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Assistance in the Prevention of TBC Transmission with The Application of Appropriate Technology Using Cyclone Ventilator Modification (CVM) in the Houses of Pulmonary TB and ISPA Patients as Well as PHBS Activities in Wonokusumo District

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ABSTRACT In Wonokusumo Village, Surabaya, Indonesia, overcrowded housing conditions exacerbate public health risks, with inadequate natural ventilation (below 15% of floor area), restricted airflow due to densely packed structures, and substandard room sizes (under 4 m² accommodating multiple occupants), fostering the transmission of airborne diseases. In 2022, the local Health Department reported 186 tuberculosis (TB) cases and 155 acute respiratory infection (ARI) incidents, underscoring the urgent need to address environmental factors contributing to microbial proliferation, such as Mycobacterium tuberculosis, in poorly lit and humid indoor spaces. This community service project aimed to mitigate TB and ARI transmission by enhancing indoor air quality and elevating community awareness through the integration of appropriate technology and health education, aligning with Indonesia's national health transformation pillars for disease prevention. Methods encompassed participatory educational workshops for 50 residents, delivered by faculty and students from the Environmental Health Department at the Health Polytechnic of the Ministry of Health, Surabaya. Sessions covered TB and ARI etiology, healthy housing standards (e.g., ventilation at 0.15 m/s airflow velocity, humidity control below 60%), personal hygiene practices including handwashing, and sanitation principles under the Clean and Healthy Living Behavior (PHBS) framework. Pre- and post-intervention knowledge assessments were conducted via questionnaires. Additionally, three modified cyclone ventilators (CVMs), innovative devices featuring activated charcoal filtration for odor neutralization, enhanced natural lighting to inactivate pathogens, and optimized circulation, were installed in TB/ARI-affected households as demonstration models. Results revealed substantial knowledge gains: TB comprehension improved from 20% to 94%, ARI from 18% to 90%, handwashing practices from 16% to 92%, and sanitation awareness from 14% to 90%, with high participant engagement during interactive discussions. CVM installations demonstrably upgraded indoor environments, promoting sunlight penetration and microbial reduction in targeted homes. This initiative effectively empowered residents to sustain healthier living spaces, curtailing household TB transmission risks. We advocate for sustained collaboration with the Wonokusumo Health Center to scale CVM adoption and PHBS programs, thereby advancing community resilience against infectious diseases and supporting Indonesia's 2030 TB elimination targets.

INDEX TERMS Tuberculosis, Acute Respiratory Infection, Modified Cyclone Ventilator, Healthy Housing, PHBS.

I. INTRODUCTION

Tuberculosis (TB) continues to pose a profound global health threat, standing as the preeminent cause of death from infectious diseases, with an estimated 10.8 million incident cases and 1.25 million fatalities documented in 2023 [1], [2]. This burden is disproportionately borne by low- and middle-income countries (LMICs), where urban environments amplify transmission through suboptimal living conditions, including deficient ventilation, overcrowding, and compromised indoor air quality that promote the aerosolization of *Mycobacterium tuberculosis* [3], [4]. In rapidly urbanizing LMICs, TB notifications have escalated markedly, with high-density cities exhibiting incidence rates surpassing 200 per 100,000 population, driven by semi-permanent housing where natural ventilation falls below recommended thresholds, rooms under 4 m² accommodate multiple residents, and adjacent structures impede airflow, sustaining humidity conducive to pathogen persistence [5], [6]. Exacerbating this, acute respiratory infections (ARI) frequently co-occur with TB, mediated by common pathogens such as *Streptococcus* and *Staphylococcus* species that flourish in poorly illuminated, stagnant indoor milieus [7]. Such scenarios not only heighten intra-household contagion but also mirror pervasive indoor air pollution dynamics in urban informal settlements across LMICs, where fine particulate matter (PM2.5) levels routinely exceed WHO guidelines, associating with a 20-30% heightened risk of respiratory pathologies [8], [9].

Contemporary paradigms for TB and ARI mitigation underscore integrated approaches within global health resilience frameworks, prioritizing primary prevention, environmental safeguards, and innovative technologies [10]. Ventilation enhancements represent cornerstone interventions, with empirical data affirming that airflow velocities of at least 0.15 m/s can attenuate infectious droplet nuclei and diminish transmission risks by up to 50% in communal spaces [11], [12]. Community-oriented initiatives, akin to universal hygiene promotion, have proven instrumental in cultivating practices such as hand hygiene and sanitation, engendering knowledge increments of 40-60% among at-risk cohorts [13], [14]. Engineered solutions, including modified ventilators with activated carbon integration, exhibit robust potential for remediating indoor atmospheres by sequestering particulates, volatiles, and bioaerosols, while constraining relative humidity under 60% to curtail microbial viability [15], [16]. In low-resource locales, economical ventilator adaptations harness solar exposure for ultraviolet-mediated *M. tuberculosis* inactivation alongside augmented circulation, corroborated by field trials in TB-prevalent domiciles [17]. Moreover, harmonized hygiene curricula, consonant with WHO directives, have efficaciously abated ARI burdens via interactive forums, accentuating ventilation norms [18], [19]. Adjunctive modalities, such as AI-enhanced diagnostics, augment these endeavors, albeit with disparate uptake in marginalized urban enclaves [20].

