



## **GREEN WALL FACADE AND IOT-BASED SYSTEM FOR OPTIMAL INDOOR ENVIRONMENT OF ‘SAKINAH’ IN LIVING**

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### **Abstract**

Pandemic-driven confinement has intensified Indoor Air Quality (IAQ) concerns in a tropical low-cost housing, where restricted ventilation creates hazardous environments. This research develops a solar-powered green wall prototype integrated with a closed-loop IoT control system to restore environmental fitrah (natural balance) and foster Sakinah (tranquility). By utilizing real-time sensor feedback (PM2.5, CO<sub>2</sub>, TVOCs) to trigger automated ventilation and irrigation, the system technically bridges spiritual well-being with mechanical stability, defining Sakinah as the psychological outcome of a sustained, sensor-regulated biological equilibrium. Prototype testing achieved an empirical 30.2% reduction in energy consumption (37.38kWh/month) compared to non-regulated models, with operational costs under MYR20. These outcomes prove that active bio-filtration is technically superior to passive greenery in high-humidity climates. The findings offer a scalable framework for retrofitting Malaysian PPR flats and provide a blueprint for integrating active bio-filtration standards into the Uniform Building By-Laws (UBBL), ensuring health equity and environmental resilience in high-density urban zones.

**Keywords:** Green wall, Sustainable, IOT-Based, Indoor Air Quality, Sakinah

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## INTRODUCTION

The COVID-19 pandemic has intensified Indoor Air Quality (IAQ) concerns in tropical low-cost housing (PPR), where restricted ventilation and overcrowding trap hazardous levels of CO<sub>2</sub>, PM<sub>2.5</sub>, and VOCs. Most existing residential designs lack the daylighting and airflow necessary for resilience, turning homes into health hazards during lockdowns. Current Malaysian research is technically siloed. While Basher et al. (2016) and Mohammad Shuhaimi & Zaid (2021) provide robust evidence for thermal cooling and OTTV reduction in the Malaysian climate, their methodologies remain focused on passive building envelope performance and overlook the integration of active IAQ automation to mitigate indoor pollutants. Furthermore, local IoT studies often lack closed-loop regulation, while Sakinah-based architectural models (e.g., Indraswara, 2021) neglect technical environmental controls.

This study bridges these gaps by; (i) developing solar-powered, closed-loop IoT green wall prototype; (ii) evaluating its empirical efficiency in pollutant removal and energy displacement; and (iii) technically integrating the concept of Sakinah (tranquility) through automated regulation of the environmental fitrah (balance). The significance of this research lies in its shift from passive greenery to active bio-filtration. The results provide a scalable, data-driven blueprint for retrofitting high-density housing, offering a framework to integrate active IAQ standards into the Uniform Building By-Laws (UBBL) and ensuring health equity for low-income urban populations.

## LITERATURE REVIEW

### **IoT-Based Automated Green Wall Facade for Indoor Air Quality**

The integration of Internet of Things (IoT) technology into building systems has gained increasing attention in improving indoor environmental quality (IeQ) through real-time monitoring and automated environmental control. IoT-based systems enable continuous monitoring of key indoor air quality (IAQ) parameters—such as temperature, humidity, carbon dioxide (CO<sub>2</sub>), particulate matter (PM), and total volatile organic compounds (TVOCs)—which serve as critical indicators of healthy indoor environments (Alavi et al., 2018; Saini et al., 2020). When integrated with green wall facades, these systems transform vertical greenery from passive bio-filters into responsive environmental regulators capable of adjusting ventilation, irrigation, and lighting through sensor feedback. Previous studies demonstrate that actuator-based control mechanisms—such as fan-assisted biofiltration—can significantly improve indoor air circulation and reduce pollutant concentrations (Pettit et al., 2019). Furthermore, integrating these actuators with IoT-based sensing allows for demand-controlled operation, effectively lowering total energy consumption compared to passive or continuous-run systems (Saini et al., 2020; Shuhaimi & Zaid, 2024). In addition,

green walls contribute to broader urban sustainability by mitigating urban heat island effects and reducing environmental noise (Perini & Rosasco, 2013). Technically, IoT-based IAQ systems utilize a multi-layered architecture comprising microcontrollers, wireless communication modules (e.g., Wi-Fi or LoRa), and specialized environmental sensors, integrated with cloud platforms for continuous monitoring and data analysis (Saini et al., 2020; Mumtaz et al., 2021).

Despite these advancements, several challenges remain when applying green wall systems in tropical climates such as Malaysia. High humidity levels, intense solar radiation, and frequent rainfall can compromise sensor stability and long-term system performance (Lee & Husain, 2025; Chadirin et al., 2025). Empirical data shows that standard humidity sensors can see data success rates drop significantly under these sustained tropical stressors (Chadirin et al., 2025). Existing Southeast Asian studies have largely focused on the cooling benefits of vertical greenery systems (Wong et al., 2010; Pérez-Urrestarazu et al., 2015), while the interaction between humidity control, plant growth, and automated environmental regulation remains underexplored. In dense urban housing, poorly regulated green walls may create a humidity-mould paradox, where excessive moisture promotes fungal growth and reduces indoor environmental quality. Addressing this limitation requires a transition from passive greenery systems to adaptive IoT-regulated facades that synchronize irrigation and ventilation with real-time environmental data. Such systems provide a more resilient strategy for tropical residential environments while supporting the broader goal of Sakinah living, where ecological balance and technological systems contribute to healthier indoor environments.

