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Association Between Housing Environmental Factors and Pulmonary Tuberculosis Incidence Among the Elderly: A Case - Control Study in Indonesia

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Abstract

Background: Pulmonary tuberculosis continues to pose a significant global public health challenge, particularly in developing countries such as Indonesia. Adverse environmental conditions within households, including inadequate lighting, elevated humidity, insufficient ventilation, and overcrowding, have been identified as factors that may elevate the risk of tuberculosis transmission.

Methods: This study employed an analytic observational approach with a case–control design in the Perumnas Simalingkar Public Health Center area of Medan, Indonesia. A total of 128 participants were included: 64 pulmonary tuberculosis cases and 64 controls, selected through purposive sampling. Data collection involved direct observation and measurement of housing environmental conditions using a lux meter, a hygrometer, and a roll meter, in accordance with the Indonesian Ministry of Health's healthy housing standards.

Result: The variables assessed were lighting, humidity, ventilation area, and housing density. Statistical analysis was conducted using the chi-square test (significance level $p < 0.05$) and Odds Ratio (OR) to estimate risk. The findings indicated that all assessed housing environmental factors were significantly associated with the incidence of pulmonary tuberculosis. Specifically, inadequate lighting (p=0.002; OR=3.477), unsuitable humidity (p=0.005; OR=3.151), insufficient ventilation area (p=0.007; OR=2.943), and overcrowded housing density (p=0.007; OR=2.943) were significantly linked to increased risk.

Conclusion: These results underscore that poor housing environmental conditions contribute to the risk of pulmonary tuberculosis.

Keywords: Tuberculosis, Elderly, Housing Environment.

BACKGROUND

The elderly population is defined as individuals aged 60 years and older and represents a group that is biologically vulnerable to various health problems associated with aging (1). Aging is characterized by a gradual decline in physiological functions, including decreased immune response, known as immunosenescence, which reduces the body's ability to fight infectious diseases. This condition makes older adults more susceptible to various infections, including respiratory diseases such as pulmonary tuberculosis (2). In addition to biological vulnerability, elderly individuals are also influenced by environmental, social, and economic factors that may increase their risk of exposure to infectious diseases in the community (3).

Tuberculosis (TB) is a contagious infectious disease that remains a global public health problem, caused by the bacterium *Mycobacterium tuberculosis*, which primarily attacks the lungs. This disease is transmitted through the air when people with pulmonary TB release droplets or droplet nuclei containing germs through coughing, sneezing, or talking, allowing people around them to inhale and become infected (4). This condition makes pulmonary TB sufferers the primary source of transmission, especially in crowded and unhealthy environments, where dense housing and poor ventilation increase the risk of aerosol-borne transmission (3).

According to international literature, tuberculosis is a chronic infectious disease caused by the bacterium *Mycobacterium tuberculosis*, a rod-shaped, aerobic bacillus belonging to the acid-fast bacilli group, which has a thick, lipid-coated cell wall, making it appear acid-fast on special stains (5). This bacterium primarily attacks the lung parenchyma and causes pulmonary tuberculosis, but can also spread hematogenously and lymphatically to other organs, causing extrapulmonary tuberculosis, including the lymph nodes, pleura, bones and joints, kidneys, central nervous system, skin, and other organs (6). This multi-organ involvement, coupled with the fact that a large portion of the world's population has been infected and some sufferers experience long-term disability after TB, indicates that tuberculosis is a global health problem with a broad and lasting impact on quality of life and human morbidity and mortality (7).

Tuberculosis remains a major global public health challenge, with a significant burden of disease and millions of new cases each year. Tuberculosis is an infectious disease caused by *Mycobacterium tuberculosis. It is* primarily spread through the air when droplets or droplet nuclei containing the bacteria are inhaled by a susceptible person, for example, when an infected person coughs, speaks, or breathes (8). Transmission via these small airborne particles makes TB highly contagious, particularly in crowded, poorly ventilated environments, thereby triggering ongoing chains of transmission in communities and healthcare facilities (9). The combination of efficient airborne transmission, high incidence and mortality rates, and a large reservoir of latent infection that can progress to active disease makes tuberculosis a disease requiring comprehensive, integrated, and sustainable control efforts, including early detection, effective treatment, breaking the chain of transmission, and strengthening health systems (10).

