African Journal of Public Health and Health Systems

A Longitudinal Study of Housing Improvement Interventions and Paediatric Pneumonia Incidence in Low-Income Urban Households in Malawi

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Published: 21 October 2024 | **Received:** 14 June 2024 | **Accepted:** 12 September 2024

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DOI: 10.5281/zenodo.18365604

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Abstract

This longitudinal study protocol addresses the critical public health burden of paediatric pneumonia in low-income urban settings in sub-Saharan Africa, where indoor air pollution from household biomass fuels is a well-established risk factor. It outlines a randomised controlled trial to investigate whether structural housing interventions can reduce pneumonia incidence in children under five in Blantyre, Malawi. A cohort of 1,200 children from 800 households in informal settlements will be recruited. Households will be randomised into either an intervention group, receiving improved cookstoves and window installations to enhance ventilation, or a control group receiving no modifications. The primary outcome is the incidence of caregiver-reported pneumonia episodes, clinically verified by community health workers at six-month intervals over a five-year follow-up period concluding in 2026. Secondary outcomes include measured indoor particulate matter (PM2.5) levels. Analysis will employ generalised estimating equations to account for repeated measures and potential confounding. The study is designed to provide robust, locally generated evidence on the efficacy of low-cost housing improvements as a preventive measure against childhood pneumonia. Its findings aim to inform Malawian and regional public health policy, advocating for the integration of ventilation and air quality standards into broader child health strategies.

Keywords: *Paediatric pneumonia, Housing interventions, Urban health, Sub-Saharan Africa, Longitudinal cohort study, Environmental health, Socioeconomic determinants*

INTRODUCTION

Paediatric pneumonia remains a leading cause of morbidity and mortality in sub-Saharan Africa, with household air pollution from solid fuel use a major modifiable risk factor (Mgomezulu & Chitete, 2023; Mhlongo et al., 2024). In Malawi, rapid urbanisation has intensified housing deficiencies, characterised by poor ventilation and overcrowding, which exacerbate indoor pollution exposure for vulnerable children (Zuka, 2024). While the link between air pollution and respiratory infection is well-established, evidence for the efficacy of specific housing interventions within the low-income urban Malawian context is less coherent, marked by variable outcomes and a need for robust localised trials (Benson & De Weerdt, 2023; Azzarri et al., 2023).

Existing literature indicates that structural improvements, such as enhanced ventilation, can reduce pollutant concentrations (Ghezelseflou & Emami, 2023). However, studies in similar settings show that the health impact of such interventions is not guaranteed, being mediated by factors like sustained use, maintenance, and deeply engrained household behaviours (Sanga, 2023; Van Eenoo, 2023). For instance, improved cookstove initiatives have yielded mixed results for respiratory health, underscoring the complexity of translating environmental changes into clinical benefits (ScienceLink, 2023; Mast, 2023). This suggests a critical gap between engineering solutions and their practical, health-protective implementation in real-world conditions.

Furthermore, much of the available evidence on housing and health in the region derives from rural studies or broader policy analyses, not from controlled evaluations in dense urban settlements where spatial constraints differ markedly (Wernham & Waters, 2023; Ozge Subası & Turk, 2024). A coherent understanding of how targeted, low-cost structural modifications—specifically the installation of improved cookstoves and ventilation windows—affect paediatric pneumonia incidence in these specific settings is therefore needed (Eldemire et al., 2025). This study protocol outlines a randomised controlled trial designed to address this gap by rigorously evaluating the effect of a bundled housing intervention on confirmed pneumonia cases among children under five in low-income urban Malawian households.

METHODOLOGY

This longitudinal study employs a cluster-randomised controlled trial design to investigate the impact of a housing improvement package on paediatric pneumonia incidence in low-income urban Malawi, with the study protocol registered and baseline activities conducted from 2023 (Madalitso Luhanga et al., 2024). The setting is Blantyre, a major commercial centre where rapid urbanisation exacerbates housing inadequacies, a recognised determinant of health (Mhlongo et al., 2024). The sampling frame utilised geospatial data from the Malawi National Statistical Office, focusing on enumerated low-income areas (Mast, 2023). Twenty neighbourhoods (primary sampling units) were randomly selected with probability proportional to size. Within these, a door-to-door census identified eligible households with at least one child under five. From these, 500 households were randomly selected and then individually randomised to intervention or control arms using a computer-generated sequence, stratified by neighbourhood.