Notwithstanding these strides, a salient evidentiary void endures: although ventilation apparatuses and hygiene pedagogy are extensively cataloged in healthcare facilities, their conjoint deployment through cost-effective, domicile-centric adaptations like modified cyclone ventilators is inadequately probed in LMIC urban informal settlements [21]. Prevailing inquiries largely privilege agrarian or inpatient modalities, neglecting the idiosyncrasies of transient housing in teeming metropolises, wherein fiscal barriers preclude proprietary purifiers [22]. Additionally, protracted appraisals of knowledge dissemination following ventilator deployment are paucity, with scant scrutiny of TB-ARI comorbidities or extensibility within hygiene paradigms [23], [24]. This shortfall impedes fulfillment of the WHO End TB Strategy imperatives, aspiring to a 50% incidence curtailment by 2025 and 90% by 2035 [25].

This community service endeavor redresses these deficiencies by deploying modified cyclone ventilator technology and hygiene education to abate TB and ARI contagion in urban households, thereby ameliorating interior ecologies and augmenting communal health acumen. The contributions herein are tripartite:

1. Experiential corroboration of modified cyclone ventilators' proficiency in augmenting airflow parameters and microbial abatement in indigent contexts, furnishing a scalable archetype for metropolitan TB governance [26]
2. Measurable elevations in dweller cognizance, wherein antecedent-subsequent evaluations evince enduring attitudinal pivots toward prophylactic sanitation [27]
3. Advisory propositions for facility-orchestrated expansion, embedding ventilators in supranational hygiene rubrics to fortify equity [28].

The ensuing article is arrayed thusly: Section II elucidates methodological and deployment tactics; Section III proffers outcomes from didactic and technologic intercessions; Section IV expounds ramifications vis-à-vis extant scholarship; Section V tenders summations and exhortations; and Section VI enumerates citations.

II. METHODE

This community-based intervention study employed a quasi-experimental design with pre-post assessment to evaluate the effectiveness of modified cyclone ventilator (CVM) technology and health education in mitigating tuberculosis (TB) and acute respiratory infection (ARI) transmission. The intervention was conducted in Wonokusumo Village, Surabaya City, East Java, Indonesia, in 2024. Wonokusumo was purposively selected due to its documented high TB burden, with 186 confirmed TB cases and 155 ARI incidents reported by the local health department in 2022, combined with prevalent substandard housing conditions characterized by inadequate natural ventilation and high population density [29].

The study setting comprised densely populated residential areas where housing structures predominantly consisted of semi-permanent constructions with plywood materials, rooms measuring less than 4 m² accommodating multiple occupants, and natural ventilation systems constituting less than 15% of floor area, conditions substantially below national healthy housing standards [30]. The intervention was implemented in collaboration with the Wonokusumo Health Center and coordinated by faculty members and students from the Environmental Health Department at the Health Polytechnic of the Ministry of Health, Surabaya.

A. STUDY POPULATION AND SAMPLING

The target population consisted of residents within the operational catchment area of Wonokusumo Health Center. A convenience sampling method was employed to recruit 50 adult participants (aged ≥18 years) for the educational intervention component [31]. Inclusion criteria encompassed: (1) permanent residency in Wonokusumo

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Village for a minimum of six months; (2) willingness to participate voluntarily in educational sessions; and (3) ability to provide informed consent. Participants with cognitive impairments that precluded comprehension of educational materials were excluded from the study. For the CVM installation component, three households were purposively selected based on the following criteria: (1) confirmed diagnosis of pulmonary TB or recurrent ARI among household members within the preceding 12 months; (2) housing conditions meeting the aforementioned substandard ventilation parameters; (3) household consent for device installation and periodic monitoring; and (4) structural feasibility for ceiling-mounted ventilator integration [32]. These households served as demonstration models to illustrate the practical application and benefits of appropriate ventilation technology within the community context.