Globally, tuberculosis remains one of the most burdensome infectious diseases, with an estimated 10 million people falling ill with TB in 2019–2020 and more than 1.4–1.5 million deaths annually. The WHO estimates approximately 9.9–10 million new TB cases in 2020, with the largest burden in Southeast Asia, Africa, and the Western Pacific, with Indonesia among the top three contributors (11). The slow decline in incidence, the increase in deaths in 2020, and the disruption of services during the COVID-19 pandemic demonstrate that TB remains a serious global health problem that requires a strong commitment from all countries, including Indonesia, to strengthen detection, treatment, and prevention on an ongoing basis (12).

In Indonesia, tuberculosis remains a highly prevalent infectious disease, placing Indonesia among the countries with the highest TB burden in the world. National data show an estimated incidence of

824,000–969,000 TB cases per year during 2018–2021, with an increase in incidence from 2019 to 2021, partly attributable to service disruptions during the pandemic and improved case detection (13). In 2022–2023, the estimated number of cases even reached more than 724,000 to 809,000 new cases per year, confirming that TB remains a serious public health problem in Indonesia. Its control efforts still face various challenges, such as late detection, non-adherence to treatment, drug resistance, and constraints on the healthcare system (14).

At the regional level, North Sumatra Province also faces a high tuberculosis burden and is one of the largest contributors to TB cases in Indonesia (15). Data from the North Sumatra Provincial Health Office show that in 2018, there were approximately 23,237 recorded cases of pulmonary TB, which increased to approximately 33,779 in 2020, representing an increase of more than 10,000 cases in two years (16). More recently, approximately 34,714 TB cases were reported in 2022, with a further increase to an estimated 74,434 cases in 2024, placing North Sumatra in the top three provinces with the highest TB burden nationally (15). This increasing trend confirms that tuberculosis remains a major health problem in North Sumatra and requires more intensive and integrated prevention, early detection, and control efforts (16).

Home environmental conditions are particularly relevant to pulmonary tuberculosis because transmission occurs predominantly through the air and is influenced by indoor space characteristics. Inadequate ventilation can reduce air exchange and allow infectious aerosols to persist indoors, while high humidity and insufficient natural lighting may contribute to unfavorable indoor conditions (17). Overcrowded housing can further increase the frequency and duration of close contact among household members, thereby facilitating airborne transmission (18). Previous studies have reported associations between poor housing conditions and pulmonary tuberculosis, including inadequate ventilation, insufficient lighting, inappropriate humidity, and high occupancy density. These findings provide a basis for considering the home environment as an important modifiable factor in tuberculosis prevention (19).

However, although the relationship between housing conditions and pulmonary tuberculosis has been investigated in the general population, evidence focusing specifically on elderly individuals remains limited. This population warrants particular attention because physiological aging and immunosenescence may reduce the ability to respond effectively to infectious diseases, potentially increasing vulnerability to tuberculosis (20). Therefore, the effect of unfavorable housing conditions may be particularly important among older adults. In addition, evidence from the local community setting, particularly in the working area of the Perumnas Simalingkar Public Health Center in Medan, is still limited. Assessing specific housing characteristics, lighting, humidity, ventilation area, and occupancy density may provide more specific evidence regarding which environmental conditions are associated with pulmonary tuberculosis among elderly residents (21). Therefore, this study aims to analyze the relationship between specific home environmental factors, namely lighting, humidity, ventilation area, and occupancy density, and the incidence of pulmonary tuberculosis among elderly individuals in the working area of the Perumnas Simalingkar Public Health Center, Medan, Indonesia.

METHODS

Study Design

This study employed an analytic observational case–control design to examine the association between housing environmental factors and pulmonary tuberculosis among older adults. The case–control design was used to compare housing environmental conditions between older adults with pulmonary tuberculosis (cases) and those without pulmonary tuberculosis (controls). Tuberculosis status was identified first, followed by an assessment of housing environmental factors, including indoor lighting, relative humidity, ventilation area, and occupancy density. The reporting of this study

followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for case–control studies.

Participants /Sample

The study population comprised adults aged ≥60 years. The case population consisted of older adults diagnosed with pulmonary tuberculosis based on health center medical records, with 177 individuals identified in the initial case population. The control population consisted of older adults without pulmonary tuberculosis.

The sample size was determined using the Slovin formula with a 10% margin of error, resulting in 64 cases and 64 controls, with a case-to-control ratio of 1:1. Participants were selected using purposive sampling. The inclusion criteria were age ≥60 years, residence within the study area, availability of tuberculosis status in the medical records, and willingness to participate. Individuals who had moved outside the study area, declined participation, or had incomplete data were excluded.