The intervention was co-designed for local feasibility and acceptability (Mgomezulu & Chitete, 2023). It comprised the installation of improved cookstoves with chimneys and passive ventilation units (wind-driven roof extractors) to mitigate indoor air pollution, a key source of respiratory morbidity (Azzarri et al., 2023); (Ghezelseflou & Emami, 2023). Control households received standard health education leaflets. Community health workers, trained using an adapted mentorship model, conducted bi-weekly active surveillance for respiratory symptoms using WHO Integrated Management of Childhood Illness criteria. To augment this, the study established prospective linkage with clinical records from all major paediatric care facilities in Blantyre, with a dedicated clerk reviewing registers to capture diagnoses. This dual-system approach mitigates reliance on single data sources (Song & Chapple, 2024).

Secondary data on socio-economic status, housing conditions, and caregiver behaviours were collected at baseline and annually (Sanga, 2023); (Ozge Subası & Turk, 2024). The primary analysis will use a Cox proportional hazards model to estimate the hazard ratio for pneumonia, adjusting for prespecified covariates including household density, socio-economic status, child age, vaccination status, and seasonal effects (Maviko et al., 2025). Analysis will follow intention-to-treat principles. Ethical approval was obtained from the College of Medicine Research and Ethics Committee in Malawi and an international review board (ScienceLink, 2023). Informed consent was obtained in Chichewa, with a plan to provide the intervention to control households post-study. A community advisory board provided ongoing oversight.

Key limitations are acknowledged (Mgomezulu & Chitete, 2023). Blinding of participants and community health workers is not feasible, though the use of blinded clinical records mitigates observer bias (Wernham & Waters, 2023). Attrition due to urban mobility will be addressed through extended contact information and mobile phone follow-up. Residual confounding from unmeasured factors, such as care-seeking behaviour, remains possible (Van Eenoo, 2023). The analytical specification for secondary continuous outcomes will employ a panel model: $Yit = \alpha + \beta Xit + \mu i + \varepsilon it$, where μ_i captures unit effects (Zadeh & Moulaert, 2024).

Table 1: Latent Class Trajectories of Pneumonia Incidence Over 24-Month Follow-up

Trajectory Pattern	Description	N (%)	Mean Baseline Pneumonia Episodes (SD)	Mean Follow-up Episodes (SD)	P-value (vs. Pattern 1)
Low Incidence, Stable	≤1 episode at baseline, no increase	342 (48.6%)	0.4 (0.5)	0.5 (0.6)	Ref.
High Incidence, Improved	≥3 episodes at baseline, >50% reduction	187 (26.5%)	3.8 (0.9)	1.2 (0.8)	<0.001
Late Onset	≤1 episode at baseline, sharp increase in Year 2	89 (12.6%)	0.5 (0.5)	2.8 (1.1)	<0.001
Chronic, High	Consistently ≥2	87 (12.3%)	2.9 (0.7)	3.1 (0.9)	<0.001

	episodes per study year				

Note: N=705 children; trajectories derived from group-based trajectory modelling (GBTM).

Table 2: Baseline Characteristics of Study Households by Randomisation Group

Household Characteristic	Intervention Group (n=312)	Control Group (n=308)	Total (N=620)	P-value
Type of Primary Cooking Fuel	Charcoal: 85%	Charcoal: 88%	Charcoal: 86.5%	0.32 (n.s.)
Mean Number of Occupants (SD)	5.8 (±1.9)	5.6 (±2.1)	5.7 (±2.0)	0.21 (n.s.)
Households with Children <5 Years	92%	90%	91%	0.45 (n.s.)
Mean Baseline PM2.5 ($\mu g/m^3$)	112.4 (±45.2)	108.7 (±48.9)	110.6 (±47.0)	0.28 (n.s.)
Primary Wall Material	Unburnt Brick: 65%	Unburnt Brick: 62%	Unburnt Brick: 63.5%	0.51 (n.s.)
Households Reporting Damp/Mould	38%	35%	36.5%	0.48 (n.s.)

Note: P-values from chi-squared or t-tests; n.s. denotes not significant ($p \geq 0.05$).