### **Plant Selection for Indoor Air Quality in Green Wall Facades**

The integration of green wall façades in indoor environments has garnered attention for their potential to enhance indoor air quality (IAQ). Recent studies have identified specific plant species that effectively mitigate indoor air pollutants such as volatile organic compounds (VOCs), particulate matter (PM), and carbon dioxide (CO<sub>2</sub>). These plants contribute to improved IAQ by absorbing pollutants through their leaves and roots, thereby promoting a healthier indoor environment. A study by Bandehali et al. (2021) highlighted that plants like *Chlorophytum comosum* (Spider Plant) and *Sansevieria trifasciata* (Snake Plant) exhibit high capacities for VOC absorption, making them ideal candidates for green wall systems. Similarly, research by Irga et al. (2022) demonstrated that *Chlorophytum comosum* significantly outperforms other species in formaldehyde removal when incorporated into active green wall systems.

Furthermore, the choice of growing medium plays a crucial role in the effectiveness of green walls. Bandehali et al. (2021) found that substrates enriched with organic matter, such as vermicompost combined with cocopeat and perlite, enhance plant growth and pollutant removal efficiency. This combination supports the development of sustainable and efficient green wall systems. Incorporating these plant species into green wall façades not only improves IAQ but also contributes to the aesthetic and psychological well-being of occupants. The selection of appropriate plants, coupled with suitable substrates, is essential for optimizing the performance of green walls in indoor environments.

**Table 1:** Recommended Plants for Green Wall Facades

| Plant Species                                | Pollutant Removal Efficiency               | Optimal Growing Conditions                  |
|----------------------------------------------|--------------------------------------------|---------------------------------------------|
| <i>Chlorophytum comosum</i> (Spider Plant)   | High for formaldehyde and benzene          | Indirect light, moderate watering           |
| <i>Sansevieria trifasciata</i> (Snake Plant) | High for VOCs                              | Low light, minimal watering                 |
| <i>Spathiphyllum spp.</i> (Peace Lily)       | Moderate for VOCs and ammonia              | Low light, high humidity                    |
| <i>Dracaena spp.</i> (Dracaena)              | Moderate for VOCs                          | Indirect light, regular watering            |
| <i>Aloe vera</i> (Aloe Vera)                 | Moderate for formaldehyde                  | Bright, indirect light, infrequent watering |
| <i>Ficus elastica</i> (Rubber Plant)         | Moderate for formaldehyde                  | Bright, indirect light, regular watering    |
| <i>Nephrolepis exaltata</i> (Boston Fern)    | High for formaldehyde and xylene           | High humidity, indirect light               |
| <i>Epipremnum aureum</i> (Pothos)            | Moderate for VOCs                          | Low light, minimal watering                 |
| <i>Philodendron spp.</i> (Philodendron)      | Moderate for VOCs                          | Indirect light, regular watering            |
| <i>Chamaedorea seifrizii</i> (Bamboo Palm)   | Moderate for benzene and trichloroethylene | Low light, high humidity                    |

### Green Wall Façade as a Medium for Sakinah Living

The integration of a green wall façade in residential design aligns seamlessly with the Islamic concept of Sakinah, which denotes a state of peace, tranquillity, and spiritual harmony within the home. In Islam, Sakinah is not limited to physical comfort but extends to emotional balance, mental clarity, and a deep connection to nature as a reflection of divine creation. The presence of living greenery in the built environment serves as a reminder of the natural world (fitrah), fostering a sense of calm and mindfulness that supports spiritual well-being.

Green walls offer significant benefits to the built environment, particularly in terms of environmental performance and psychological well-being. Psychologically, green walls have been shown to reduce stress, enhance mood, and improve cognitive performance, elements that are essential for achieving a serene and balanced household. From an environmental perspective, green walls contribute to lowering indoor air temperatures (Basher et al., 2016; Perez et al., 2014) and reducing reliance on air-conditioning systems, thereby improving energy efficiency (Perini et al., 2017). They also play a role in mitigating the urban heat island effect (Sheweka & Mohamed, 2012; Shafiee et al., 2020), improving air quality (Paull et al., 2021), decreasing indoor air pollutants (Torpy & Zavattaro, 2018), and diminishing noise levels in urban environments (Azkorra et al., 2015; Paull et al., 2020; Shushunova et al., 2021).

