Green Wall Systems as a Solution for PM2.5 Mitigation in Indoor Environments: Comparing Passive and Active Systems

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Manuscript received September 25, 2023; revised December 13, 2023; accepted March 3, 2024; published October 16, 2024

Abstract—**The problem of PM2.5 particulate matter pollution in Thailand poses significant health risks for both tourists and population country. While this problem is commonly associated with outdoor environments, PM2.5 particulate matter has also been found to exceed the standard in indoor environments, particularly in areas with natural ventilation systems such as building corridors. The aim of this study is to identify the most cost-effective approach for utilizing plant walls to mitigate PM2.5 concentrations. The study examines two types of green walls, namely mixed plants and single plants. For the mixed plant condition, three ornamental species, *Episcia cupreata* (Hook.), *Ficus lyrata* Warb, and *Nephrolepis exaltata* (L.) Schott, were used on the green wall. Only *Episcia cupreata* (Hook.), a plant with hairs covering the surface of the leaves, was used for the single plant condition. The green wall structure was designed into two systems, active and passive, and the experiment was conducted in a building corridor during a period when the PM2.5 concentration exceeded the standard threshold. The findings of this study reveal that active green walls exhibit an efficacy in reducing PM2.5 concentrations that is approximately 5.45 times greater compared to passive green walls. The scanning electron microscope (SEM) images support the implementation of an active system that enhances the efficiency of plants in capturing PM2.5. Two active green wall panels with a single plant of *Episcia cupreata* (Hook.) represent the optimal solution for reducing PM2.5 in this case. This solution can control PM2.5 concentration within standard with a cost-effective rate. Additionally, plants exhibiting hairy leaves demonstrated a higher proficiency in the accumulation of PM2.5 particles compared to plants without such characteristics.**

Keywords—**active system, cost-effective rate, hairy leaves, passive system, PM2.5**

I. Introduction

The building serves as a fundamental human habitation, wherein individuals allocate a substantial portion, approximately 90 percent, of their daily time for indoor activities [1]. Consequently, the quality of indoor air assumes paramount significance due to its direct impact on the well-being and health of occupants [2]. Particulate matter with a diameter smaller than 2.5 microns (PM2.5) is a critical parameter in evaluating indoor air quality due to its direct impact on the health of individuals residing within a building [3, 4]. According to the standards of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has specified that indoor PM2.5 concentrations should not exceed the average 35 $\mu g/m^3$ within 24 h [5]. In areas with natural ventilation, such as indoor corridors, the accumulation of PM2.5 exceeding the standard threshold is frequently observed. Furthermore, the concentration of indoor PM2.5 is subject to variation based on the outdoor PM2.5 concentration levels [6]. The utilization of green walls as a strategy for augmenting indoor air quality constitutes a feasible method to foster sustainability in the domain of building design and construction, owing to its potential for curbing the main energy consumption of buildings and fostering the improvement of occupants' health and well-being [7–10]. The meticulous selection of plant varieties for installation within green walls is deemed crucial, as each plant possesses a distinctive capacity to mitigate pollution in specific dimensions [11]. In the context of mitigating PM2.5, the efficiency of plant dust capture is notably governed by the physical attributes of plant leaf surfaces. For instance, plants exhibiting a coarse leaf texture, characterized by convexity, demonstrate enhanced efficacy in trapping PM2.5 compared to those with a smoother leaf surface [12]. Developing an effective indoor air quality enhancement system that optimizes energy consumption for efficient air quality improvement is crucial for cost reduction and the preservation of the health and well-being of building occupants. Prior examinations have underscored the criticality of a careful plant selection process. Nevertheless, a comprehensive analysis of the specific attributes of plant leaves, particularly those related to the efficacy in diminishing PM2.5 concentrations, is lacking, notably in the realm of hairy leaf surfaces. Consequently, the principal aim of this research is to examine the efficacy of both passive and active green wall systems in mitigating PM2.5 concentrations by utilizing plants with varying physical characteristics of leaf surfaces.

