Optimizing Energy Efficiency and Indoor Air Quality in Building Design for Hot and Humid Climates

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Abstract. Optimizing energy efficiency and indoor air quality is essential in hot and humid climates like Thailand, where high energy consumption and poor ventilation are common challenges in air-conditioned spaces. This research presents two case studies that focus on improving energy performance and environmental quality in distinct building types: a commercial building and a university classroom. The first case study investigates energy efficiency in a commercial building by analyzing various door configurations. Experiments conducted in an 18-square-meter room compare the energy consumption of outward-opening doors with air curtains, sliding doors with air curtains, and vestibule doors without air curtains. The results show that sliding vestibule doors without air curtains were the most energy-efficient, while outward-opening doors with air curtains consumed the highest amount of energy, highlighting the importance of door selection in reducing energy use in commercial settings. The second case study examines a university classroom where green walls were integrated to improve indoor air quality and energy efficiency. This study evaluates the impact of both active and passive green wall systems on energy use and CO_2 levels in a classroom with 10 occupants. Active green walls (AGW) using Epipremnum aureum plants demonstrated a 35% reduction in CO_2 concentrations and a 26% decrease in energy consumption compared to classrooms without green walls. Together, these case studies provide valuable insights for optimizing energy efficiency and indoor environmental quality in commercial and educational buildings, offering practical solutions for reducing energy consumption and enhancing occupant comfort in hot and humid climates.

1 Introduction

Energy efficiency and indoor air quality are critical components of sustainable building design, especially in hot and humid climates like Thailand, where air conditioning is essential for occupant comfort. In such climates, designing buildings that minimize energy consumption while maintaining comfortable indoor environments, typically between 22°C and 27°C with relative humidity between 20% and 75%, is necessary [1]. A significant source

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of energy loss in commercial buildings occurs through air leakage at entrances, particularly in the growing number of superstores and shopping malls. These buildings frequently employ air curtains to reduce air infiltration and maintain indoor temperatures [2]. Air curtains Despite their effectiveness, air curtains continuously consume electricity and are more efficient in reducing energy losses when installed in buildings under positive pressure differences [3]. While air curtains are effective, they also consume considerable electricity, as they must operate continuously [4]. Studies show that air curtains reduce energy consumption by preventing heat loss from indoor spaces in cold climates [5]. Air curtain installed at a building entrance acts as a barrier against infiltration and exfiltration of airflow between the outdoor environment and in the indoor space [6]. Previous studies have shown that air curtains can reduce infiltration air volume by 40%-80%, depending on the air supply speed and pressure differences between indoor and outdoor environments [7]. In educational facilities, particularly university classrooms, energy consumption is dominated by air conditioning, which accounts for over 65% of the total energy used in buildings [8]. Students spend around 70% of their time indoors during school days, resulting in elevated CO_2 levels that often exceed acceptable standards [9]. Traditional solutions, such as increasing ventilation rates, can improve air quality but are often energy-intensive and costly [10]. An innovative alternative is the use of green walls, specifically active green wall systems (AGW), which have shown promise in reducing CO_2 concentrations and improving indoor air quality without the high energy costs associated with mechanical ventilation [11]. Research suggests that green walls can also help lower indoor temperatures, further contributing to energy efficiency. This study explores two case studies aimed at addressing the dual challenge of optimizing energy efficiency and indoor air quality in Thailand: one focusing on door configurations in commercial buildings and the other on the use of green walls in university classrooms. By examining the energy performance of different door systems and evaluating the impact of green walls on air quality and energy use, this research aims to provide practical insights for designing buildings that enhance both energy efficiency and occupant comfort in hot and humid climates like Thailand's.

2 Methodology

The methodology for this research, which aims to optimize energy efficiency and indoor air quality (IAQ) in hot and humid climates through case studies of commercial buildings and university classrooms.