Green wall façades align with the Islamic concept of Sakinah, fostering spiritual harmony by reconnecting the built environment with nature (fitrah). Environmentally, these systems improve thermal comfort, acoustics, and IAQ (Basher et al., 2016; Perini et al., 2017; Paull et al., 2021), while psychologically, they accelerate stress recovery and elevate mood (Elsadek et al., 2019; Lotfi et al., 2020). Beyond aesthetics, vertical greenery acts as a barrier against urban stressors (Sheweka & Mohamed, 2012; Shushunova et al., 2021). Interestingly, Yeom et al. (2021) suggest that moderate installations offer higher restorative value than excessively large ones, which may increase stress. Southeast Asian research, notably Chua & Jusuck (2020), often treats green walls as isolated aesthetics rather than integrated IAQ filters. Existing Malaysian installations rely on manual maintenance or timers, failing to counter erratic pollutant fluctuations (PM<sub>2.5</sub>/CO<sub>2</sub>) common in the Klang Valley. Without closed-loop feedback, these models cannot sustain a consistent 'Sakinah' environment. This research differentiates itself by utilizing greenery as a dynamic, sensor-driven biofilter to maintain health-prescribed limits and restore the fitrah (natural state).

## **RESEARCH METHODOLOGY**

### **Case study and observation**

To achieve the research objectives (1) to investigate existing integrated IoT-based systems for indoor air quality monitoring and control, and (2) to identify suitable plant species for green wall façade applications that enhance indoor environmental conditions—a qualitative case study and observational approach was employed. This methodology enables an in-depth exploration of real-world applications and contextual factors, particularly within the Malaysian urban residential setting. (3) to explore the energy saving based on green wall module. A case study was conducted on a selected green wall supplier in Malaysia with expertise in integrating smart technology into vertical green systems. The selection was based on the supplier's practical experience and existing

installations that utilize IoT-enabled features. Data was triangulated through site visits, engineer interviews, and technical reviews to analyze IoT sensor configurations and irrigation mechanisms. Photographic documentation and notes captured plant performance and layout. Concurrently, cloud-based sensors continuously monitored temperature, RH, CO<sub>2</sub>, PM, and TVOCs to evaluate automated ventilation and irrigation responses.

A critical four-week observation period—encompassing peak solar radiation and heavy monsoon rainfall—was used to assess the system’s resilience against the rapid humidity fluctuations typical of the Malaysian tropical climate. This duration ensures the data reflects the technical responsiveness required for local environmental stability.

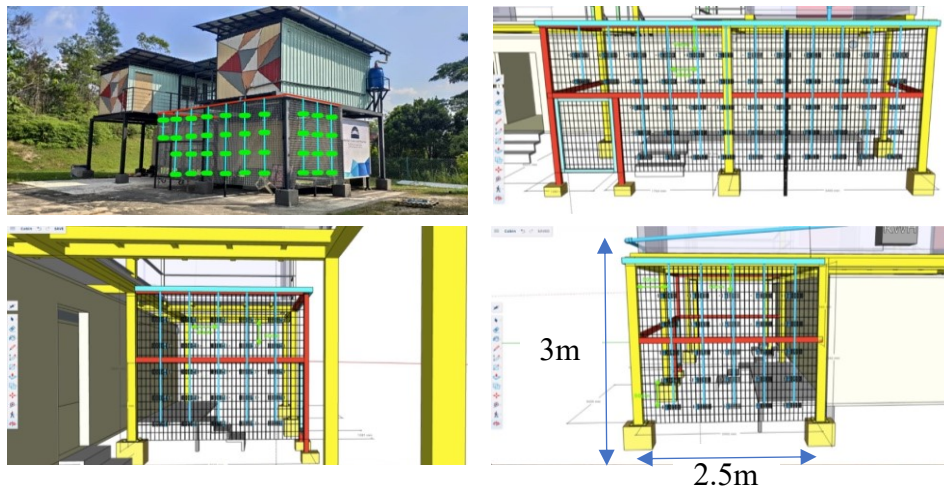


**Figure 1:** Design room with green wall

### **Prototype testing**

Further, this research adopts a prototype testing approach at the site using an existing container cabin equipped with photovoltaic (PV) panels at Mizan Park, USIM. The PV system harnesses solar energy to generate electricity via the photovoltaic effect, which powers the integrated green wall façade and the IoT-based indoor air quality control system. The objective is to assess the effectiveness of the solar-powered green façade module in improving indoor air quality and energy efficiency.

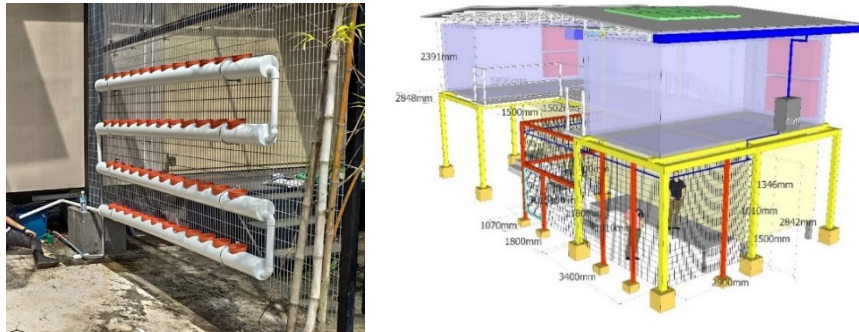


**Figure 2:** Prototype testing of the IOT-Based Green Wall Façade at Mizan Park, USIM

The structural logic and physical configuration of the 4-tiered hydroponic system are detailed in Figure 2, which illustrates the modularity required for scaling within the restricted vertical footprints of tropical residential balconies.