II. Material in the Experiment

In this study, featured green walls were categorized into two types: mixed plants and single plants. The assessment of past research reviews indicates that the three species of plants implemented on the green wall, namely *Episcia cupreata* (Hook.) [13], *Ficus lyrata* (Warb) [14], and *Nephrolepis exaltata* (L.) Schott. [15], exhibit commendable characteristics in trapping PM2.5. In the mixed plants condition, three ornamental plants were placed on the green wall, namely 28 pots of *Episcia cupreata* (Hook.), 28 pots of *Ficus lyrata* (Warb), and 28 pots of *Nephrolepis exaltata* (L.) Schott. On the other hand, the single plant green wall exclusively consisted of *Episcia cupreata* (Hook.). Fig. 1 presents the physical attributes of the leaf surface for each plant specimen used in the experimental study.

To optimize plant growth, the green wall panel was constructed using angle steel and covered with a transparent acrylic sheet, allowing for the transmission of natural light.

doi: 10.18178/ijesd.2024.15.5.1498

The panel dimensions were 2.00 m × 1.80 m × 0.40 m. The experimental setup encompassed two conditions for both mixed and single plant green walls: active and passive. In the active green wall, six fans with a diameter of fifteen centimeters were strategically placed at the bottom and top of the panel. The three fans at the bottom facilitated the circulation of polluted air through the plants within the active panel, while the remaining three fans at the top ensured the distribution of fresh air back into the area, as depicted in Fig. 2. Conversely, during the experiments involving the passive green wall, none of the fans were operated.

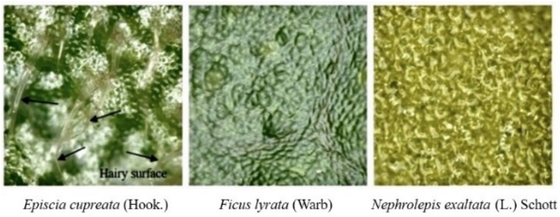


Fig. 1. Photograph that captures the physical characteristics of each plant with an optical microscope.

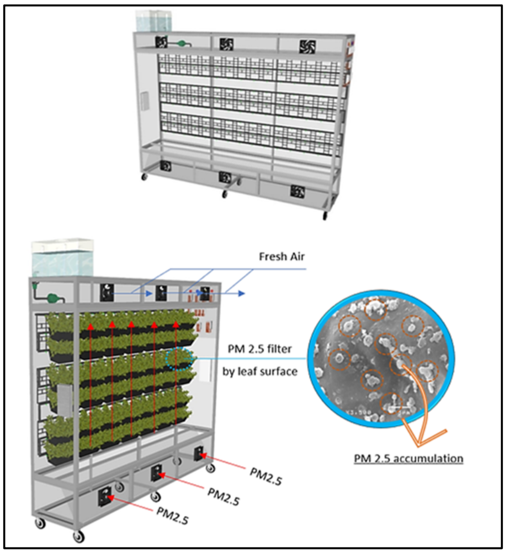


Fig. 2. Air quality improvement mechanisms of active experiments.

The acquisition of empirical data entailed the deployment of multiple sensors. The measurement of energy consumption, quantified in kilowatt-hours (kWh), was conducted using a ZMAi-90 device that established a Wi-Fi connection via the Tuya Smart application. To obtain PM2.5 data, air quality sensors of the D701 V.3 models were employed, which were connected to a 4G network and utilized the Milesight IoT Cloud application to capture data at 15-minute intervals. In order to collect PM2.5 concentration data, the sensors were strategically installed at two distinct locations, namely indoor and outdoor environments.

III. Methodology

The investigation was executed within the spatial limits of the building's corridors, covering an expanse measuring 73 square meters (m^2). The experimental procedures were performed during a period in which the outdoor PM2.5 concentrations in Thailand exceeded the established regulatory thresholds. Throughout the course of the experiments, the windows were consistently maintained in an open position, as shown in Fig. 3. Each trial in the study spanned a total duration of 24 hours.