2.1 Case Study 1: Door Configurations in Commercial Buildings

Air leakage at building entrances is a significant contributor to energy loss in air-conditioned commercial spaces, particularly in tropical climates. Outward-opening doors, commonly used in these buildings, allow substantial amounts of conditioned air to escape with frequent opening and closing. This study compares the energy performance of outward-opening doors with sliding doors equipped with air curtains, which help create a barrier to minimize air exchange and reduce energy loss. Air curtains generate a laminar airflow that prevents outdoor air from entering and indoor conditioned air from escaping, thus enhancing energy efficiency. Air curtains show higher sealing efficiency in reducing infiltration through doorways in stores [12] [13]. The experiments were conducted in a controlled environment, simulating a commercial building. Four experiments were conducted as listed in Table 1. Two door configurations were tested: outward-opening doors with and without air curtains, and sliding doors with and without air curtains as shown in Figure 1. Indoor temperature was maintained at 25°C to reflect typical cooling settings in Thailand’s commercial buildings. Energy meters were installed to measure electricity consumption continuously using a digital electricity consumption reader connected to a data logger. The air conditioning unit, with a cooling capacity of 12,129 BTU/hr and an electric power of 3,555 watts, was used to maintain the room temperature. The air curtain, with an input of 50 watts and an air velocity of 7 meters per second, was used during experiments. The setup included both single opening and vestibule door configurations as shown in Figures 2 and 3. Door usage was standardized at 30 openings per hour, with each configuration subjected to a two-hour testing session. During each session, the door was opened 60 times at two-minute intervals to simulate typical commercial building usage. The goal was to determine which door configuration led to lower energy usage while maintaining the desired indoor climate.

Table 1. Experimental Characteristic of Four Experiments.

Experiments	Characteristic for Experiments		Air Curtain
	Single Opening	Vestibule Door	
1	Open Out	-	Yes
2	Sliding	-	Yes
3	-	Open Out	No
4	-	Sliding	No

Fig. 1. An Experimental Room.

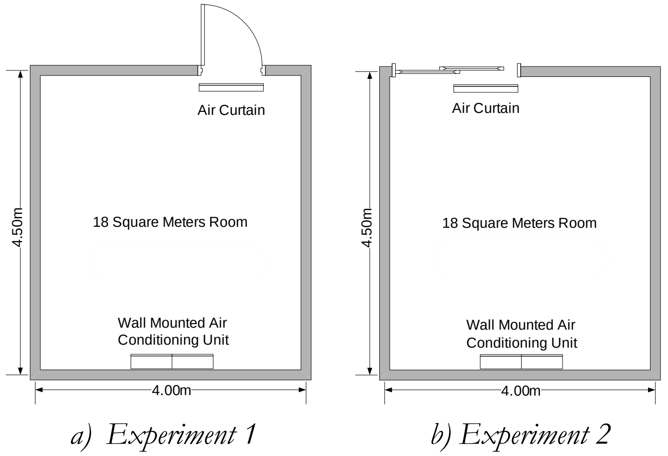

Fig. 2. Floor Plan of a Single Door Opening with Air Curtain Experiment.

2.2 Case Study 2: Green Walls in University Classrooms

The second part of the study focuses on improving indoor air quality in university classrooms, which rely heavily on air conditioning for temperature control. High CO_2 levels, due to insufficient ventilation, are common in these spaces and can lead to poor cognitive performance and discomfort. This research investigates the use of green walls to enhance IAQ by absorbing CO_2 and reducing the reliance on mechanical ventilation, thereby lowering energy consumption. The study was conducted in a classroom measuring 28.2 m² with a volume of 99 m³, occupied by 10 students during the experiments. The indoor temperature was maintained at 25°C. The green walls in this study are divided into two types, which are mixed plants and single plants as shown in Figure 4.

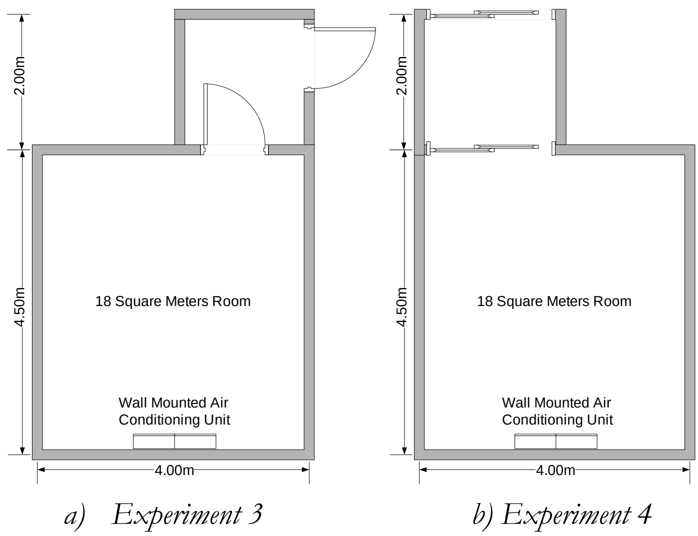

Fig. 3. Floor Plan of a Vestibule without Air Curtain Experiment.