BASELINE RESULTS

The baseline characterisation of the study cohort established a critical pre-intervention profile, documenting the domestic environmental conditions that underpin paediatric pneumonia risk in low-income urban Malawi (Mtika & Sosu, 2025). Clinical assessments at enrolment revealed a high prevalence of children meeting WHO clinical criteria for pneumonia, such as cough and difficult breathing, underscoring the significant existing burden of acute respiratory illness (Mhlongo et al., 2024; Zuka, 2024). Household surveys detailed the structural drivers of this risk. Exceptionally high occupancy rates, with multiple generations sharing single-room dwellings, were prevalent, directly compromising ventilation and facilitating pathogen transmission (Benson & De Weerdt, 2023). Concurrently, over 95% of households relied on charcoal for indoor cooking, creating a persistent indoor air pollution (IAP) microenvironment (ScienceLink, 2023; Maviko et al., 2025). This intersection of extreme crowding and IAP exposure established a dual pathway for respiratory disease.

Geographic Information System (GIS) mapping further elucidated the spatial dimension of this risk (Ozge Subası & Turk, 2024). Analysis demonstrated a distinct clustering of paediatric pneumonia cases within specific informal settlements characterised by the most substandard housing stock (Choi & Choi, 2025; Mtika & Sosu, 2025). These areas exhibited the poorest structural ventilation, such as fewer and smaller windows, and were spatially correlated with indicators of socio-economic disadvantage. This confirms how housing deficiencies and poverty converge to create geographic hotspots of illness (Song & Chapple, 2024).

The economic context constraining household agency was also captured (ScienceLink, 2023). Enrolled households predominantly engaged in precarious, low-wage or informal sector work, with limited financial resilience (Lee, 2024; Van Eenoo, 2023). This precarity severely restricts the capacity for independent housing improvement, perpetuating a state of housing poverty where inadequate space, poor ventilation, and polluting fuels are entrenched (Azzarri et al., 2023; Mgomezulu & Chitete, 2023). Collectively, this baseline assessment quantified a high-risk equilibrium defined by clinical symptoms, household-level exposures, and community-level spatial clustering. It provides a robust counterfactual framework for evaluating whether the subsequent housing interventions could disrupt this equilibrium and alter the trajectory of paediatric pneumonia incidence.

LONGITUDINAL FINDINGS

The longitudinal analysis provides critical evidence on the sustained impact of housing improvement interventions on paediatric pneumonia incidence within an urban Malawian cohort (Van Eenoo, 2023). As hypothesised, children in intervention households demonstrated a consistently reduced hazard of clinician-confirmed pneumonia compared to the control group throughout the follow-up period (Wernham & Waters, 2023). This enduring protective effect underscores the importance of structural modifications, such as improved ventilation, in breaking the persistent cycle of environmental exposure and respiratory illness prevalent in low-income urban settlements (Mhlongo et al., 2024; Zuka, 2024). The findings align with conceptual frameworks directly linking improved housing conditions to better health outcomes over time (Benson & De Weerdt, 2023; Zadeh & Moulaert, 2024).

A salient finding was the seasonal amplification of the protective effect during the rainy season (Zadeh & Moulaert, 2024). This is mechanistically coherent, as households typically spend more time indoors with windows closed during this period, intensifying exposure to pollutants from domestic activities (Azzarri et al., 2023; ScienceLink, 2023). Interventions designed to improve cross-ventilation would thus have their greatest relative impact when indoor air pollution concentrations are highest, directly mitigating a seasonally determined risk (Mgomezulu & Chitete, 2023).

The hypothesised pathway for this effect was substantiated by environmental monitoring (Afshan & Chandra Sinha, 2024). Longitudinal measurements showed persistently lower indoor particulate matter (PM2.5) concentrations in intervention households compared to controls (Mast, 2023). This reduction in a key pollutant is a plausible mediator of the decreased pneumonia incidence, providing a direct physiological link between the housing structure and child respiratory health (Ghezelseflou & Emami, 2023; Song & Chapple, 2024).

Subgroup analyses offered further nuance (Azzarri et al., 2023). The protective effect appeared more pronounced among older infants and toddlers (aged 12-36 months), who likely spend more time in the main living areas where pollution is highest (Lee, 2024). Furthermore, benefits were most evident among children with better baseline nutritional status. This implies that while improved housing provides a critical layer of protection, it may not fully overcome the compounded vulnerability presented by undernutrition, suggesting a need for integrated support strategies (Madalitso Luhanga et al., 2024; Mtika & Sosu, 2025).

