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Comparative Study of the Existing and Post Intervention of the Mr. Dwiyanto's House in Gunungkidul, Yogyakarta, Indonesia

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ABSTRACT: This study presents a quantitative comparative analysis of environmental performance before and after an architectural intervention on a vernacular dwelling in the Gunungkidul District, Yogyakarta Special Region, Indonesia. Conducted as a longitudinal field investigation, the research employed a baseline-endline methodology with data collection in June 2025 (pre-intervention) and October 2025 (post-intervention). Key metrics included surface temperatures of building components (ceiling, walls, floor) and comprehensive indoor air quality (IAQ) parameters, notably particulate matter (PM10 and PM2.5) concentrations, measured against national ambient air quality standards (NAB). The results demonstrate a pronounced dual outcome. The intervention achieved its primary objective of drastically improving IAQ, with PM10 and PM2.5 levels reduced by over 90%, transitioning from exceeding to far below the NAB thresholds. However, this significant improvement coincided with a critical trade-off. A severe reduction in indoor air velocity (78%) altered the thermal environment, leading to mixed results: while floor temperatures decreased consistently, other components showed varied responses, and the heat stress index (WBGTi) slightly increased despite a lower dry-bulb temperature. The study concludes that while passive architectural strategies can effectively protect against outdoor particulate pollution, they can inadvertently compromise natural cooling ventilation. These findings highlight the essential ventilation-filtration dilemma in tropical climates and underscore the necessity for integrated, balanced design approaches in sustainable housing retrofits to simultaneously ensure occupant health and thermal comfort.

KEYWORDS: Housing Intervention, Building Components, Indoor Air Quality, Thermal, Particulate Matter

I. INTRODUCTION

Global and regional climate change has significantly impacted the built environment, particularly residential structures in tropical regions where passive cooling is traditionally prioritized. Ensuring adequate indoor environmental quality has become a central concern due to its direct link to occupant health and well-being [1]. In locations such as the Gunungkidul District, Yogyakarta Special Regency, many existing dwellings are increasingly vulnerable to indoor thermal discomfort and elevated levels of airborne pollutants, underscoring the need for targeted, sustainable interventions [2]. Evaluating the effectiveness of such retrofit strategies requires a rigorous scientific approach that compares pre- and post-intervention performance across multiple environmental parameters [3].

This study conducts a Comparative Study of the Existing and Post-Intervention Conditions of Mr. Dwiyanto's House in the Gunungkidul District, Yogyakarta, Indonesia. The primary objective is to quantitatively analyze the impact of an architectural habitat intervention on two critical aspects of indoor habitability: the thermal performance of key building components and the indoor air quality, with a specific focus on particulate matter concentration. A structured baseline-End-line methodology was employed, with initial data collected in June 2025 and post-intervention data collected in October 2025.

The analysis compares thermal data—including surface temperatures of the ceiling, walls, and floor at different times of day against established thermal comfort ranges. Furthermore, indoor air quality parameters such as air temperature, humidity, wind speed, and concentrations of PM10 and PM2.5 are evaluated against Indonesia's National Ambient Air Quality Standards (NAB) [4]. Preliminary analysis of the data reveals a notable dual outcome: while the intervention led to a dramatic reduction in particulate matter concentrations, bringing them well below the NAB threshold, the effects on thermal metrics were more heterogeneous, with mixed patterns of increase, decrease, and stabilization across different building components and times of day [5].

The significance of this research lies in its holistic, data-driven evaluation of a real-world intervention. It contributes to the growing body of knowledge on sustainable housing retrofits in tropical climates by providing empirical evidence on the trade-offs

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and synergies between improving air quality and managing thermal conditions. The findings offer practical insights for architects, engineers, and policymakers aiming to design and implement effective, low-cost habitat improvements that enhance occupant health and comfort in similar environmental contexts [6].