Three ornamental plants were put on a green wall for mixed plants condition. They are 28 pots of Epipremnum aureum, 28 pots of Spathiphyllum spp., and 28 pots of Ficus Lyrata. Only Epipremnum aureum was put on a green wall for single plants condition due to its well known ability to reduce CO_2 from previous research. Pichlhöfer et. al. [14] found that the green wall of Epipremnum aureum had the ability to reduce the CO_2 concentration better than the others plant. Each planting pot has a size of 25 x 11 x 11 cm. The green wall panel is made of angle steel and covered by a clear acrylic sheet to allow natural light for plant growing. The panel has a size of 2.00 (W) x 1.80 (H) x 0.40 (D) meters. Six fans with a diameter of 15 centimeters were installed on the top and bottom of the panel to exchange polluted air in room with fresh air inside panels. Two LED daylight (125W) were installed on the side of the panel to increase active green wall ability in reducing CO_2 in room. A total of 10 experiments were conducted in this study as shown in Table 2. They are label and shown in first and second column of the Table. NGW means no green wall, PGW means passive green wall, and AGW means active green wall. The active green wall system included integrated air circulation fans and LED lighting to enhance air filtration. Since, light intensity and angle of light on green wall are important factors in CO_2 absorption efficiency [15]. CO_2 levels, temperature, humidity, and energy consumption were continuously monitored to assess the effectiveness of both systems. The AGW was designed to actively pull air through the plant roots, facilitating more efficient CO_2 reduction and contributing to overall energy savings by reducing the workload on the AC system. One exhaust fan with a of diameter 8" and 36,000 BTU air conditioner were installed in the classroom. The room temperature is controlled and set at 25 °C. The green wall is installed inside classroom with its back facing the window. Watering is set automatically at 17:00 PM for 2 minutes per day. Data collection started at 8:00 AM and ended at 12:00 PM or a test duration of 240 minutes. The teaching period is 120 minutes. 9 students with average age of 20 years old were presented in the classroom with one teacher. Average artificial light intensity of 4,500 lux were turned on during experiments.

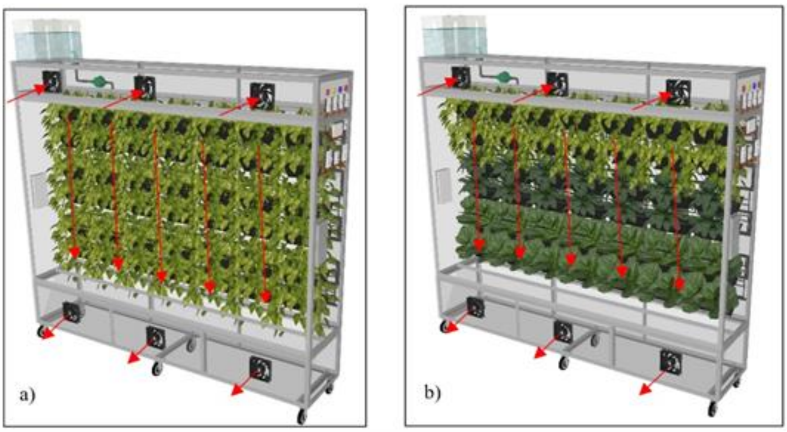

Fig. 4. Green wall panel a) is single plants condition and b) is mixed plants condition.

Table 2. Ten situations in the experimental.

NO	Experimental name	Exhaust fan in room	LED on green wall panel	Ventilation fan on green wall panel	Plants species			Number of green wall panels
					Epipremnum aureum	*Spathiphyllum spp.*	*Ficus Lyrata*	
1	NGW	off	-	-	-	-	-	-
2	NGW / turn on exhaust fan	on	-	-	-	-	-	-
3	1 PGW mixed	off	off	off	✓	✓	✓	1
4	2 PGW mixed	off	off	off	✓	✓	✓	2
5	1 AGW mixed	off	on	on	✓	✓	✓	1
6	2 AGW mixed	off	on	on	✓	✓	✓	2
7	1 PGW single	off	off	off	✓	-	-	1
8	2 PGW single	off	off	off	✓	-	-	2
9	1 AGW single	off	on	on	✓	-	-	1
10	2 AGW single	off	on	on	✓	-	-	2

3 Results

3.1 Energy Consumption for Door Types and Air Curtains

Each experiment were performed twice for reliability of data results. All data were normalized to minimized the variation effects due to different external temperature and humidity. For the open out experiments, the normalized results show that the electricity consumption was 0.80 kWh and 0.78 kWh as shown in the column 4 of Table 3. In the sliding experiments, the normalized electricity consumption was the same for both, at 0.40 kWh. The energy requirements were consistent for experiments involving a sliding door and an air curtain. For the vestibule open out experiments, the energy consumptions were 0.32 kWh and 0.34 kWh. Finally, the vestibule sliding door experiments both showed an electricity consumption of 0.16 kWh.

Table 3. Energy consumption of Four Experiments.