To maintain the ornamental plants within the panel, a 23-liter water tank is installed at the upper section. This tank is connected to a polyethylene (PE) pipe, for the purpose of conveying water from the top of the panel. Automated watering is scheduled to occur daily at 8:00 a.m., with a duration of 2 minutes per day. The research encompassed three different experimental setups: a scenario Without a Green Wall (NGW), an active green wall (AGW), and a Passive Green Wall (PGW). To ensure the reliability of the findings, each experiment was conducted thrice, to use averages to analyze the results. A comprehensive set of thirteen situations was carried out in the scope of this study. The conducted experiments were methodically labeled and are prominently presented in the initial columns of Table 1.

Fig. 3. The corridor area in the experiment.

Table 1. Thirteen situations in the experiment

Experimental model	**Fan on green wall panel**	**Plants species on the green wall**			**Number of green wall panels**
		***Episcia cupreata* (Hook.)**	***Ficus lyrata* Warb**	***Nephrolepis exaltata* (L.) Schott**	
NGW	-	-	-	-	-
1 PGW_{mixed}	off	✓	✓	✓	1
2 PGW_{mixed}	off	✓	✓	✓	2
3 PGW_{mixed}	off	✓	✓	✓	3
1 PGW_{single}	off	✓	-	-	1
2 PGW_{single}	off	✓	-	-	2
3 PGW_{single}	off	✓	-	-	3
1 AGW_{mixed}	on	✓	✓	✓	1
2 AGW_{mixed}	on	✓	✓	✓	2
3 AGW_{mixed}	on	✓	✓	✓	3
1 AGW_{single}	on	✓	-	-	1
2 AGW_{single}	on	✓	-	-	2
3 AGW_{single}	on	✓	-	-	3

IV. RESULTS

A. Ability to Reduce PM2.5 Concentration in Corridor Areas by Green Wall

Table 2. Average indoor PM2.5 concentrations for each experiment during 24 hours

Experimental model	PM2.5 (µg/m³)	PM2.5 (µg/m³)	PM2.5 (µg/m³)	PM2.5 (µg/m³)
	No.1	No.2	No.3	Average
NGW	43.0	50.0	45.9	46.3
1 PGW $_{mixed}$	43.1	48.5	48.7	46.8
2 PGW $_{mixed}$	49.5	52.4	53.3	51.7
3 PGW $_{mixed}$	43.4	46.7	41.8	44.0
1 PGW $_{single}$	42.5	43.3	44.9	43.6
2 PGW $_{single}$	41.2	42.0	42.7	42.0
3 PGW $_{single}$	46.3	45.9	42.6	44.9
1 AGW $_{mixed}$	49.4	41.9	46.6	46.0
2 AGW $_{mixed}$	40.4	40.5	50.7	43.9
3 AGW $_{mixed}$	32.8	33.6	33.0	33.1
1 AGW $_{single}$	41.6	38.6	39.9	40.0
2 AGW $_{single}$	32.1	33.4	31.5	32.3
3 AGW $_{single}$	21.7	24.1	24.8	23.5

Table 3. Average outdoor PM2.5 concentrations for each experiment during 24 hours

Experimental model	PM2.5 (µg/m³)	PM2.5 (µg/m³)	PM2.5 (µg/m³)	PM2.5 (µg/m³)
	No.1	No.2	No.3	Average
NGW	42.5	49.6	45.4	45.8
1 PGW $_{mixed}$	43.1	48.6	48.7	46.8
2 PGW $_{mixed}$	50.0	52.7	54.5	52.4
3 PGW $_{mixed}$	45.4	48.6	43.5	45.8
1 PGW $_{single}$	43.5	44.3	45.9	44.6
2 PGW $_{single}$	42.7	43.4	44.1	43.4
3 PGW $_{single}$	49.1	48.7	45.3	47.7
1 AGW $_{mixed}$	55.1	47.2	51.7	51.3
2 AGW $_{mixed}$	51.6	51.8	61.9	55.1
3 AGW $_{mixed}$	51.5	52.4	51.4	51.8
1 AGW $_{single}$	48.3	45.2	46.7	46.7
2 AGW $_{single}$	45.6	46.8	44.9	45.8
3 AGW $_{single}$	43.2	45.0	44.8	44.3

In the study, the results presented the average PM2.5 concentration obtained from both indoor and outdoor environments during the repeated experiments conducted over a 24-hour data collection period. These results are summarized in Table 2 and Table 3 for indoor and outdoor concentration, respectively.