II. MATERIAL AND METHODS

This study employs a comparative, longitudinal field investigation to evaluate the impact of a residential habitat intervention. The research design, procedures, and analytical methods are described in detail in the following sections.

A. Research Design and Type

This study was conducted using a pre-test/post-test (baseline-end line) quasi-experimental design [7]. As a field-based case study, it focuses on the in-depth analysis of a single dwelling unit before and after a specific architectural intervention. The design allows for direct comparison of identical environmental parameters measured at the same location under two distinct conditions: the original, unmodified state (Existing) and the state following the completion of modifications (Post Intervention).

B. Research Duration and Timeline

The research was conducted over a five-month period to capture seasonal conditions within the tropical climate of Yogyakarta. Baseline (Pre-Intervention) Data Collection: June 2025 (see Figure 1.a). This period represents the dry season, providing data on the house's performance under typical warm and dry conditions. Intervention Implementation: July – September 2025 (see Figure 1.b). End line (Post-Intervention) Data Collection: October 2025 (See Figure 1.c). This marks the early transition toward the rainy season, allowing for an assessment of the intervention's performance under slightly different, more humid conditions.

(a) *(b)* *(c)*

Figure 1. Before (a), During (b), After (c) Intervention [8]

C. Study Subject and Site Description

1) ***Choice of Subject and Inclusion Criteria:*** Choice of subject and inclusion criteria were conducted. The subject of this study is the family residence of Mr. Dwiyanto, located in the Gunungkidul District, Yogyakarta Special Region, Indonesia. The dwelling was selected based on the following criteria: Inclusion Criteria: 1) Low-income community, 2) Vernacular/traditional construction typical of the region, 3) Planned for a defined architectural intervention aimed at improving thermal comfort and air quality. Exclusion Criteria: 1) Conventional construction with passive cooling systems, such as using of opening windows 2) Ongoing major construction was related to the planned intervention during the monitoring period.

The site is characterized by a tropical climate, with the house originally featuring minimal passive design strategies for cross-ventilation and pollutant filtration.

D. Data Collection Methodology

1) ***Measurement of Building Component Temperature: of Subject and Inclusion Criteria:*** Choice of subject and inclusion criteria were conducted. The subject of this study is the family residence of Mr. Dwiyanto, located in the Gunungkidul District, Yogyakarta Special Region, Indonesia. The dwelling was selected based on the following criteria: Inclusion Criteria:

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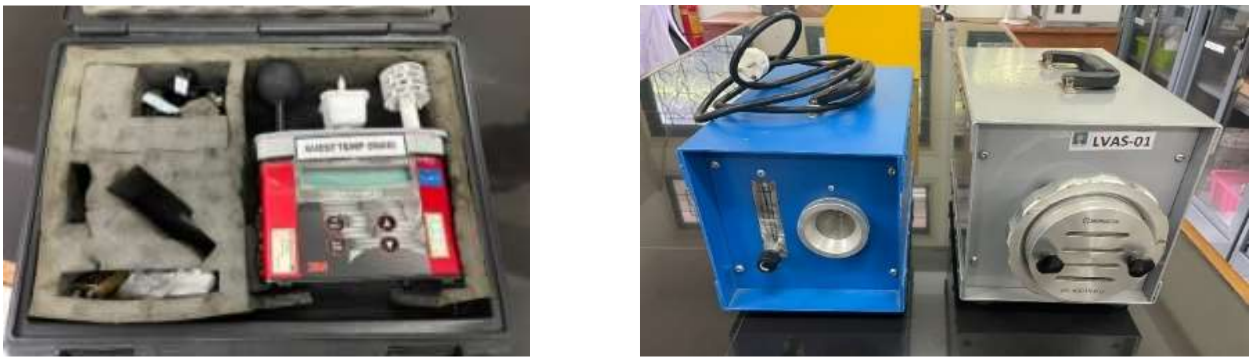
Three readings per component per time interval were recorded, and the average was used for analysis [9].