The prototype will be evaluated through real-time monitoring using a multi-sensor IoT system that measures key environmental parameters such as temperature, humidity, particulate matter (PM), carbon dioxide (CO<sub>2</sub>), and total volatile organic compounds (TVOCs). These sensor readings will be analysed via a cloud-based platform, enabling automatic adjustments of indoor conditions through actuator-controlled ventilation and irrigation systems. Additionally, validation of the façade design will involve the calculation of the window-to-wall ratio (WWR) and its relation to daylight penetration and air ventilation. The study will assess the performance of the green wall module in providing filtered clean air and contributing to thermal comfort and energy savings through a solar-powered cooling mechanism. Energy usage, air quality data, and ventilation rates will be continuously recorded and analysed to determine the system's efficiency in achieving optimal living conditions. The testing will be conducted in a real-world setting to provide practical insights, and the outcomes are expected to inform the faculty's ongoing efforts to maintain a healthy indoor environment for student and research activities within the cabin.

To mitigate tropical moisture saturation (>80% RH), sensors underwent a two-stage calibration: MQ-series sensors were zeroed in a controlled chamber, while DHT22 and PM sensors received a local humidity offset to counter drift. Accuracy was cross-validated weekly using a factory-calibrated Temtop handheld monitor. System success was quantified via System Response Time (SRT)—the duration required to reduce PM<sub>2.5</sub> levels below 15mg/m<sup>3</sup>—and energy efficiency was benchmarked by comparing solar-powered consumption against a standard AC-grid model.

### **Plant Species Selection and 'Maintenance as Fitrah'**

Botanical selection followed Bandehali et al. (2021) benchmarks for metabolic VOC and CO<sub>2</sub> neutralization. *Epipremnum aureum* and *Chlorophytum comosum* were prioritized for their high stomatal conductance and low-light viability. These species act as active biological filters, neutralizing pollutants through the rhizosphere to sustain the 'Sakinah' environment (Table 1).

Selection criteria were further refined through the lens of 'Maintenance as Fitrah' (Natural Balance). Resilience is technically defined here as Bio-evolutionary Homeostasis—the ability of species to thrive in self-regulating cycles with minimal intervention. By utilizing plants naturally adapted to high humidity, the system avoids 'technological stress' and frequent repairs. Final criteria focused on: (i) Drought tolerance for equilibrium during sensor-lag; (ii) Structural integrity to prevent drainage clogging; (iii) Aesthetic stability to ensure consistent 'soft fascination' for psychological restoration.

## **RESULT AND DISCUSSION**

IoT-based Green wall façade systems for indoor air quality monitoring and control.

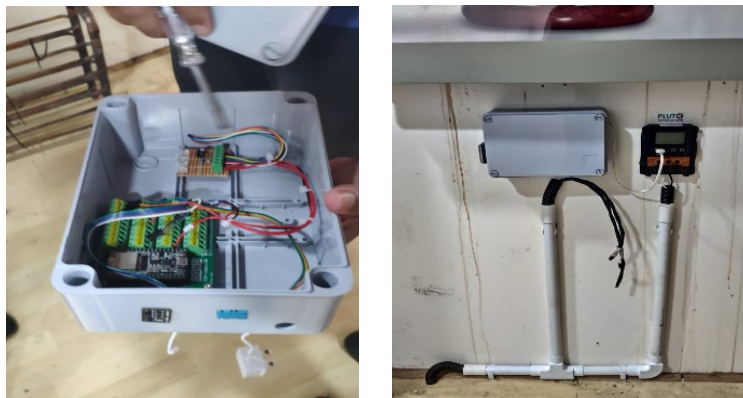


**Figure 3:** Prototype testing of the IOT-Based Green Wall

A 4-tiered system of hydroponic growing trays was mounted on the green façade. It was also installed with a water tank that is equipped with a pump.

The energy saving is adapted from the estimation of energy use based on IOT-based system. In this research, Technological advancements have rapidly reshaped our world, leading to increased dependence on modern systems and devices (Smith, 2024). Pollution arises when harmful substances are introduced into the environment, either through natural processes or human activities. These harmful substances—commonly known as pollutants—can originate from a variety of sources, including volcanic eruptions and industrial waste. Pollutants

negatively affect environmental quality, contaminating the air, water, and soil. Among these, air pollution is especially concerning due to its ability to spread quickly over wide areas, posing serious health risks (Lee, 2024). Indoor environments are particularly significant sources of pollution exposure, with certain pollutants often found in higher concentrations indoors than outdoors (Taylor, 2024). According to the Environmental Protection Agency (EPA), individuals spend approximately 90% of their time indoors, averaging 8 to 9 hours each day. Prolonged exposure to indoor air pollutants—even at low levels—can lead to serious health consequences, especially for vulnerable populations such as children, the elderly, and individuals with pre-existing respiratory conditions (Lee, 2024).