Due to the variation in outdoor PM2.5 concentration conditions across the different experimental days for the thirteen situations, it was necessary to normalize the PM2.5 data for each experiment in order to facilitate meaningful comparisons. To achieve this, the outdoor PM2.5 concentrations of the 3 PGW (Passive Green Wall) single experiment were chosen as the baseline for normalization, with a value of 47.7 µg/m³. This value was selected as it was closest to the mean value of all the experiments. The calculation method for normalization is presented in column 3 of Table 4. Furthermore, column 4 of Table 4 shows the average indoor PM2.5 concentrations after normalization, enabling effective comparison among the different experiments.

The analysis of column 4 in Table IV revealed that green walls possess the capability to reduce PM2.5 concentrations. Among the different experimental setups, the 3 AGW with single plants of *Episcia cupreata* (Hook.) demonstrated the highest effectiveness in reducing PM2.5 concentrations. It achieved the lowest PM2.5 concentration at 26.9 µg/m³, which is 44% lower than the NGW experiment with a PM2.5 concentration of 48.2 µg/m³. It is worth noting that for the well-being of occupants in buildings, ASHRAE recommends that indoor PM2.5 concentrations should not exceed 35 µg/m³. In this research, three experimental models, namely 3 AGW$_{single}$, 3 AGW$_{mixed}$, and 2 AGW$_{single}$, effectively controlled PM2.5 concentrations within the recommended standard range.

Table 4. Normalizing PM2.5 concentrations at 47.7 µg/m³ for comparison

Experimental model	Average outdoor PM2.5 (µg/m³)	Calculation	NormalizedPM2.5 at 47.7 µg/m³ (µg/m³)	Ability to reduce PM2.5 (µg/m³)
NGW	47.7	(47.7 – 45.8) + 46.3	48.2	-
1 PGW $_{mixed}$	47.7	(47.7 – 46.8) + 46.8	47.7	0.5
2 PGW $_{mixed}$	47.7	(47.7 – 52.4) + 51.7	47.0	1.2
3 PGW $_{mixed}$	47.7	(47.7 – 45.8) + 44.0	45.8	2.4
1 PGW $_{single}$	47.7	(47.7 – 44.6) + 43.6	46.7	1.5
2 PGW $_{single}$	47.7	(47.7 – 43.4) + 42.0	46.3	1.9
3 PGW $_{single}$	47.7	(47.7 – 47.7) + 44.9	44.9	3.3
1 AGW $_{mixed}$	47.7	(47.7 – 51.3) + 46.0	42.3	5.9
2 AGW $_{mixed}$	47.7	(47.7 – 55.1) + 43.9	36.5	11.7
3 AGW $_{mixed}$	47.7	(47.7 – 51.8) + 33.1	29.1	19.1
1 AGW $_{single}$	47.7	(47.7 – 46.7) + 40.0	41.0	7.2
2 AGW $_{single}$	47.7	(47.7 – 45.8) + 32.3	34.2	14.0
3 AGW $_{single}$	47.7	(47.7 – 44.3) + 23.5	26.9	21.3

Furthermore, the study revealed that incorporating *Episcia cupreata* (Hook.) within the active green wall system significantly enhanced the efficiency of PM2.5 capture. Specifically, compared to the installation of *Episcia cupreata* (Hook.) in passive panels, the active system demonstrated a remarkable improvement in PM2.5 capture efficiency, increasing from 2.2 µg/m³ to 14.2 µg/m³ as shown in Table 5. In the case of active green walls, it was observed that single plants exhibit a 14% greater capacity to diminish PM2.5 concentration compared to mixed plant configurations as shown in Table 6.