Instruments

Data were collected using a structured observation checklist and standardized environmental measurement instruments to ensure consistent assessment of housing conditions. Indoor lighting was measured using a lux meter, relative humidity using a hygrometer, and ventilation and floor areas using a measuring tape. Floor area and the number of household occupants were used to determine occupancy density.

Housing environmental conditions were classified according to the Indonesian Ministry of Health Regulation No. 1077/2011 concerning healthy housing standards. Adequate indoor lighting was defined as ≥60 lux, acceptable relative humidity as 40–60%, adequate ventilation area as ≥10% of the floor area, and adequate occupancy density as ≥8 m^2 per person.

Data Collection

Data collection was conducted from July 2025 to January 2026 in the working area of the Perumnas Simalingkar Public Health Center, Medan, Indonesia. Tuberculosis status was identified from health center medical records and was used to classify eligible participants into case and control groups.

Primary data on housing environmental conditions were collected through direct observation and measurement at each participant's residence. Indoor lighting, relative humidity, ventilation area, floor area, and occupancy density were assessed using the specified measurement instruments, and the findings were recorded on a structured observation checklist. Secondary data obtained from health center medical records were used to confirm pulmonary tuberculosis status and participant eligibility.

Data Analysis

Data were checked for completeness, coded, entered, and analyzed using SPSS. Univariate analysis was performed to describe participant characteristics and the distribution of the study variables. Bivariate analysis using the chi-square test was conducted to examine the associations between housing environmental factors, including indoor lighting, relative humidity, ventilation area, and occupancy density, and pulmonary tuberculosis status.

The magnitude of each association was estimated using odds ratios (ORs) with 95% confidence intervals (CIs). Statistical significance was established at $p < 0.05$.

Ethical Consideration

The study was conducted in accordance with ethical principles for research involving human participants and received ethical approval from the Health Research Ethics Committee of Akademi Akupuntur Aceh under approval number 045/KEPK-AAA/VII/2026. Before participation, all

participants received information regarding the purpose and procedures of the study, the voluntary nature of participation, and their right to decline or withdraw from the study. Informed consent was obtained from all participants before data collection. Participant privacy and confidentiality were maintained throughout the study, and all collected data were used solely for research purposes.

RESULT AND DISCUSSION

RESULT

Demographic Characteristics of Responden

A total of 128 older adults were included in the study, comprising 64 participants with pulmonary tuberculosis and 64 participants without pulmonary tuberculosis. Table 1 summarizes the participants' sociodemographic and health-related characteristics, including sex, educational level, economic status, income level, history of diabetes mellitus, and smoking status, as well as housing environmental conditions, including indoor lighting, relative humidity, ventilation area, and occupancy density.

Table 1. Sociodemographic, health-related, and housing environmental characteristics of participants (N = 128)

Characteristics	n	%
Gender		
Female	62	48.4
Male	66	51.6
Last Education		
No Schooling	23	18.0
Elementary School	33	25.8
Junior High School	26	20.3
High School	38	29.7
College	8	6.3
Economic Status		
Upper	15	11.7
Middle	27	21.1
Lower	86	67.2
Income Level		
> Rp 2,700,000	15	11.7
Rp 2,700,000	27	21.1
< Rp 2,700,000	86	67.2
History of Diabetes Mellitus		
None	89	69.5
Yes	39	30.5
Smoking Behavior Status		
Non-Smoking	45	35.2
Smoking	83	64.8
Pulmonary Tuberculosis Incidence		
Pulmonary Tuberculosis	64	50.0
No Pulmonary Tuberculosis	64	50.0
Lighting		
Does Not Meet Requirements < 60 Lux	80	62.5
Meet Requirements > 60 Lux	48	37.5
Humidity		
Does Not Meet Requirements < 40% and > 60%	84	65.6
Meet Requirements > 40% and < 60%	44	34.4
Ventilation Area		
Does Not Meet Requirements < 10%	50	39.1
Meet Requirements < 10%	78	60.9

Occupancy Density		
Does Not Meet Requirements < 8 m2 / person	78	60.9
Meet Requirements > 8 m2 / person	50	39.1

Note : Data are presented as frequency (*n*) and percentage (%). Pulmonary tuberculosis status was determined from health center medical records. Housing environmental conditions were classified according to the applicable Indonesian healthy housing standards. Adequate indoor lighting was defined as ≥60 lux; acceptable relative humidity as 40–60%; adequate ventilation area as ≥10% of the floor area; and adequate occupancy density as ≥8 m²/person. IDR = Indonesian Rupiah.