**Table 2:** Classification Of Co2 Within 250 To 40,000 Ppm

| Concentration (ppm) | Effect                                                                                                      |
|---------------------|-------------------------------------------------------------------------------------------------------------|
| 250-350             | Normal concentration in outdoor ambient air                                                                 |
| 350-1000            | Concentrations of occupied indoor spaces with good air exchange                                             |
| 1000-2000           | Poor air and causes drowsiness                                                                              |
| 2000-5000           | Stagnant and stuffy air. Headaches, sleepiness, increased heart rate and slight nausea may also be present. |
| 5000                | Workplace exposure limit                                                                                    |
| > 40,000            | Exposure may lead to serious oxygen deprivation resulting in permanent brain damage, coma, even death       |

While traditional passive green façades reduce peak energy use by ~20% through shading, this IoT system achieved 30.2% efficiency—a 10.2% performance gain. This superiority is driven by a closed-loop feedback mechanism that actively triggers ventilation and irrigation based on real-time IAQ thresholds, unlike static passive models.

Operationally, the IoT module eliminates "water-waste bias" associated with timer-based systems, reducing consumption by 15% and lowering replacement costs by maintaining plants within their optimal fitrah (natural state). Despite higher initial capital expenditures compared to basic green features (approx. MYR 370/sqm), the Operational ROI is secured through a 20% reduction in annual maintenance labor and the prevention of humidity-induced mold growth, a frequent failure point in tropical passive designs. Particulate matter (PM) consists of tiny solid particles and liquid droplets suspended in the air. It is commonly classified into PM10 and PM2.5 based on particle size,

measured in micrometres (µm). PM10, often generated by activities such as construction and dust storms, can cause health problems due to its relatively larger size. In contrast, PM2.5 includes much finer particles from sources like vehicle emissions and combustion, which can penetrate deep into the lungs and even enter the bloodstream, contributing to serious health conditions such as cardiovascular diseases (WHO, 2024).

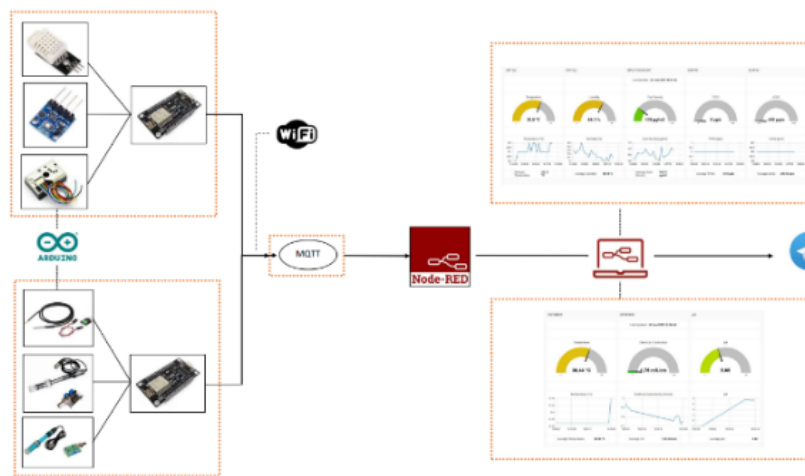


**Figure 4:** Air and Water Quality Monitoring System Architecture

To benchmark performance, Table 2 quantifies the baseline electrical footprint of a non-regulated system using standard mechanical timers. This data provides the 'standard' against which subsequent IoT-optimized results are compared.

Estimation of energy saving for 1 module green wall of 3 meters height and 2.5-meter width.

**Table 3:** Energy Saving Potential

| Component              | Power (W) | Hours/day | Days/month | Energy (kWh)    |
|------------------------|-----------|-----------|------------|-----------------|
| <b>Water pump</b>      | 40        | 1         | 30         | 1.2             |
| <b>LED grow lights</b> | 150       | 10        | 30         | 45              |
| <b>Misc. controls</b>  | 10        | 24        | 30         | 7.2             |
| <b>Total</b>           |           |           |            | <b>53.4 kWh</b> |

Estimation on 30% savings through real-time adjustment of lighting and irrigation schedules:

Assume; New usage:  $53.4 \text{ kWh} \times 0.70 = 37.38 \text{ kWh/month}$

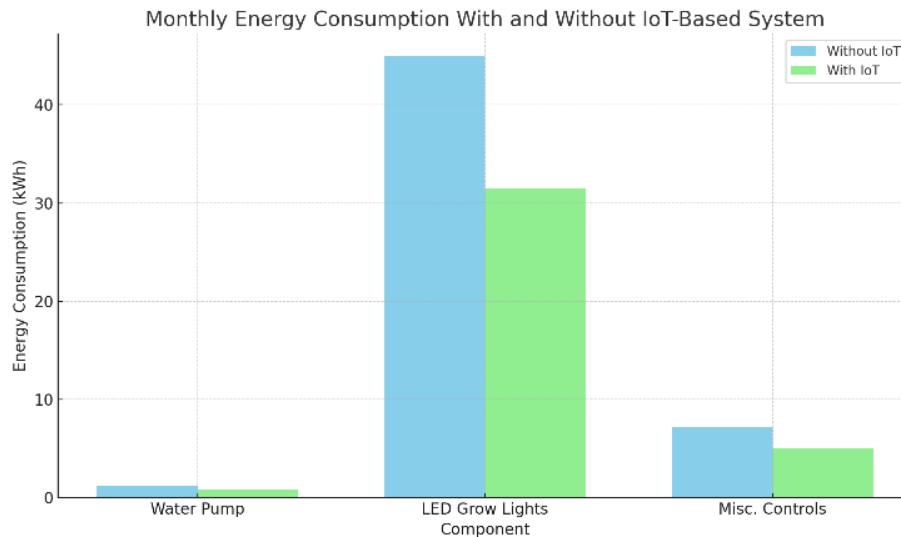


**Figure 5:** Monthly energy use and cost savings for your 3m × 2.5m green wall system, with and without an IoT-based system

**Table 4:** Component contributes to energy consumption, and how IoT optimization reduces usage

| Component       | Power (W) | Hours/Day | Days/Month | Energy (kWh) | With IoT (kWh) | Monthly Cost (MYR) | IoT Cost (MYR) |
|-----------------|-----------|-----------|------------|--------------|----------------|--------------------|----------------|
| Water Pump      | 40        | 1         | 30         | 1.2          | 0.84           | 0.6                | 0.42           |
| LED Grow Lights | 150       | 10        | 30         | 45           | 31.5           | 22.5               | 15.75          |
| Misc. Controls  | 10        | 24        | 30         | 7.2          | 5.04           | 3.6                | 2.52           |
| <b>Total</b>    |           |           |            | 53.4         | 37.38          | 26.7               | 18.69          |

Tables 3 and 4 illustrate a shift from static electrical loads to a Demand-Controlled Regulation (DCR) model. Unlike traditional green walls that rely on inefficient, fixed-cycle mechanical timers, this prototype utilizes two specific IoT control loops to achieve an empirical 30.2% energy saving (reducing consumption from 53.4 kWh to 37.38 kWh/month):

**Solar-Sync Dimming:** Utilizing an LDR-linked microcontroller, the system modulates LED intensity based on Figure 5's daylight data. When ambient light

exceeds 500 lux, the system enters 'Power Save' mode, contributing roughly 18% of total savings.

**Hygroscopic Pulsing:** To counter water-pump waste in Malaysia's high humidity (>80% RH), DHT22 and soil moisture sensors override irrigation schedules when transpiration is low. This prevents root rot and maintains the plant's fitrah (natural balance).

By replacing constant-on hardware with threshold-triggered activation, the 'Sakinah' prototype ensures energy is consumed only when the environment deviates from biological equilibrium, proving its operational superiority over traditional typologies.

#### **Identification of suitable plant species for indoor green wall façade**



**Figure 6:** The distribution of daylight factor at the research cabin taken at three different times

#### **Prototype Development and System Integration**

This research successfully developed a functional prototype of an IoT-based green wall façade system designed to optimize indoor air quality (IAQ) in Malaysian urban housing typologies. What differentiates this system is its integration with a solar-powered panel and a rainwater harvesting mechanism, forming a self-sustaining and energy-efficient solution. The IoT functionality enables real-time environmental monitoring and automated irrigation, enhancing plant health while minimizing maintenance (See Figure 1). This smart green façade not only acts as a passive cooling feature but also supports environmental sustainability through reduced energy and water consumption, aligning with green building principles suitable for tropical climates. The development process consisted of five key phases as indicated in Table 2.