Table 5. Compare passive versus active green walls

Experimental model	Ability to reduce PM2.5 (µg/m³)	Average reduction of PM2.5 (µg/m³)	Type of Green Walls
1 PGW $_{single}$	1.5		
2 PGW $_{single}$	1.9	2.2	Passive
3 PGW $_{single}$	3.3		
1 AGW $_{single}$	7.2		
2 AGW $_{single}$	14.0	14.2	Active
3 AGW $_{single}$	21.3		

Table 6. Compare active green wall mixed versus single plants

Experimental model	Ability to reduce PM2.5 (μg/m³)	Average reduction of PM2.5 (μg/m³)	Type of Plant on Green Walls
1 AGW $_{mixed}$	5.9	12.2	*Episcia cupreata* (Hook.), *Ficus lyrata* (Warb), and *Nephrolepis exaltata* (L.) Schott.
2 AGW $_{mixed}$	11.7		
3 AGW $_{mixed}$	19.1		
1 AGW $_{single}$	7.2	14.2	*Episcia cupreata* (Hook.)
2 AGW $_{single}$	14.0		
3 AGW $_{single}$	21.3		

Supporting this finding, Thomas *et al.* [8] discovered that active green walls were effective in reducing Total Suspended Particles (TSP) by 42.6% over a 20-minute period. The utilization of an active green wall system that boosts the plants' efficiency in capturing PM2.5 is further supported by the Scanning Electron Microscope (SEM) images obtained during the study, as depicted in Fig. 4 to Fig. 6.

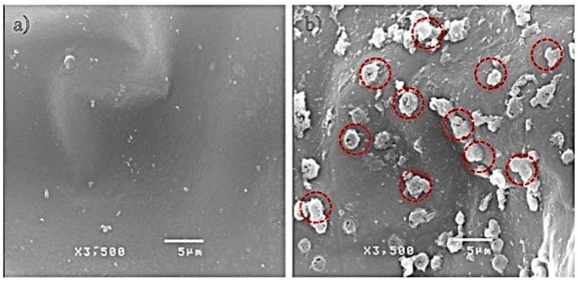


Fig. 4. The deposition of PM2.5 on the leaf surface of *Episcia cupreata* (Hook.), with a) denoting Passive Green Wall (PGW) and b) representing Active Green Wall (AGW).

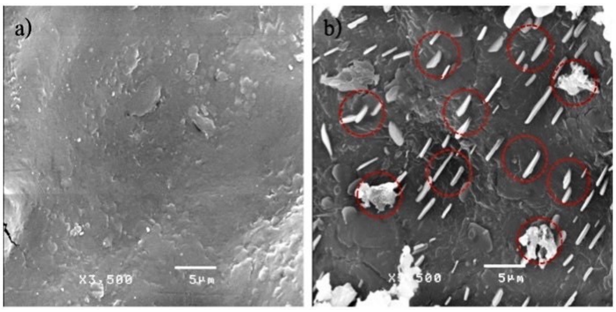


Fig. 5. The deposition of PM2.5 on the leaf surface of *Ficus lyrata* (Warb) with a) denoting Passive Green Wall (PGW) and b) representing Active Green Wall (AGW).

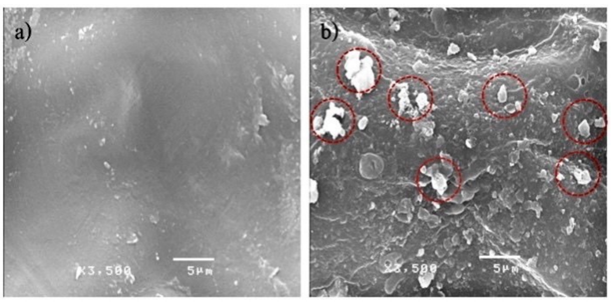


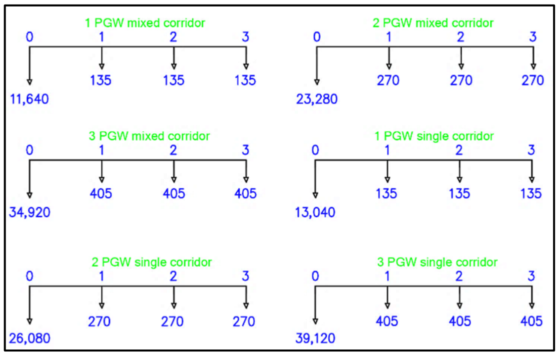
Fig. 6. The deposition of PM2.5 on the leaf surface of *Nephrolepis exaltata* (L.) Schott with a) denoting Passive Green Wall (PGW) and b) representing Active Green Wall (AGW).