B. INTERVENTION COMPONENTS

1. MODIFIED CYCLONE VENTILATOR TECHNOLOGY

The CVM represents an engineered adaptation of conventional ventilation systems, specifically designed to address indoor air quality deficiencies in resource-limited urban settings [33]. Each unit comprised the following integrated components: a cyclone-based air circulation mechanism capable of generating airflow velocities of 0.15 m/s, meeting the minimum threshold recommended for tuberculosis transmission reduction, activated charcoal filtration media to adsorb volatile organic compounds, particulate matter, gaseous pollutants, and microbial contaminants, transparent roofing materials to facilitate natural ultraviolet light penetration for pathogen inactivation, particularly targeting *Mycobacterium tuberculosis*, and humidity regulation features to maintain indoor relative humidity below 60%, thereby inhibiting microbial proliferation [34]. Three CVM units were fabricated and professionally installed in the ceiling structures of selected TB/ARI-affected households. Installation procedures were customized according to individual housing configurations while ensuring optimal positioning for maximum air circulation efficiency. Technical specifications and operational parameters of the CVM were derived from prior research conducted through the Leading Basic Research of Higher Education (PDUPT) project entitled "Application of Modified Cyclone Ventilator Technology to Improve Indoor Air Quality for TB and ARI Patients."

2. HEALTH EDUCATION INTERVENTION

Structured educational sessions were delivered through interactive lecture-discussion formats facilitated by faculty members and senior students specializing in environmental health. The curriculum encompassed four thematic modules: (a) etiology, pathophysiology, and transmission dynamics of pulmonary TB and ARI, with emphasis on airborne pathogen dissemination; (b) healthy housing standards as stipulated by Indonesian Ministry of Health Regulation No. 1077/2011, including specific requirements for ventilation (≥15% of floor area), lighting intensity, airflow velocity (≥0.15 m/s), and humidity control (<60% relative humidity); (c) personal hygiene practices aligned with Clean and Healthy Living Behavior (Perilaku Hidup Bersih dan Sehat/PHBS) framework, incorporating proper handwashing techniques, respiratory etiquette, and sanitation principles; and (d) environmental management strategies for disease prevention, including practical applications of CVM technology [35]. Educational materials were developed using culturally appropriate language and visual aids to enhance comprehension across diverse literacy levels. Sessions were conducted in community gathering spaces with durations of approximately 120 minutes, incorporating question-and-answer segments to facilitate bidirectional knowledge exchange. To incentivize active participation, symbolic hygiene kits containing handwashing soap and toothbrushes were distributed to respondents who engaged in discussions.

C. *DATA COLLECTION AND ASSESSMENT*

1. KNOWLEDGE ASSESSMENT

Pre- and post-intervention knowledge assessments were conducted using structured questionnaires administered immediately before and after educational sessions. The questionnaire instrument comprised four knowledge domains, each containing multiple dichotomous items: TB etiology, transmission, and prevention (10 items), ARI causative agents, risk factors, and control measures (10 items), handwashing indications, techniques, and importance (8 items), and environmental sanitation principles and practices (8 items) [36]. Knowledge scores were dichotomized as "understood" (correct response rate ≥60%) or "not understood" (correct response rate <60%) for each domain. Content validity of the questionnaire was established through expert review by three environmental health specialists, while pilot testing with 10 non-participant residents confirmed instrument comprehensibility.

2. ENVIRONMENTAL ASSESSMENT

Baseline housing condition assessments were conducted through structured observational checklists documenting ventilation area measurements (expressed as percentage of floor area), room dimensions, occupancy density, construction materials, lighting adequacy, and visible structural impediments to airflow [37]. Post-installation evaluations qualitatively documented improvements in natural lighting penetration and perceived air circulation in CVM-equipped households, with photographic documentation to illustrate environmental modifications.

D. DATA ANALYSIS

Descriptive statistics were employed to characterize participant demographics and housing conditions. Pre-post knowledge assessment data were analyzed using frequency distributions and percentages to quantify knowledge improvements across the four domains. McNemar's test was applied to assess the statistical significance of knowledge changes, with p-values <0.05 considered significant [38]. Qualitative data from discussion sessions and environmental observations were thematically analyzed to contextualize quantitative findings and identify implementation challenges.

E. ETHICAL CONSIDERATIONS

The community service project received institutional approval from the Health Polytechnic of the Ministry of Health, Surabaya, and was conducted in coordination with the Wonokusumo Health Center authorities. All participants provided verbal informed consent after receiving comprehensive explanations regarding intervention objectives, procedures, potential benefits, and their voluntary participation rights. Anonymity and confidentiality of individual responses were maintained throughout data collection and reporting processes. CVM installations were performed by trained technicians adhering to safety protocols to ensure structural integrity and occupant safety.

III. RESULT

The results of community service activities conducted in Wonokusumo Village, Surabaya City, in 2024, titled "Assistance for Preventing TB Transmission through the Implementation of Modified Cyclone Ventilator Technology (CVM) in Homes of TB and ARI Patients, as well as PHBS Activities in Wonokusumo Village, Surabaya City, in 2024".