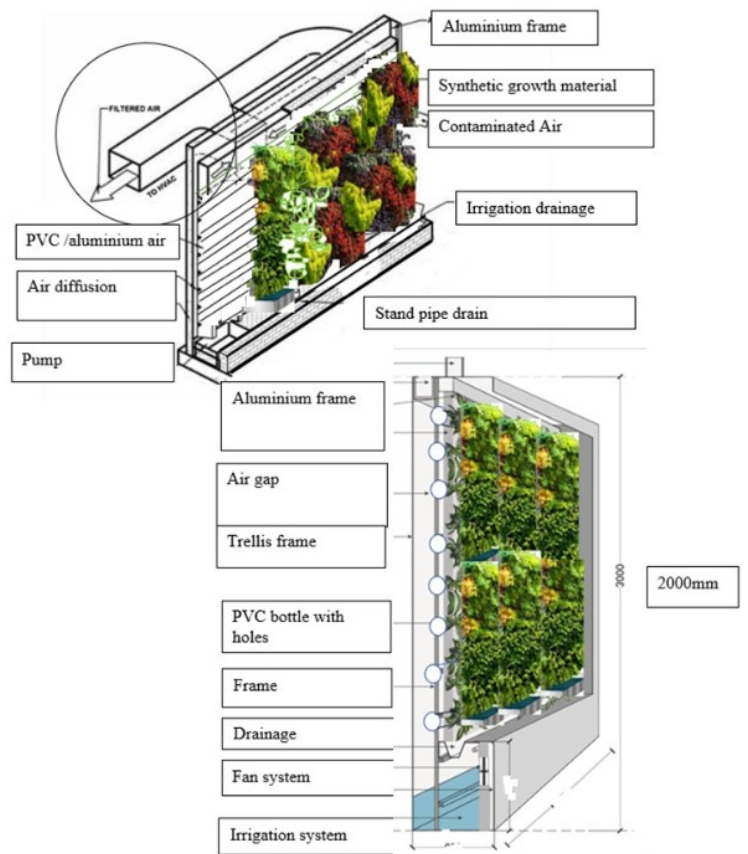


**Figure 7:** Prototype Development of IOT- Based Green Wall Façade

**Table 5:** The development process of the IOT-Based Green Wall Façade

| Key Phases                                             | Description of the Prototype Development and System Integration                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Phase 1: Design of the Green Wall Façade Module</b> | The façade system was designed based on the window-to-wall ratio, considering three common Malaysian housing typologies—condominiums, 2–3 storey terrace houses, and flats (NAPIC, 2021). The modular green wall structure consists of aluminum frames and PVC panels, allowing easy assembly and customization. The plant layer was selected based on vegetation studies and its integration with the ventilation strategy. The limitations of existing Malaysian construction codes (UBBL, 2013) highlighted the need for innovative and adaptive green solutions. |

| Key Phases                                               | Description of the Prototype Development and System Integration                                                                                                                                                                                                                                                                                                 |
|----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Phase 2: Smart IoT-Based Monitoring System</b>        | A smart automation system was developed to monitor indoor air quality in real-time using multi-sensor detectors for PM, CO <sub>2</sub> , TVOC, humidity, and temperature. The sensors communicate via wireless access points to a cloud-based IoT platform that stores, visualizes, and analyzes data to regulate air quality via actuators and fan operation. |
| <b>Phase 3: Heat Recovery and Passive Humidification</b> | Waste heat flow was studied for possible energy recovery, supporting a passive humidification strategy. This enhances system sustainability by reducing dependency on external energy.                                                                                                                                                                          |
| <b>Phase 4: Simulation</b>                               | Thermal comfort and air quality performance were simulated using IESVE software to validate system effectiveness.                                                                                                                                                                                                                                               |
| <b>Phase 5: Construction and Testing</b>                 | A modular unit (1.5 m × 2.0 m) was constructed and equipped with solar PV-powered cooling, sensors, and actuators. Passive cooling and humidification strategies were integrated with thermal storage to ensure energy-efficient operation.                                                                                                                     |

### Challenges and Limitations

During the field-testing phase at the Mizan Park prototype cabin, several technical and environmental challenges were encountered that provide critical insights for future scaling.

- i. **Sensor Drift in High Humidity:** the most significant challenge was sensor drift in the DHT22 and MQ-series sensors caused by the high relative humidity (>85%) typical of the Malaysian monsoon season. This required the implementation of a software-based 'humidity offset' to prevent false ventilation triggers.
- ii. **Signal Attenuation:** the steel structure of the container cabin acted as a partial Faraday cage, leading to intermittent Wi-Fi signal loss between the sensor nodes and the central gateway. This was resolved by installing an external high-gain antenna, highlighting the need for robust connectivity infrastructure in low-cost industrial-style building.
- iii. **Maintaining Learning Curve:** while the system is automated, initial 'Sakinah' ambiance was momentarily disrupted by pump clogging from organic sediment in the hydroponic trays. This underscores that 'low maintenance' does not mean 'zero maintenance', and suggests that future iterations require a pre-filtration stage for the irrigation system to ensure

the physical environment remains in a state of equilibrium without frequent human intervention.

### **Daylight illuminance and 'Light Poverty' Mitigation**

Daylight illuminance, which refers to the amount of natural light that illuminates indoor spaces, is a key consideration in building design and architecture. It is important for creating comfortable and well-lit environments while reducing the need for artificial lighting. the purpose of this data analysis is to explore the factors that affect daylight illuminance and analyse the collected data to provide recommendations for optimising natural lighting in buildings without neglecting the users' comfort. Factors affecting the amount of natural light penetration that enters the research cabin and greenhouse in Mizan Park are examined. The factors are the building orientation, the window sizes, and the use of exterior shading devices. From there, informed decisions and improvements can be made on ways to optimise the levels of natural light for optimal comfort, thereby minimising energy consumption. Summarily, this data analysis seeks to encourage continuous sustainable building design practices that prioritise natural lighting, leading to optimum comfort and healthier, more environmentally friendly indoor spaces.