These SEM images, taken at a magnification level of 3,500x, provide visual evidence that reinforces the effectiveness of the active system in facilitating enhanced PM2.5 capture by the plant leafs. According to Zhong *et al.* [13] found that the leaf hairs acting as obstacles and leaves with lower Specific Leaf Area (SLA), characterized by smaller and thicker structures, can work together to favor the deposition and retention of particulate matter on plant leaves. These leaf traits contribute to the overall dust collection efficiency of plants.

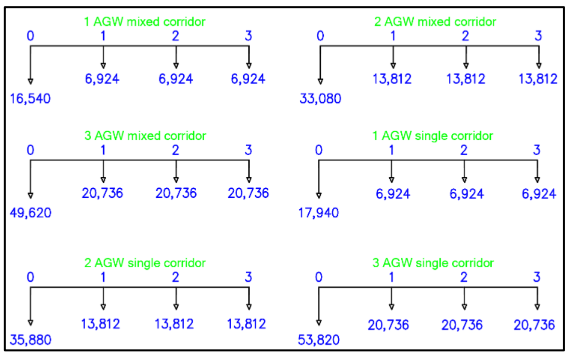
B. Cost Spent on Improving Air Quality with Green Walls

The cost analysis of enhancing air quality through the implementation of green walls entails the division of expenses into three distinct categories. These categories consist of green wall preparation costs, which encompass expenditures related to the supply of plants in panels and the panel production process. The cost commences at 11,640 Baht per panel for passive green walls and 16,540 Baht per panel for active green walls. The expenditure escalates with an augmentation in the number of panels.

Additionally, plant maintenance costs within panels account for ongoing expenses associated with the maintenance of plants, including activities such as watering and fertilization. The cost of green walls, encompassing both passive and active systems, is uniform at 135 Baht per panel per year, with the expense rising proportionally to the quantity of panels.



(A)



(B)

Fig. 7. The cash flow diagram illustrates the expenditure associated with enhancing air quality through the implementation of green walls, denoted in currency units (Baht), with (A) representing Passive Green Wall (PGW) and (B) representing Active Green Wall (AGW).

Finally, energy costs allocated to improving air quality for the AGW system encompass the energy consumption and associated expenses attributed to the mechanisms employed within the AGW system to enhance air quality. This cost pertains exclusively to AGW systems and is derived from the collection of electricity consumption data, which is subsequently multiplied by 4.4217 Baht, representing the unit price of electricity in Thailand (Baht/kWh). The findings indicate that 1 AGW system consumes 18.60 kWh annually, 2 AGW systems consume 37.1 kWh per year, and 3 AGW systems consume 55.7 kWh per year. Consequently, the cost associated with enhancing air quality through green walls amounts to 6,789 Baht, 13,542 Baht, and 20,331 Baht annually for 1 AGW, 2 AGW, and 3 AGW, respectively. All of these expenses can be used to write a cash flow plan showing the cost spent (Unit: Baht) on improving air quality, as shown in Fig. 7.