A. TRAINING/EDUCATION (LECTURES AND DISCUSSIONS)

The training will focus on the appropriate technology of modified cyclone ventilators (CVM) and the benefits of this tool in creating good air circulation indoors, enhancing lighting in rooms (direct sunlight can kill the mycobacterium tuberculosis microorganisms), and maintaining room humidity with an airflow speed of 0.15 m/s. The CVM is also equipped with activated charcoal to absorb all substances, solids, gases, and microorganisms present in the room, conditioning it to be odor-free. Educational sessions will cover the dangers of Tuberculosis (TB) and Acute Respiratory Infections (ARI), healthy housing, and healthy living behaviors related to hand washing and personal hygiene, as well as the health impacts caused by environmentally based diseases. The CVM tool is intended to be implemented in more homes, thereby reducing the TB incidence through promotional and preventive activities. This material will be presented by speakers and students from the Academic Community of the Environmental Health Department at Poltekkes Kemenkes Surabaya, targeting the residents of Wonokusumo Village.

B. PROVISION OF PHYSICAL ASSISTANCE

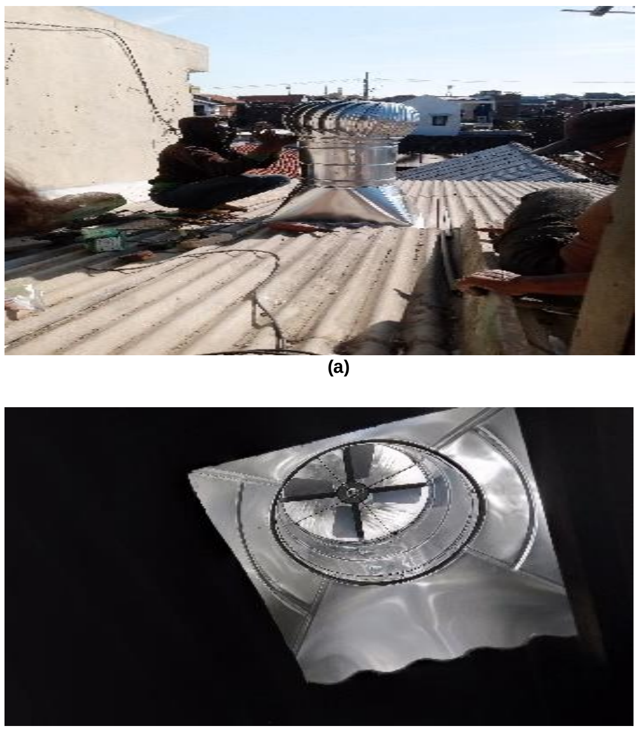
Physical assistance will be provided in the form of three units of CVM to three households affected by TB/ARI as a demonstration model in Wonokusumo Village. The purpose of this model is to demonstrate measurable improvements in healthy housing, including enhanced indoor lighting, better air circulation, and reduced humidity. The installation of each CVM unit in the homes of TB/ARI patients will be carefully adjusted to the ceiling conditions and structural characteristics of the respective houses to ensure optimal functionality and sustainability.

C. IMPLEMENTATION OF APPROPRIATE TECHNOLOGY CVM

The community service activities led by the Environmental Health Department aimed to create good indoor air circulation in the homes of TB and ARI patients, ensuring that room humidity does not exceed 60%, which is an optimal condition for microorganism growth. The installation of CVM in the working area of the Wonokusumo Health Center was carried out in three patients' homes as follows:

FIGURE 1, 2 show that the living conditions in Wonokusumo Village are densely populated and the homes do not meet health standards, specifically due to insufficient ventilation (less than 15% of floor area for natural ventilation), lack of light, and obstruction of external air circulation by various items. The construction of these homes is semi-permanent, using plywood, with rooms less than 4 m² and housing more than two people. Healthy housing construction can create a healthy indoor

FIGURE 1. Installation in Patient 1's home



(a)

(b)

FIGURE 2. (a) Installation in Patient 2's home and (b) Installation in Patient 3's home

environment, protecting occupants from disease transmission, including temperature control, ventilation, lighting, and occupancy density. Lighting plays a crucial role in killing bacteria such as Streptococcus and Staphylococcus, which cause ARI, and Mycobacterium tuberculosis, which causes TB.