(a) (b) (c)

Figure 2. Thermal Logs to measure the temperature of the ceiling, walls and floors of a building (a); Anemometer is used to measure wind speed inside buildings (b); Laptops are used to record data and analysis from Thermal Log and Anemometer tools (c) [8]

2) ***Indoor Air Quality (IAQ) and Microclimate Monitoring:*** Comprehensive indoor air quality and environmental parameters were monitored. Parameters: Air temperature (°C), Wet Bulb Temperature (°C), Dry Bulb Temperature (°C), Wet Bulb Globe Temperature Index (WBGTi), Relative Humidity (%), Air Pressure (mmHg), Wind Speed (m/s), PM10 (µg/m³), and PM2.5 (µg/m³).



(a) (b)

Figure 3. Psychrometer or Wet-Dry Bulb Thermometer: A tool for measuring wet and dry bulb temperatures (a); LVAS (Low Volume Air Sampler), a tool for measuring particulate concentrations (PM10, PM2.5)(b) [8]

Instrumentation: A multi-parameter environmental monitor (See Figure 3.a) with integrated sensors for temperature, humidity, pressure, and airflow. Particulate matter concentrations were measured using a calibrated digital scattering dust monitor (See Figure 3.b). Protocol: Monitoring was conducted over a representative 24-hour period during both baseline and end line phases. Sensors were placed in the central living area at breathing height (1.5m above floor level). Data for PM10 and PM2.5 are presented as mean ± standard deviation from continuous logging.

E. Data Processing and Analysis

1) Data Processing: Raw data from all instruments were compiled into a structured database (Microsoft Excel). For time-series data (e.g., particulate matter), hourly averages were calculated. Baseline and End-line datasets were organized into comparative tables for direct component and parameter analysis.

2) ***Simple Numeric Analysis and Comparative Framework:*** Given the case-study design with paired measurements (same location, different times), primary analysis focused on descriptive numeric and comparative assessment [10]. Descriptive Statistics: means, deviations, and ranges were calculated for all continuous variables (e.g., PM concentrations, temperature values). Comparative Analysis: The core analysis involved a direct side-by-side comparison of baseline and end line values for each parameter. The magnitude and direction of change were calculated (Δ = End line – Base line).

Benchmarking: Results for temperature parameters were compared against the generic thermal comfort range of ≈18–30°C, as indicated in the data tables. PM10 and PM2.5 concentrations were evaluated against the Indonesian National Ambient Air Quality Standards (NAB) of 70 µg/m³ and 25 µg/m³, respectively (4). Trend Categorization: Changes for each parameter were categorized as "Increased," "Decreased," "Stabilized," or "Drastically Decreased" based on the calculated Δ value and its practical significance. This methodological framework ensures a transparent, replicable, and systematic approach to evaluating the physical and environmental outcomes of the habitat intervention on Mr. Dwiyanto's residence.

III. RESULTS

A. The Case Study Profile

The subject of this study is a vernacular dwelling located in the Gunungkidul Regency of Yogyakarta, Indonesia (see Figure 4). This rural region is characterized by a distinctive karst (limestone) landscape and a tropical monsoon climate (Köppen Am), featuring a pronounced dry season (May–September) that elevates ambient dust levels and a humid rainy season (October–April) [11]. This geographical context directly influenced pre-intervention conditions, with particulate matter ($PM_{2.5}$ and PM_{10}) originating from the dry, dusty environment exceeding national air quality standards [12]. The site's specific coordinates (approx. 08°00'55.5" S, 110°34'55.4" E) place it within a typical agricultural settlement in Southern Java [13]. The core design challenge was to mitigate dust infiltration while preserving the natural ventilation essential for thermal comfort in a hot, humid climate [14].