Bivariate Analysis

Bivariate analysis was performed to examine the associations between housing environmental factors and pulmonary tuberculosis status among older adults. The environmental factors assessed included indoor lighting, relative humidity, ventilation area, and occupancy density. Differences between the case and control groups were analyzed using the chi-square test, while odds ratios (ORs) with 95% confidence intervals (CIs) were used to estimate the magnitude of the associations. The results are presented in Table 2.

Table 2. Analysis of home environmental factors with the incidence of pulmonary tuberculosis in the elderly

Variables	Pulmonary Tuberculosis Incident				OR 95% CL	p-value
	Case		Control			
	n	%	n	%		
Lighting						
Does Not Meet Requirements	49	76.6	31	48.4	3.477	0.002
Meet Requirements	15	23.4	33	51.6		
Humidity						
Does Not Meet Requirements	50	78.1	34	53.1	3.151	0.005
Meet Requirements	14	21.9	30	46.9		
Ventilation Area						
Does Not Meet Requirements	33	51.6	17	26.6	2.943	0.007
Meet Requirements	31	48.4	47	73.4		
Occupancy Density						
Does Not Meet Requirements	47	73.4	31	48.4	2.943	0.007
Meet Requirements	17	26.6	33	51.6		

Note: Data are presented as frequency (*n*) and percentage (%). OR = odds ratio; CI = confidence interval. The "meets requirements" category was used as the reference group for each housing environmental factor. Associations were analyzed using the chi-square test, with statistical significance set at $p < 0.05$. Adequate indoor lighting was defined as ≥60 lux, acceptable relative humidity as 40–60%, adequate ventilation area as ≥10% of the floor area, and adequate occupancy density as ≥8 m²/person.

Table 2 shows that all assessed housing environmental factors were significantly associated with pulmonary tuberculosis status. Inadequate indoor lighting was more frequent among cases than controls (76.6% vs. 48.4%) and was associated with approximately 3.5-fold higher odds of pulmonary tuberculosis (OR = 3.477; 95% CI: 1.629–7.422; p = 0.002). Similarly, inappropriate relative humidity was more prevalent among cases (78.1%) than controls (53.1%) and was associated with increased odds of pulmonary tuberculosis (OR = 3.151; 95% CI: 1.460–6.803; p = 0.005).

Inadequate ventilation area was observed in 51.6% of cases compared with 26.6% of controls and was associated with approximately threefold higher odds of pulmonary tuberculosis (OR = 2.943; 95% CI: 1.404–6.170; p = 0.007). Likewise, inadequate occupancy density was more common among cases than controls (73.4% vs. 48.4%) and showed a significant association with pulmonary tuberculosis (OR = 2.943; 95% CI: 1.404–6.170; p = 0.007). Overall, inadequate indoor lighting, inappropriate humidity, insufficient ventilation area, and inadequate occupancy density were associated with greater odds of pulmonary tuberculosis among older adults.

DISCUSSION

This study found that several physical environmental factors of housing, including lighting, humidity, ventilation area, and occupancy density, were significantly associated with the incidence of

pulmonary tuberculosis. These findings indicate that the quality of the residential environment plays an important role in the transmission of tuberculosis, particularly among vulnerable populations such as the elderly. Aging is associated with physiological changes, including decreased immune function, which increases susceptibility to infectious diseases. When elderly individuals live in environments that do not meet healthy housing standards, the risk of infection and disease transmission may increase. One of the environmental factors identified in this study was home lighting. The results showed that most houses in the case group had lighting levels below the recommended standard of 60 lux. Inadequate lighting was significantly associated with the incidence of pulmonary tuberculosis, with an odds ratio of 3.477. These findings suggest that houses with poor lighting conditions have a higher risk of tuberculosis than houses with adequate natural lighting.

Observations during data collection showed that many houses in the study area had limited access to sunlight due to dense building layouts and inadequate window design. These conditions reduce the amount of natural light entering the house, creating darker indoor environments. Similar conditions have been reported in densely populated settlements where buildings are closely spaced, and sunlight is obstructed by surrounding structures (22). Natural sunlight plays an important role in maintaining environmental hygiene because its ultraviolet radiation can reduce the survival of microorganisms in indoor environments, including pathogenic bacteria (23). Houses with limited sunlight exposure tend to be darker and more humid, which may support the survival of airborne bacteria and increase the risk of tuberculosis transmission (24).