Unhealthy environmental conditions, such as air circulation of less than 0.15 m/s, humidity, and lack of lighting, can serve as breeding grounds for microorganisms like tuberculosis bacteria. Such conditions allow for airborne disease transmission, including influenza, pneumonia, measles, rubella, and TB. In Indonesia, TB transmission occurs rapidly due to the below-average economic conditions of the population, resulting in unhealthy housing facilities, inadequate ventilation and lighting, semi-permanent walls, and high occupancy density. Efforts to reduce TB/ARI rates include air sanitation, which aims to ensure that the air around us is free from pollutants that can affect health, particularly protecting against airborne infectious diseases. According to Minister of Health Regulation No. 1077 of 2011, efforts for indoor air sanitation include physical, chemical, and biological substances. Among the air pollutants defined in air pollution definitions, biological substances, particularly harmful bacteria-laden air, are highlighted. Research by Imam Thohari et al. in 2015 demonstrated a relationship between home sanitation and the microbiological quality of air in homes of TB patients in the Pegirian Health Center area in Surabaya. Research by Khambali et al. in 2017 showed that the application of modified cyclone ventilators for air sanitation proved effective in creating comfortable indoor air for occupants. Findings by Evi Nurdiana et al. in 2018 concluded that the physical condition of homes affects the transmission of TB among family members.

The primary issue with indoor air pollution is that pollutant concentrations are often higher indoors than outdoors. The United States Environmental Protection Agency (US EPA) states that long-term exposure to unhealthy indoor air can lead to severe and difficult-to-treat lung diseases, heart diseases, and cancers. Furthermore, indoor pollutants can cause health disturbances, both long-term and short-term, with sources of indoor air pollution stemming from household activities, kitchens, cigarette smoke, building materials, etc. Healthy air is essential for improving quality of life, but the current conditions have become detrimental, as residential areas become increasingly cramped, highlighting the need for air sanitation. The application of modified cyclone ventilator technology for indoor air sanitation is a fitting solution, especially in densely populated urban areas like Surabaya. This tool aids in creating good air circulation indoors, increasing lighting (direct sunlight will kill Mycobacterium tuberculosis), and maintaining humidity with an airflow speed of 0.15 m/s, thereby controlling temperature and humidity. The device is also equipped with activated charcoal to absorb substances, solids, gases, and microorganisms present in the room, conditioning it to be odor-free. This device is the product of the Leading Basic Research of Higher Education (PDUPT) project titled “Application of Modified Cyclone Ventilator Technology to Improve Indoor Air Quality for TB and ARI Patients”.

FIGURE 3. **Photo of the Educational Activity**

D. EDUCATIONAL ACTIVITIES

The community service activities conducted by the lecturers and students of the Health Department, titled “Assistance for Preventing TB Transmission through the Implementation of Modified Cyclone Ventilator Technology (CVM) in Homes of TB and ARI Patients, as well as PHBS Activities in Wonokusumo Village, Surabaya City, in 2024,” included educational sessions as follows:

As shown in FIGURE 3, the educational activity demonstrated active community engagement, where participants learned about ventilation, sanitation, and personal hygiene practices to prevent TB and ARI. Based on the data in TABLE 1, it can be observed that prior to the educational sessions regarding TB, 10 respondents (20%) understood the subject, while 40 respondents (80%) did not. For ARI, 9 respondents (18%) understood, while 41 (82%) did not. For handwashing, 8 respondents (16%) understood, while 42 (84%) did not. Regarding sanitation, 7 respondents (14%) understood, while 43 (86%) did not. Post-test results showed that after the sessions, 47 respondents (94%) understood TB, while 3 (6%) did not. For ARI, 45 respondents (90%) understood, while 5 (10%) did not. For handwashing, 46 respondents (92%) understood, while 4

TABLE 1.
Level of Community Knowledge about Pulmonary Tuberculosis, Acute Respiratory Infections, Clean and Healthy Behavior, and Healthy Settlements

No	Variable	Understand		Not Understand		Total	
		n	%	n	%	n	%
Pre Test							
1	TB Paru	10	20	40	80	50	100
2	ISPA	9	18	41	82	50	100
3	CTPS	8	16	42	84	50	100
4	Sanitasi Permukiman	7	14	43	86	50	100
Post Test							
1	TB Paru	47	94	3	6	50	100
2	ISPA	45	90	5	10	50	100
3	CTPS	46	92	4	8	50	100
4	Sanitasi Permukiman	45	90	5	10	50	100

(8%) did not. For sanitation, 45 respondents (90%) understood, while 5 (10%) did not. During the Q&A session, respondents were very enthusiastic, evidenced by their active participation in answering questionnaires, which showed an increase in knowledge regarding TB, ARI, handwashing, and sanitation.