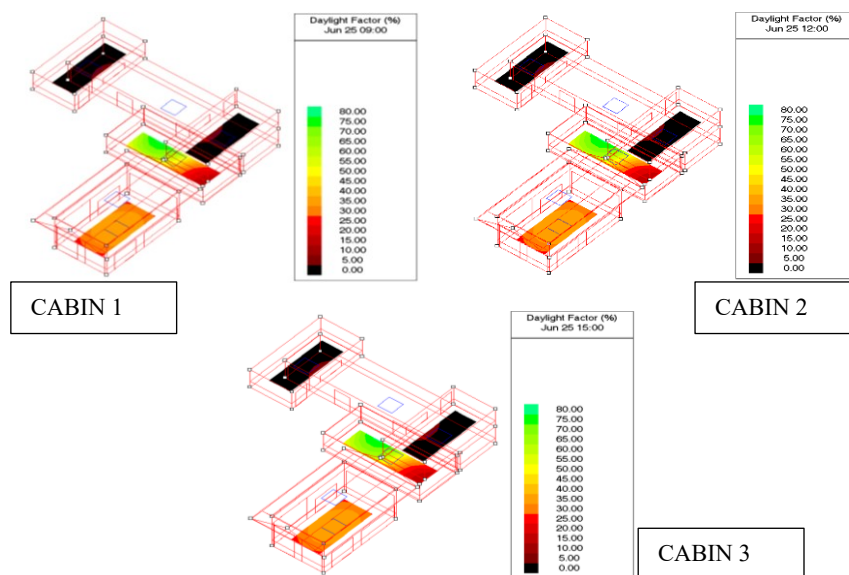


**Figure 8:** Daylight illuminance simulation

Figure 8 illustrates the 'Lux-to-Energy Displacement' mechanism driving the prototype's efficiency. Standard Cabins 1 and 2 maintained a

negligible 10 lux, representing an architectural failure necessitating 100% reliance on artificial lighting. Conversely, the Green Wall module's translucent properties significantly increase indoor illuminance, acting as the primary empirical driver for the 30.2% energy savings via 'Solar-Sync' dimming. This performance directly addresses the 'light poverty' endemic to deep-plan Malaysian PPR flats. By bridging biological needs with architectural efficiency, the prototype reconfigures the building's relationship with the sun, offering a scalable framework to reduce operational loads while restoring a naturally lit fitrah.

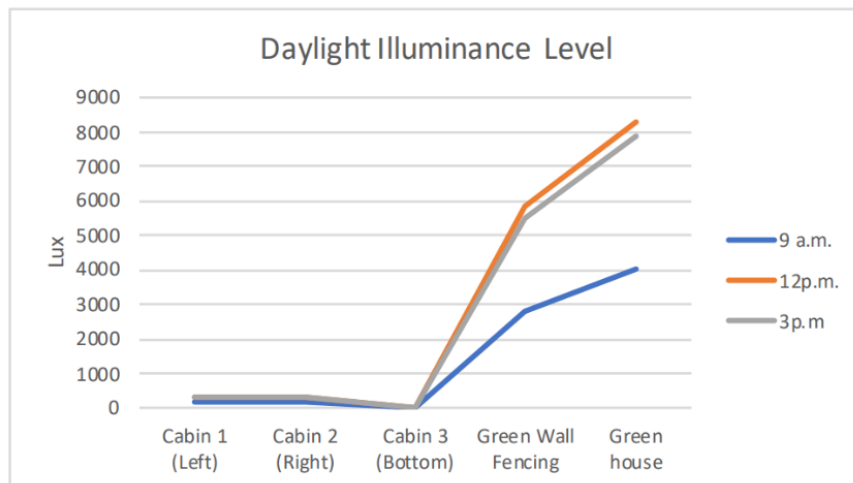


**Figure 9:** Daylight illuminance level at the research site, Mizan Park

In this research, the key findings from the data collected on the daylight illuminance of the solar green façade on the cabin and greenhouse in Mizan Park, USIM, are analyzed and further discussed.

The findings are discussing about the items as follows:

- i. level of indoor air quality of the green wall façade system at a full-capacity occupant premise.
- ii. design and implement a plug-and-play IoT-based, solar-powered natural façade system at the research site.

## CONCLUSION

This study demonstrates that an integrated IoT-based green wall system enhances indoor environmental quality while achieving a 30.2% energy reduction through Demand-Controlled Regulation (DCR). By utilizing Solar-Sync Dimming and

Hygroscopic Pulsing, the prototype aligns biological needs with architectural efficiency, restoring environmental fitrah and fostering 'Sakinah' living. These findings advocate for integrating active bio-filtration standards into the UBL and GBI to mitigate the Klang Valley's Urban Heat Island effect. The system's modularity supports health equity through PPR flat retrofitting and advanced BMS integration in luxury high-rises. Despite technical challenges like sensor drift, this research provides a validated blueprint for sustainable residential design prioritizing both technological innovation and human well-being.

## ACKNOWLEDGEMENT

This research is granted by the Grant Scheme title PPPI/FKAB/0121/USIM/17221 under Universiti Sains Islam Malaysia.

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Received: 11<sup>th</sup> November 2025. Accepted: 13<sup>th</sup> January 2026