Humidity was also significantly associated with the incidence of pulmonary tuberculosis in this study. Most houses in the case group had humidity levels outside the recommended range of 40–60%, a significantly higher proportion than in the control group. The statistical analysis showed that houses with inappropriate humidity levels had a 3.151-fold higher risk of pulmonary tuberculosis.

Elevated indoor humidity creates favorable conditions for microbial growth and survival. Moist air supports the persistence of airborne microorganisms and can extend the survival of pathogens in enclosed spaces. Environmental studies have demonstrated that microbial growth increases with higher humidity levels, particularly when these levels exceed recommended standards (25). In residential settings, excessive humidity frequently results from inadequate ventilation and limited sunlight exposure, leading to damp indoor conditions. Such environments may facilitate the persistence of airborne pathogens, including *Mycobacterium tuberculosis* (17, 26).

Ventilation area was also identified as a significant factor associated with the incidence of pulmonary tuberculosis. The study found that houses with ventilation areas below the recommended standard were more prevalent in the case group. Inadequate ventilation was linked to an increased risk of pulmonary tuberculosis, with an odds ratio of 2.943.

Ventilation plays a crucial role in maintaining indoor air quality by enabling air exchange between indoor and outdoor environments. Adequate ventilation helps remove airborne contaminants, reduce humidity, and improve oxygen circulation within the house. In contrast, limited ventilation restricts air movement and may allow airborne particles containing infectious agents to accumulate inside the house (27). Previous studies have reported that poor ventilation significantly increases the risk of tuberculosis transmission because droplets containing *Mycobacterium tuberculosis* may remain suspended in poorly ventilated spaces for longer periods (28).

Occupancy density was also identified as a significant environmental risk factor in this study. Houses with occupancy density below the recommended standard were more frequently observed in the case group than in the control group. The analysis indicated that overcrowded housing conditions increased the risk of pulmonary tuberculosis by approximately 2.943 times.

High residential density increases the likelihood of close, prolonged contact among household members, which may facilitate the transmission of airborne infectious diseases. In crowded living conditions, the distance between occupants becomes very limited, making it easier for respiratory

droplets containing pathogens to spread among residents. Houses with limited floor space relative to the number of occupants are often characterized by reduced air circulation, increased humidity, and decreased indoor air quality, which together create an environment conducive to the survival of tuberculosis bacteria (29). Previous studies conducted in several regions in Indonesia have similarly reported that overcrowded housing is significantly associated with an increased risk of pulmonary tuberculosis (30, 31).

From a community health perspective, these findings highlight the importance of improving housing environmental conditions as part of tuberculosis prevention strategies. Community-based interventions focusing on healthy housing, environmental sanitation, and health education can play an important role in reducing the risk of tuberculosis transmission. Community nurses and health workers have a strategic role in identifying environmental risk factors, educating families about healthy housing conditions, promoting proper ventilation and sunlight exposure, and encouraging behaviors that support disease prevention. Environmental assessment and health promotion at the household level are particularly important for protecting vulnerable groups such as the elderly.

CONCLUSION

This study finds a significant association between housing environmental conditions and pulmonary tuberculosis among elderly individuals in the Perumnas Simalingkar Public Health Center area, Medan. Inadequate lighting, poor humidity control, limited ventilation, and high occupancy density were linked to increased odds of pulmonary tuberculosis. These results suggest that improving housing conditions, including lighting, ventilation, humidity control, and living space, should be integrated into community-based tuberculosis prevention for the elderly. This case–control study did not account for all potential confounding factors. Future research should include larger, more representative elderly populations and apply multivariable or longitudinal methods to further explore the relationship between housing conditions and individual factors such as smoking, diabetes mellitus, socioeconomic status, and household tuberculosis exposure.

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AUTHOR'S CONTRIBUTION STATEMENT

AES: Conceptualization, literature search, data analysis, writing – original draft, and manuscript preparation. DJB, FS, RN: Conceptualization, methodology development, supervision, manuscript review, and editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

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DATA AVAILABILITY
The dataset generated and analyzed during the current study is available from the corresponding author upon request.

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