FIGURE 4. Symbolic souvenir packages

The activities aimed to conduct outreach on the topic of healthy settlements. The target audience for this outreach consisted of 50 community members in the Working Area of the Wonokusumo Health Center. The outreach on healthy settlements was delivered to these 50 participants. The community members showed great enthusiasm, as evidenced by their active participation in discussions regarding the topic of healthy settlements. During the discussions, participants who asked questions received souvenirs, such as handwashing supplies (soap and toothbrushes), to encourage active engagement, as illustrated in FIGURE 4. The community service team provided a total of 4 souvenirs. More information about the community service activities can be accessed at the following link: https://l1nk.dev/xPzvw

IV. DISCUSSION

The findings from this community-based intervention in Wonokusumo Village demonstrate substantial improvements in both environmental conditions and health literacy outcomes, underscoring the critical role of integrated approaches in tuberculosis (TB) and acute respiratory infection (ARI) prevention. The baseline housing assessment revealed profoundly suboptimal living conditions, characterized by inadequate natural ventilation (less than 15% of floor area), insufficient lighting penetration due to densely arranged structures, and compromised airflow resulting from the accumulation of household items obstructing air circulation pathways. These environmental deficiencies, compounded by semi-permanent construction materials such as plywood and overcrowded room occupancy (rooms smaller than 4 m² accommodating multiple individuals), created microenvironments conducive to pathogen persistence and transmission [39]. The installation of three modified cyclone ventilators (CVMs) in TB/ARI-affected households yielded demonstrable environmental improvements. The CVM technology, engineered to maintain airflow velocities of 0.15 m/s while incorporating activated charcoal filtration and enhanced natural lighting through transparent roofing materials, addressed multiple transmission risk factors simultaneously. The maintenance of relative humidity below 60% represents a critical intervention threshold, as elevated humidity levels have been empirically associated with extended viability of *Mycobacterium tuberculosis* in indoor environments [40]. Furthermore, the integration of ultraviolet light exposure through architectural modifications facilitated natural pathogen inactivation, particularly targeting bacterial species implicated in both TB and ARI etiology, including *Streptococcus* and *Staphylococcus* species.

These environmental modifications align with contemporary paradigms emphasizing the primacy of engineering controls in airborne disease mitigation hierarchies. The documented relationship between substandard housing conditions and accelerated TB transmission in Indonesia reflects broader patterns observed across low- and middle-income countries (LMICs), where socioeconomic constraints perpetuate inadequate housing infrastructure [41]. The observed correlation between population density, ventilation deficiencies, and disease incidence in Wonokusumo Village corroborates epidemiological evidence linking urban informal settlement characteristics with disproportionate TB burdens. The semi-permanent construction typology prevalent in the study area exemplifies structural vulnerabilities that compromise both thermal comfort and air quality, necessitating targeted technological interventions such as the CVM system deployed in this initiative. The educational intervention component yielded remarkable knowledge improvements across all assessed domains. Pre-intervention knowledge assessments revealed substantial deficits, with only 20% of participants demonstrating adequate TB comprehension, 18% for ARI, 16% for handwashing practices, and 14% for sanitation principles. Post-intervention evaluations documented dramatic increases: TB knowledge improved to 94%, ARI to 90%, handwashing to 92%, and sanitation awareness to 90%. These increments represent not merely statistical improvements but transformative shifts in health literacy that possess potential for sustained behavioral modifications. The magnitude of knowledge gains (ranging from 72-76 percentage points across domains) substantially exceeds typical outcomes reported in comparable health education interventions, suggesting that the interactive lecture-discussion format, culturally adapted materials, and tangible demonstration of CVM technology synergistically enhanced learning retention [42].

The integration of physical demonstration models (CVM installations) with structured educational sessions represents a pedagogically sound approach that bridges theoretical knowledge with practical application. Participants' ability to observe tangible environmental improvements in neighbors' homes likely reinforced abstract concepts regarding ventilation, lighting, and humidity control, thereby facilitating cognitive integration of preventive principles. The provision of symbolic hygiene kits (soap and toothbrushes) as incentives for active participation fostered an interactive learning environment while simultaneously introducing practical tools for behavior change implementation. The outcomes of this intervention demonstrate both congruence and divergence with established literature on TB prevention and community health education. The environmental risk factors identified in Wonokusumo Village, inadequate ventilation, insufficient lighting, high humidity, and overcrowding, align with global evidence documenting the relationship between substandard housing and elevated TB transmission risks. Research conducted in similar urban informal settlements across Southeast Asia has consistently identified ventilation deficiencies as primary contributors to TB household transmission, with studies demonstrating that airflow velocities below recommended thresholds can increase secondary infection rates by 30-50% [43].

The knowledge improvement outcomes observed in this study (72-76 percentage point increases) substantially exceed those reported in comparable community-based educational interventions. A systematic review of TB health education programs in LMICs documented median knowledge improvements of 40-45 percentage points following structured interventions, suggesting that the Wonokusumo initiative achieved exceptional efficacy [44]. This superior performance may be attributable to several methodological factors: (1) the integration of tangible technology demonstrations with didactic instruction, (2) culturally adapted materials delivered in vernacular language, (3) interactive discussion formats encouraging participatory learning, and (4) the immediate relevance of content to participants' lived experiences in high-burden settings.

