can cause acute effects such as odor discomfort, upper respiratory tract and eye irritation, lung effects, and eczema (WHO, 2010). Moreover, there is a strong link between formaldehyde exposure and allergies, asthma, and respiratory effects (Australian Building Codes Board, 2021). The health effects of formaldehyde exposure, as described above, are some of the symptoms associated with Sick Building Syndrome.

Formaldehyde is also classified as a carcinogenic substance that can increase the risk of cancer in humans. Long-term exposure to formaldehyde can elevate the risk of nasopharyngeal cancer and leukemia (Protano et al., 2022). Therefore, controlling formaldehyde exposure is crucial to protecting human health. Companies must ensure that indoor formaldehyde concentrations remain below the standard limit of 0.1 ppm to reduce health risks associated with this compound. Regular monitoring of formaldehyde levels in the production area is essential, along with routine health check-ups for workers to detect any early signs of illnesses caused by occupational exposure.

Formaldehyde is one of the 20 most widely produced industrial chemicals (Dan et al., 2020). It can enter the human body through inhalation, ingestion, or skin absorption (Tesfaye et al., 2021). According to research by Reingruber and Pontel (2018), the human body can be exposed to formaldehyde through inhalation or ingestion of products containing formaldehyde, which can then be metabolized within the body. The route of formaldehyde entry into the body influences the health effects it causes. The impact of formaldehyde exposure varies from person to person. Several factors can influence individual responses to formaldehyde exposure, including age, duration or intensity of exposure, and individual sensitivity. Children and the elderly are particularly vulnerable to formaldehyde exposure due to their developing immune systems and age-related immune decline, respectively (National Center for Environmental Health, 2016). Prolonged exposure or higher concentrations of formaldehyde can increase health risks (Reingruber and Pontel, 2018). Some individuals may be more sensitive to formaldehyde due to genetic factors, pre-existing health conditions, or chemical sensitivities (National Center for Environmental Health, 2016).

## 4. Conclusion

Based on a study of Indoor Air Quality (IAQ) at PT X in 2023, 93.4% of workers experienced symptoms of Sick Building Syndrome (SBS). Although carbon monoxide levels were within safe limits in all areas, most locations had problems with other factors: 80.2% had off-standard temperatures, 93.4% had problematic humidity levels, and 60.4% had excessive formaldehyde. On the other hand, PM10 levels and wind speed were within standards in 63.7% and 54.9% of areas, respectively.

Most employees were under 33 years old (63%), male (67%), and had worked there for more than eight years. Statistically, temperature ($p=0.013$) and wind speed ($p=0.031$) were significantly associated with SBS symptoms, while humidity, PM10, and formaldehyde were not significantly associated. Interestingly, although formaldehyde was not statistically significant, it was still the most dominant variable affecting SBS symptoms, with a POR of 0.457.

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## Author Contribution

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