Figure 4. The Case Study Location in the Wonosari Sub-District, Gunungkidul District, Yogyakarta Special Region, Indonesia [8]

B. Comparative Analysis of Environmental Parameters

A comparative assessment of environmental data from the baseline (June 2025) and endline (October 2025) phases demonstrates varied impacts on the dwelling's performance. The results are categorized into two primary areas: the thermal performance of building components and indoor air quality parameters.

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1) Thermal Performance of Building Components: Surface temperatures of the ceiling, walls, and floor were recorded at three diurnal intervals. The results, evaluated against a thermal comfort range of 18–30°C appropriate for naturally ventilated tropical buildings [15], are presented in Table 1 and illustrate divergent thermal behaviors across components.

Table 1. Baseline and Endline Thermal of the Building Component: Before and After Intervention

No	Test Parameter	Unit	Baseline Result	Endline Result	Threshold (NAB*)	Test Method	Notes
1	Ceiling Temperature	°C	Morning: 25.5	Morning: 27.3	± 18–30	IK U/SUHU-001	Increased
		°C	Noon: 31.0	Noon: 31.5	± 18–30	IK U/SUHU-001	Stable
		°C	Afternoon: 31.0	Afternoon: 29.5	± 18–30	IK U/SUHU-001	Decreased
2	Wall Temperature	°C	Morning: 27.4	Morning: 27.3	± 18–30	IK U/SUHU-001	Decreased
		°C	Noon: 30.3	Noon: 30.8	± 18–30	IK U/SUHU-001	Increased
		°C	Afternoon: 29.1	Afternoon: 29.9	± 18–30	IK U/SUHU-001	Increased
3	Floor Temperature	°C	Morning: 27.4	Morning: 26.8	± 18–30	IK U/SUHU-001	Decreased
		°C	Noon: 30.3	Noon: 27.6	± 18–30	IK U/SUHU-001	Decreased
		°C	Afternoon: 29.1	Afternoon: 26.9	± 18–30	IK U/SUHU-001	Decreased

The thermal response varied notably among building elements [16]. The floor exhibited the most consistent cooling effect, with temperature reductions recorded across all measurement intervals, including a notable decrease of 2.7°C during the midday period. Conversely, the ceiling and walls displayed mixed buffering effects. Ceiling temperatures decreased in the afternoon but rose slightly in the morning, whereas wall temperatures increased marginally during the afternoon. These variations suggest that the intervention differentially influenced heat transfer and storage dynamics in horizontal versus vertical surfaces.

2) ***Indoor Air Quality and Microclimatic Parameters:*** The intervention significantly altered indoor air quality, especially concerning particulate matter, alongside other microclimatic shifts, as detailed in Table 2. The most definitive outcome of the intervention was the The most pronounced outcome was the substantial reduction in particulate concentrations. PM10 decreased by 92.5% and PM2.5 by 90.0%, shifting from levels exceeding the National Ambient Air Quality Standards (NAB) to values well below regulatory limits [11, 17]. This indicates effective filtration against outdoor particle infiltration. However, this improvement came with a significant trade-off: indoor air velocity declined by 78% (from 1.38 m/s to 0.30 m/s). Although the dry-bulb temperature decreased by 3.3°C—beneficial for thermal comfort—the Wet Bulb Globe Temperature Index (WBGTi), which accounts for humidity, radiation, and airflow, increased slightly by 1.0 unit [12]. This implies that reduced airflow may have counteracted some benefits of lower dry-bulb temperatures, particularly under humid conditions.

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Table 2. Baseline and Endline Air Quality of the Building Before and After Intervention.