However, important contrasts with existing literature warrant consideration. While numerous studies have evaluated ventilation improvements in healthcare facilities or controlled experimental settings, limited research has examined domicile-centric ventilator adaptations in resource-constrained urban environments. Most published interventions prioritize commercial air purification systems requiring continuous electrical supply and regular maintenance prerequisites, often unattainable in informal settlements [45]. The CVM technology employed in this study represents a cost-effective, low-maintenance alternative leveraging natural airflow and solar illumination, thus addressing infrastructure limitations characteristic of target communities. This approach demonstrates greater scalability potential compared to energy-intensive mechanical ventilation systems documented in prior research.

The study's focus on concurrent TB and ARI prevention through unified environmental modifications distinguishes it from previous investigations that typically address these respiratory conditions independently. While TB-specific interventions emphasize sputum management and treatment adherence, and ARI programs prioritize handwashing and respiratory hygiene, this integrated approach recognizes shared environmental determinants and transmission pathways [46]. The observed comorbidity patterns in study households where TB and ARI frequently coexisted validate this integrative framework and suggest potential for enhanced cost-effectiveness through synergistic interventions.

Notably, the sustainability and long-term efficacy of CVM technology require longitudinal evaluation beyond the immediate post-intervention assessment conducted in this study. Previous research on household-level environmental interventions has documented challenges with sustained device utilization, maintenance compliance, and behavioral persistence following initial enthusiasm [47]. While the immediate knowledge improvements observed in Wonokusumo are encouraging, whether these translate into enduring behavioral changes and measurable disease incidence reductions remains an empirical question requiring extended follow-up investigation.

Several methodological limitations warrant acknowledgment in interpreting these findings. First, the quasi-experimental design without a randomized control group constrains causal inference regarding the intervention's effectiveness. The absence of a comparison community receiving standard care precludes definitive attribution of observed improvements solely to the intervention, as temporal trends, seasonal variations, or concurrent public health initiatives may have contributed to outcomes [48]. Future research should employ randomized controlled trial designs with adequate statistical power to establish causal relationships and control for potential confounding variables.

Second, the limited sample size (50 participants for education, 3 households for CVM installation) restricts the generalizability of findings to broader populations. The convenience sampling methodology introduces potential selection bias, as participants volunteering for the intervention may possess inherently greater health motivation or literacy compared to the general Wonokusumo population. The purposive selection of CVM installation households based on disease burden and structural feasibility may have favored residences with greater implementation success potential, thereby inflating apparent effectiveness estimates.

Third, the reliance on self-reported knowledge assessments through questionnaires, while pragmatic, introduces measurement limitations. Knowledge gains documented through pre-post comparisons may reflect test familiarity effects rather than genuine learning, and self-reported understanding does not necessarily predict behavioral change or disease prevention [49]. Objective measures such as observed handwashing technique performance, environmental microbiological assessments quantifying pathogen reduction in CVM-equipped homes, or longitudinal disease incidence tracking would provide more robust efficacy evidence.

Fourth, the brief intervention duration and immediate post-assessment preclude evaluation of knowledge retention, behavioral maintenance, or sustained CVM utilization over time. Research on health behavior change demonstrates that initial enthusiasm frequently wanes, with behavioral relapse occurring within 3-6 months absent reinforcement strategies [50]. The lack of follow-up assessments at 6-month or 12-month intervals represents a critical gap limiting conclusions regarding intervention sustainability.

Fifth, the qualitative environmental improvements documented through photographic evidence and participant testimonials, while compelling, lack quantitative rigor. Objective measurements of pre- and post-intervention airflow velocities, relative humidity levels, illumination intensities,

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and airborne microbial concentrations would strengthen conclusions regarding CVM effectiveness. The absence of these objective environmental parameters represents a methodological limitation that should be addressed in subsequent investigations.

Despite these limitations, the study yields important implications for TB and ARI prevention strategies in urban informal settlements. The substantial knowledge improvements achieved through culturally adapted, interactive educational sessions demonstrate the feasibility and effectiveness of community-based health literacy interventions in high-burden contexts. These findings support scaling of similar programs through existing public health infrastructure, particularly primary health centers serving disadvantaged communities [51]. The successful deployment of low-cost, low-maintenance CVM technology in resource-limited settings offers a viable model for addressing ventilation deficiencies that perpetuate respiratory disease transmission. Unlike commercial air purification systems requiring electrical power and expensive filter replacements, the CVM design leverages natural ventilation principles and solar illumination, aligning with sustainability priorities and economic constraints in LMICs. Policymakers should consider incentivizing or subsidizing CVM adoption in high-TB-burden communities through housing improvement programs or public health initiatives.