This study used Present Value (PV) to determine the cost of improving indoor air quality with green walls. The service life of the green wall system in this study was assumed to be 3 years, indicating the anticipated duration of its functional operation. Additionally, a discount rate (i) of 7% was applied to account for the time value of money and assess the economic feasibility of the green wall investment over the designated period. The PV can be calculated using Eq. (1) [16], where A represents the sum of plant maintenance costs within the panel and energy costs of AGW. The PV of each experiment as shown in Table 7

$$pv = \frac{A\,(1+i)^n - 1}{i\,(1+i)^n} \quad (1)$$

Table 7. The present value of the cost for improving air quality with green walls

Experimental model	Calculation	Present Value (Baht)
1 PGW mixed	$11{,}640 + \frac{135\,(1+0.07)^3 - 1}{0.07\,(1+0.07)^3}$	11,994
2 PGW mixed	$23{,}280 + \frac{270\,(1+0.07)^3 - 1}{0.07\,(1+0.07)^3}$	23,989
3 PGW mixed	$34{,}920 + \frac{405\,(1+.07)^3 - 1}{0.07\,(1+0.07)^3}$	35,983
1 PGW single	$13{,}040 + \frac{135\,(1+0.07)^3 - 1}{0.07\,(1+0.07)^3}$	13,394
2 PGW single	$26{,}080 + \frac{270\,(1+0.07)^3 - 1}{0.07\,(1+0.07)^3}$	26,789
3 PGW single	$39{,}120 + \frac{405\,(1+0.07)^3 - 1}{0.07\,(1+0.07)^3}$	40,183
1 AGW mixed	$16{,}540 + \frac{6{,}924\,(1+0.07)^3 - 1}{0.07\,(1+0.07)^3}$	34,711
2 AGW mixed	$33{,}080 + \frac{13{,}812\,(1+0.07)^3 - 1}{0.07\,(1+0.07)^3}$	69,327
3 AGW mixed	$49{,}620 + \frac{20{,}736\,(1+0.07)^3 - 1}{0.07\,(1+0.07)^3}$	104,038
1 AGW single	$17{,}940 + \frac{6{,}924\,(1+0.07)^3 - 1}{0.07\,(1+0.07)^3}$	36,111
2 AGW single	$35{,}880 + \frac{13{,}812\,(1+0.07)^3 - 1}{0.07\,(1+0.07)^3}$	72,127
3 AGW single	$53{,}820 + \frac{20{,}736\,(1+0.07)^3 - 1}{0.07\,(1+0.07)^3}$	108,238

From Fig. 7, the preparation costs of green wall per square meter is 4,594 Baht/m^2 for AGW utilizing mixed plants, while the cost for AGW employing single plants is 4,983 Baht/m^2. Regarding the installation cost of PGW, the costs are 3,233 Baht/m^2 for mixed plants and 3,622 Baht/m^2 for single plants. Green walls exhibit variability in cost due to the presence of diverse systems available in the market. In a scholarly work by the author cited as [17], a thorough analysis demonstrates that green facades exhibit an average installation cost of 190 Euro/m^2 (equivalent to 7,300 Baht/m^2), while living walls entail a higher cost of 750 Euro/m^2 (equivalent to 28,818 Baht/m^2). This research has revealed that the production of green walls, aimed at enhancing air quality in Thailand, incurs costs lower than the average installation expenses observed in the European market.

C. PM 2.5 Concentration Control and Cost Spent

In order to meet the criteria for good air quality, an alternative must maintain a PM2.5 concentration of less than 35 µg/m³. This threshold is established as the maximum acceptable level of PM2.5 concentration to ensure favorable air quality conditions. Fig. 8 presents the average PM2.5 concentrations within 24 hours in the corridor area and the PV of the cost associated with improving air quality of each experiment. Where y axis is the average PM2.5 concentration (µg/m³) and x axis is the PV of the costs associated with improving air quality (Baht). In the context of the graph, the green numbers 1, 2, and 3 represent the quantity of panels associated with PGW. Meanwhile, the red numbers 1, 2, and 3 represent the number of panels attributed to AGW. These numbers indicate the respective count of PGW and AGW panels implemented in the studied scenarios. The ASHRAE Standard line serves as a reference for air quality assessment. Areas below the ASHRAE Standard line indicate acceptable air quality. The average outdoor ambient level of PM2.5 concentration was assessed to be 47.7 µg/m³. In this research, three alternatives have been identified within the favorable region of the graph. These consist of 3 AGW single, 3 AGW mixed, and 2 AGW single. Conversely, areas located above the delineating line on the graph denote unsatisfactory air quality levels that necessitate amelioration. Other experiments have been found in this area. The active green wall, featuring two panels consisting solely of *Episcia cupreata* (Hook.) from 2 AGW single experiment, which represents a recommended solution for enhancing indoor air quality in this case. It can reduce PM2.5 concentrations by 29% when compared to NGW experiment. This result is based on the distinctive leaf surface properties of *Episcia cupreata* (Hook.), characterized by hairiness, which facilitates the efficient capture of PM2.5 particles at a cost-effective rate.