No	Test Parameter	Unit	Baseline (June 2025)	Threshold (NAB)	Endline (Oct 2025)	Change Analysis
1	Air Temperature	°C	29.9 ± 1.23	–	31.4 ± 1.23	Increased (+1.5 °C)
2	Wet Temperature	°C	26.1	–	27.4	Increased (+1.3 °C)
3	Dry Temperature	°C	30.0	–	26.7	Decreased (–3.3 °C)
4	Wet Bulb Globe Temperature Index (WBGTi)	WBGTi	27.5	–	28.5	Increased (+1.0)
5	Air Humidity	%	72.7 ± 2.30	–	72.7 ± 2.30	Stable
6	Air Pressure	mmHg	746 ± 1.68	–	746 ± 1.68	Stable
7	Wind Speed	m/s	1.38	–	0.30	Decreased significantly (–1.08 m/s)
8	PM10	µg/m³	83.3 ± 6.86	70	6.25 ± 0.49	Decreased drastically (–92%), from above threshold to far below threshold
9	PM2.5	µg/m³	41.7 ± 3.43	25	4.17 ± 0.33	Decreased drastically (–90%), from above threshold to far below threshold

In summary, the intervention successfully achieved its primary goal of markedly reducing indoor particulate pollution. However, it also reconfigured the indoor microclimate, enhancing floor cooling and lowering air temperature at the expense of natural ventilation and with a nuanced effect on perceived heat stress.

IV. DISCUSSION

This study provides a critical, data-driven evaluation of a passive architectural retrofit in a tropical vernacular dwelling, revealing a pivotal trade-off between achieving excellent indoor air quality (IAQ) and maintaining optimal thermal comfort. The findings offer empirical validation for the "ventilation-filtration dilemma," a theoretical conflict now quantified in a specific rural, low-income housing context.

A. Interpretation of the Ventilation-Filtration Trade-off

The intervention's primary success—a drastic reduction of PM_{10} and $PM_{2.5}$ by over 90%—demonstrates high efficacy in its role as a protective environmental filter [11]. This outcome aligns with established building science, where controlling air infiltration is the most effective strategy to limit the ingress of outdoor particulate matter [18]. It confirms that passive, architectural envelope improvements can be a powerful, low-cost intervention for mitigating a significant health risk in pollution-prone areas.

However, the core finding is the consequential trade-off. The severe reduction in indoor air velocity (78%) directly compromised the microclimatic condition. The result presents an instructive paradox: a 3.3°C decrease in dry-bulb air temperature coincided with a 1.0-unit increase in the Wet Bulb Globe Temperature Index (WBGTi)[12]. This discrepancy is central to understanding the thermal outcome. The dry-bulb temperature measures ambient heat, while the WBGTi is a comprehensive heat stress index that accounts for humidity, radiation, and, critically, the cooling effect of air movement on the human body via evaporation [12, 19]. The data shows that by drastically reducing airflow, the intervention removed a primary mechanism for physiological cooling, thereby increasing perceived heat stress despite a lower ambient temperature.

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This result provides strong empirical support for the adaptive thermal comfort model in warm-humid climates, which emphasizes the vital role of air movement (both actual and perceived control over it) for occupant comfort in naturally ventilated spaces [19, 20]. The evidence demonstrates that in this context, improving one aspect of habitability (air purity) inadvertently degraded another (the convective cooling potential essential for thermal adaptation).

B. Comparative Analysis with Broader Research

The quantified trade-off observed corroborates findings from studies in other climates and building types. Research on urban apartments and energy-efficient retrofits has documented similar conflicts, where improved airtightness for energy savings or pollution control leads to increased indoor temperatures, humidity, or CO_2 levels due to reduced ventilation [21]. This study extends that understanding to vernacular, rural housing, proving the dilemma is a fundamental physical conflict, not merely a feature of modern, sealed construction.

The heterogeneous thermal response of building components—with the floor cooling effectively while walls and ceilings showed mixed results—is consistent with principles of building physics regarding differential solar exposure, thermal mass, and heat transfer pathways[16]. The successful floor cooling suggests effective intervention in ground-coupled heat transfer, while the variable performance of vertical surfaces points to more complex interactions with solar gain and retained heat within the modified envelope assembly.