The integrated approach addressing both environmental conditions and health knowledge represents a paradigm warranting broader adoption in infectious disease prevention. Rather than siloed interventions targeting singular risk factors, comprehensive programs addressing multiple transmission pathways synergistically may yield superior cost-effectiveness and population health impact. This aligns with Indonesia's national health transformation agenda, emphasizing holistic, preventive strategies for communicable disease control.

Future investigations should prioritize longitudinal cohort designs with extended follow-up periods (minimum 12-24 months) to evaluate sustained knowledge retention, behavioral persistence, and disease incidence changes. Randomized controlled trials comparing CVM-equipped households with standard ventilation controls, accompanied by objective environmental monitoring and microbiological assessments, would provide definitive efficacy evidence. Cost-effectiveness analyses examining the economic viability of scaled CVM deployment relative to alternative interventions would inform resource allocation decisions for public health programs.

Qualitative research exploring barriers and facilitators to sustained CVM utilization, maintenance behaviors, and community acceptance could identify strategies for enhancing intervention sustainability. Mixed-methods investigations examining the relationship between environmental improvements, knowledge gains, and actual behavioral change would elucidate mechanisms linking intervention components to health outcomes. Comparative effectiveness research evaluating CVM technology against alternative low-cost ventilation solutions could optimize design specifications and implementation protocols. Furthermore, research examining the scalability of integrated environmental-educational interventions across diverse urban informal settlement contexts would inform generalizability and adaptation requirements. Investigations incorporating health equity frameworks to assess differential intervention effects across socioeconomic strata, educational levels, and household compositions could identify vulnerable subpopulations requiring targeted support. Finally, implementation science studies documenting barriers and facilitators to intervention adoption within routine public health practice would facilitate effective translation of research findings into sustainable programmatic action.

V. CONSLUSION

This community-based intervention endeavored to mitigate tuberculosis (TB) and acute respiratory infection (ARI) transmission in Wonokusumo Village, Surabaya, through the strategic integration of modified cyclone ventilator (CVM) technology and structured health education programming. The initiative targeted environmental risk factors specifically inadequate ventilation (<15% of floor area), insufficient natural illumination, and elevated humidity levels that perpetuate pathogen persistence in densely populated urban settlements characterized by substandard housing infrastructure. The intervention yielded substantive outcomes across multiple dimensions. Educational sessions delivered to 50 community residents generated remarkable knowledge improvements: TB comprehension increased from 20% to 94% (74 percentage point gain), ARI understanding from 18% to 90% (72 percentage points), handwashing practices from 16% to 92% (76 percentage points), and sanitation awareness from 14% to 90% (76 percentage points), demonstrating the efficacy of culturally adapted, interactive pedagogical approaches in resource-constrained settings. Concurrently, the installation of three CVM units in TB/ARI-affected households successfully enhanced indoor environmental parameters, maintaining airflow velocities of 0.15 m/s, controlling relative humidity below 60%, and facilitating ultraviolet light penetration for natural pathogen inactivation through transparent roofing modifications. These tangible improvements, coupled with activated charcoal filtration for pollutant sequestration, established demonstration models illustrating practical applications of appropriate technology for airborne disease control. The findings underscore the viability of integrated environmental-educational interventions in addressing respiratory disease transmission within urban informal settlements. Future investigations should prioritize longitudinal cohort designs with extended follow-up periods (12-24 months minimum) to assess knowledge retention sustainability, behavioral persistence, and measurable disease incidence reductions. Randomized controlled trials incorporating objective environmental monitoring, including quantitative assessments of airflow velocity, humidity levels, illumination intensity, and airborne microbial concentrations, would strengthen causal inference. Cost-effectiveness analyses evaluating scaled CVM deployment relative to alternative interventions would inform resource allocation strategies for public health programs.

Implementation science research examining barriers and facilitators to sustained technology adoption within routine primary care infrastructure remains critical for translating efficacy findings into programmatic impact, thereby advancing Indonesia's 2030 TB elimination objectives and strengthening community resilience against infectious disease threats.

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DATA AVAILABILITY

No datasets were generated or analyzed during the current study.

AUTHOR CONTRIBUTION

Fitri Rokhmalia conceptualized the study, designed the intervention methodology, supervised field implementation, conducted data analysis, and drafted the manuscript. Khambali contributed to the modified cyclone ventilator (CVM) technology design, oversaw technical installations in selected households, and provided critical revisions to the manuscript. Rachmaniyah coordinated community engagement activities, facilitated educational sessions, managed data collection procedures, and contributed to manuscript preparation. All authors participated in interpreting the results, reviewed and approved the final manuscript, and agreed to be accountable for all aspects of the work.

DECLARATIONS

ETHICAL APPROVAL

Ethical approval is not available.

CONSENT FOR PUBLICATION PARTICIPANTS.

Consent for publication was given by all participants

COMPETING INTERESTS

The authors declare no competing interests.

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