V. Conclusions

In conclusion, this research explored the effectiveness of green walls in controlling PM2.5 concentrations and promoting good air quality at a cost-effective rate. The results demonstrated that green walls, particularly active green walls, have the ability to significantly reduce PM2.5 concentrations. Among the various experimental setups, in this case the 2 AGW single with *Episcia cupreata* (Hook.) exhibited efficiency in reducing PM2.5 concentrations, achieving levels well below the recommended threshold with a cost-effective rate.

By incorporating *Episcia cupreata* (Hook.) within the active green wall system, a substantial improvement in PM2.5 capture efficiency was observed compared to passive green walls. The active system demonstrated a remarkable increase in PM2.5 capture, indicating its effectiveness in mitigating air pollution. This finding was further supported by SEM images, which visually confirmed the enhanced PM2.5 capture capabilities of the active system. The study also highlighted the importance of maintaining PM2.5 concentrations below 35 µg/m³ for good air quality. The 3 AGW single, 3 AGW mixed, and 2 AGW single experimental setups successfully met this criterion, indicating their potential for effective PM2.5 control.

Furthermore, active green walls were found to be approximately 5.45 times more effective in reducing PM2.5 concentrations compared to passive green walls. The selection of plants characterized by the hairy structures on their leaf surfaces for installation on green walls illustrates the heightened efficacy in the reduction of PM2.5 concentration.

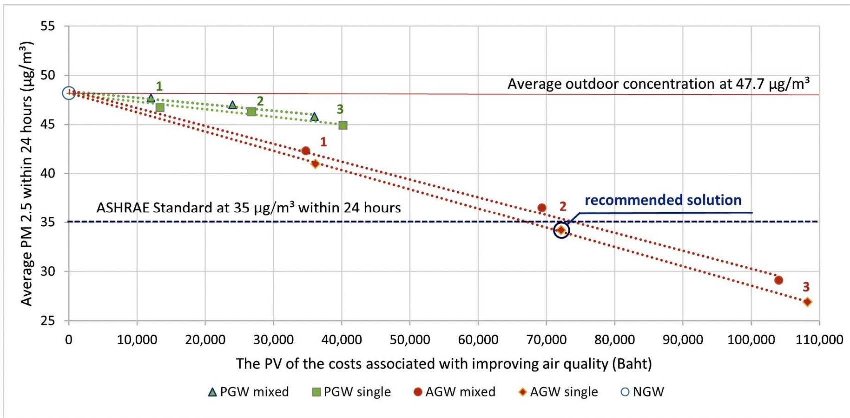


Fig. 8. The average PM2.5 within 24 hours and the cost of improving air quality of PGW and AGW.

Based on these findings, it is recommended to utilize active green walls, particularly in non-air-conditioned areas such as corridors, to effectively control PM2.5 levels and improve indoor air quality. Implementing such green wall systems can contribute to creating healthier environments for building occupants. Overall, this research contributes to the understanding of green walls as a sustainable and efficient solution for reducing PM2.5 concentrations and enhancing air quality in indoor spaces. It opens avenues for further exploration and encourages the adoption of green wall technologies to create healthier and more sustainable built environments.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The first author's responsibilities included data collection and analysis, leading to the creation of the initial draft. The second author, however, took the lead in defining the research scope, designing the methodology, and guiding the paper to its final completion.

Funding

This research was funded by King Mongkut's University of Technology North Bangkok under contract no. KMUTNB-68-BASIC-47. I would like to express my sincere gratitude for their support, which made this study possible.

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