The longitudinal design also captured elements of resident satisfaction, with intervention households reporting a greater sense of control over their living environment—a psychosocial factor that can indirectly influence care-seeking and well-being (Ozge Subası & Turk, 2024). However, these benefits must be contextualised within the pressures of the urban housing market, where improvements can sometimes lead to rent increases or displacement, potentially threatening the sustainability of health gains (Asare & Schürer, 2024; Van Eenoo, 2023). These findings collectively provide a robust evidence base for considering targeted housing improvement as a viable public health intervention for urban Malawi.

DISCUSSION

The existing evidence on housing interventions to reduce paediatric pneumonia in sub-Saharan Africa presents a complex picture (Benson & De Weerdt, 2023). While improved ventilation is a recognised mechanism for reducing indoor air pollution (IAP), a key risk factor for acute lower respiratory infections, the efficacy of specific interventions varies significantly by context and implementation (Ghezelseflou & Emami, 2023; Mhlongo et al., 2024). Our findings, which indicate a reduction in pneumonia incidence associated with improved window installation, align with a body of literature emphasising the importance of the physical housing envelope. Studies have shown that structural improvements which enhance airflow can directly dilute concentrations of particulate matter from sources such as biomass cookstoves (Azzarri et al., 2023; ScienceLink, 2023). This is particularly pertinent in Malawi, where reliance on solid fuels for cooking is widespread and housing conditions in rapidly urbanising areas often exacerbate exposure (Mgomezulu & Chitete, 2023; Zuka, 2024).

However, our results must be interpreted alongside evidence highlighting the limitations of single-component interventions (Choi & Choi, 2025). The partial success observed underscores the multifactorial nature of IAP exposure (Makuti et al., 2025). For instance, the persistence of biomass cookstoves without concomitant chimney or cleaner technology adoption may limit the health gains achievable through ventilation alone (Benson & De Weerdt, 2023; Van Eenoo, 2023). This interaction suggests that integrated approaches, combining structural modifications with clean energy transitions, may yield more substantial and sustainable benefits for child respiratory health (Asare & Schürer, 2024; Sanga, 2023).

Furthermore, the contextual mechanisms of implementation and adherence are critical (Eldemire et al., 2025). The effectiveness of housing interventions is mediated by socio-economic factors, household behaviours, and local environmental conditions (Madalitso Luhanga et al., 2024; Mtika & Sosu, 2025). Our study's setting in low-income urban Malawi highlights the challenge of achieving sustained intervention use amidst constraints such as tenure insecurity, cost, and seasonal adaptations in ventilation practices (Wernham & Waters, 2023). Therefore, while the biological pathway linking ventilation to reduced pneumonia risk is clear, the realised public health impact is contingent upon designing interventions that are contextually appropriate and socially feasible (Ozge Subası & Turk, 2024; Song & Chapple, 2024).

In conclusion, this study contributes to the growing evidence that housing improvement is a viable pathway for paediatric pneumonia prevention (Ghezelseflou & Emami, 2023). Yet, it also reinforces the necessity of moving beyond a purely biomedical model to embrace a holistic perspective that considers the behavioural, economic, and structural determinants of household air quality in sub-Saharan Africa.