C. Significance and Reconciling Outcomes with Design Expectations

The primary significance of this research is its provision of quantified, real-world evidence for a critical design trade-off. It moves the conversation from theoretical acknowledgment to measurable impact, showing that a near-total reduction in particulate pollution can correlate with a near-total loss of beneficial natural ventilation and an increase in heat stress.

If the expectation was a universally improved indoor environment, the results differ because the intervention was optimized for a single performance parameter (filtration) within a complex, coupled environmental system. This highlights the risk of "sub-optimization," where maximizing one variable degrades the overall system performance if interdependencies are not managed [22].

The findings strongly reinforce the theory that sustainable tropical housing requires integrated and balanced design. The evidence necessitates a paradigm shift toward hybrid solutions. For practice, this means future retrofits should incorporate adaptive features, such as:

1. Operable Filtered Ventilation: Incorporating adjustable vents with removable filters to allow occupants to regulate airflow based on outdoor pollution levels and indoor thermal needs [23].
2. Supplemental Low-Energy Air Movement: Using ceiling fans to restore convective cooling without compromising the envelope's protective integrity [23].
3. Holistic Performance Assessment: Adopting evaluation frameworks that mandate concurrent measurement of IAQ and thermal comfort indices like WBGTi in post-occupancy studies.

In conclusion, this study demonstrates that while targeted architectural strategies can be exceptionally effective for specific goals like pollution mitigation, their success must be evaluated against a complete set of habitability criteria. The work provides a crucial evidence base for advocating balanced design protocols that consciously navigate the trade-off between ensuring healthy air and preserving thermal livability in tropical climates[6].

V. CONCLUSION

A. Conclusions

This study provides a comprehensive, data-driven evaluation of a passive architectural retrofit on a vernacular dwelling in the Gunungkidul District, Yogyakarta, Indonesia. The intervention achieved its primary objective with exceptional success, reducing indoor concentrations of PM_{10} and $PM_{2.5}$ by over 90% and bringing them from levels exceeding to far below the National Ambient Air Quality Standards (NAB). This demonstrates the high efficacy of passive design strategies in protecting occupants from geographically-rooted particulate pollution, a significant public health concern. However, the research reveals a critical and inherent trade-off: this improvement in air quality was accompanied by a 78% reduction in indoor air velocity.

Consequently, while the dry-bulb temperature decreased, the overall heat stress index (WBGTi) slightly increased, and thermal comfort became more complex, with the floor cooling effectively but ceiling and wall temperatures showing mixed responses. These findings empirically validate the ventilation-filtration dilemma in tropical climates. The study concludes that singular-focus retrofits, while effective for specific parameters like air purity, can inadvertently compromise other essential aspects of habitability, such as thermal comfort derived from natural ventilation. Therefore, the work underscores an indispensable principle for sustainable housing: the necessity for integrated and balanced design. Future interventions must holistically address both air quality and thermal dynamics to truly enhance occupant health and well-being in similar environmental contexts.

B. Recommendations

It is recommended for the Researcher to publish the detailed methodology and findings in a peer-reviewed journal to formally contribute to tropical housing science. Extend monitoring for a full year to assess seasonal performance and durability. Complement environmental data with occupant surveys on thermal comfort and air quality perception to validate the identified trade-offs.

The Habitat for Humanity should Integrate the documented trade-off into a "Balanced Design" principle for future projects. Pilot low-cost hybrid solutions, such as operable filtered vents or ceiling fans, to restore airflow without compromising particulate filtration. Use the compelling PM2.5 reduction data (over 90%) to advocate for "Healthy Housing" in public health and funding discussions.

Finally, the Faculty of Engineering and Planning at Islamic University of Indonesia should incorporate this local case study into the curriculum for courses in Building Science and Sustainable Design as a practical example of post-occupancy evaluation. Formalize partnerships with NGOs like Habitat for Humanity to create a pipeline for community academic research, including students. Establish a focused research cluster on "Healthy and Affordable Housing" to develop scalable, evidence-based retrofit solutions for Indonesia's housing sector.

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