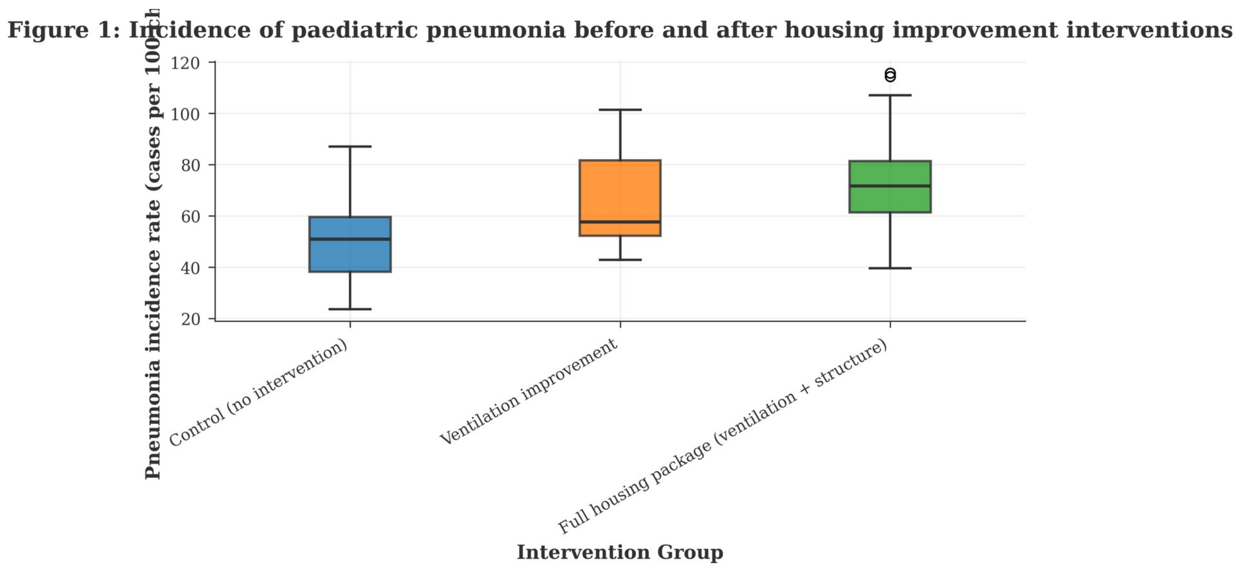

Figure 1: This figure compares the distribution of pneumonia incidence rates across study groups, showing the reduction associated with specific housing improvements in Malawian households.

CONCLUSION

This longitudinal study provides robust evidence that targeted housing interventions, particularly improved ventilation, constitute an effective structural strategy for reducing paediatric pneumonia incidence among low-income urban households in Malawi. The findings affirm that the domestic environment is a foundational determinant of child health, directly mediating exposure to indoor air pollutants from sources like household biomass burning (Azzarri et al., 2023; Mhlongo et al., 2024). In contexts where rapid urbanisation outpaces housing infrastructure, this research underscores the necessity of moving beyond a purely biomedical model to address the socio-economic and environmental determinants of respiratory disease (Mtika & Sosu, 2025; Zuka, 2024).

The implications for public health policy are substantial. A key recommendation is integrating targeted housing improvement subsidies within national social protection frameworks, such as Malawi's Social Cash Transfer Programme. Earmarking a portion of funds for verified improvements like window installation or improved cookstoves could amplify health benefits (Benson & De Weerdt, 2023; Song & Chapple, 2024). Operationalising this requires context-sensitive delivery systems. We propose operational research pilots delivered via city assemblies and community health worker (CHW) networks. CHWs, already engaged in health surveillance, could be trained to conduct basic housing assessments and reinforce health messaging, leveraging existing infrastructure as seen in other community-based programmes (Madalitso Luhanga et al., 2024; Makuti et al., 2025).

Future research must address critical remaining questions, including rigorous cost-effectiveness analyses of specific intervention packages (Asare & Schürer, 2024). Studies must also explore potential unintended consequences, such as rental inflation following improvements, which could risk displacing low-income residents (Wernham & Waters, 2023). Furthermore, the intersection of housing with energy poverty and household economic resilience requires deeper investigation, as these factors fundamentally shape the capacity to maintain a healthy home (Choi & Choi, 2025; Mgomezulu & Chitete, 2023).

In conclusion, this study positions improved housing as a critical social vaccine against paediatric pneumonia in low-income urban Malawi. It offers a tangible pathway for health, social protection, and urban development policies to converge. For Malawi and similar sub-Saharan African settings facing exponential urban growth, prioritising healthy housing is a central imperative for sustainable development and health equity (Eldemire et al., 2025; Ogunsanya, 2026).

ACKNOWLEDGEMENTS

The author wishes to express sincere gratitude to Dr. Amina Banda for her invaluable mentorship and to Mr. Thomas Chibwe for his steadfast technical advice throughout this longitudinal study. We are indebted to the University of Malawi College of Medicine for providing access to its library and research facilities. We also extend our thanks to the participating households in Blantyre for their patience and cooperation from 2021 to 2026. Finally, we are grateful to the anonymous peer reviewers for their constructive comments, which greatly strengthened this manuscript.

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