Experiments	Experiment Names	Adjusted Electricity Consumptions	
		kWs	kWh
1.1	Open Out #1	2871	0.80
1.2	Open Out #2	2803	0.78
2.1	Sliding #1	1453	0.40
2.2	Sliding #2	1453	0.40
3.1	Vestibule Open Out #1	1168	0.32
3.2	Vestibule Open Out #2	1215	0.34
4.1	Vestibule Sliding #1	562	0.16
4.2	Vestibule Sliding #2	562	0.16

3.2 CO_2 Reduction and Energy Savings from Active Green Walls

The CO_2 concentration of ten experiments when all 10 persons entered the room are shown in Figure 5. Their values were averaged and shown in Table 4.

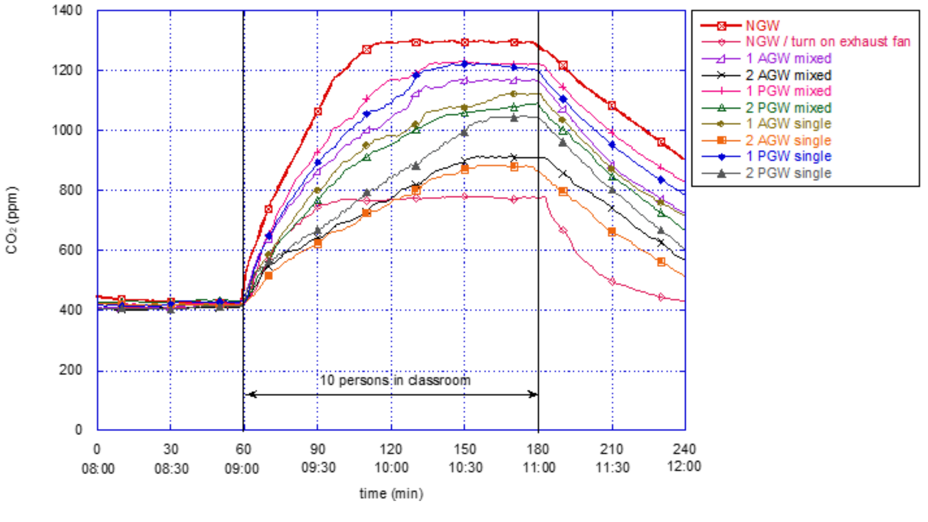

Fig. 5. The CO_2 concentration of each experimental model.

It was found that the CO_2 concentration increased when the classroom was started and decreases as the classroom is ended. The NGW / turn on exhaust fan experiment had the best control in CO_2 level. It can reduce the averaged CO_2 concentration from 1,158 ppm to 732 ppm. The second was 2 AGW single plants, it can reduce the averaged CO_2 concentration from 1,158 ppm to 735 ppm. Air conditioning energy consumption were normalized and shown in column 6 of Table 5. Energy consumption from exhaust fan is 0.1 kWh. While energy consumption from active green wall panel is 0.4 and 0.9 kWh for one active green wall panel and two active green wall panels, respectively. Combining all energy consumption from columns 6 to 8, total energy consumptions during 2 hour experiments were obtained. It was found that 1 AGW single plant experiment consume the lowest energy. It uses energy 29% less than the NGW experiment. While turning on the exhaust fan in the classroom consumes the most energy consumption. It consumes more energy to improve air quality for 12% comparing to the NGW experiment. Meanwhile, it consumes more energy than 2 AGW single for 75%, while yielding better air quality for 2 %.

Table 4. Averaged CO_2 concentration of each experimental model.

Experimental name	Averaged CO_2 (ppm)
NGW / turn on Exhaust fan	732
2 AGW single	735
2 AGW mixed	758
2 PGW single	826
2 PGW mixed	899
1 AGW single	927
1 AGW mixed	989
1 PGW single	1,029
1 PGW mixed	1,054
NGW	1,158

Table 5. Energy consumption and outdoor temperature for before and after normalization.

Experimental name	Recorded data or before normalization		Energy consumption after normalizing at 30.9 °C temperature					
	Average outdoor Temp. (°C)	Air conditioning energy (kWh)	Difference temperature from the mean value at 30.9 °C	Adjusting energy usage (kWh)	Air conditioning energy (kWh)	Exhaust fan energy (kWh)	Green wall panel energy (kWh)	Total Energy consumption (kWh)
NGW1	33.1	9.1	2.2	0.7	8.4	0.0	0.0	8.4
NGW2	32.5	8.9	1.6	0.5	8.4	0.0	0.0	8.4
NGW / turn on exhaust fan	32.1	9.7	1.2	0.4	9.3	0.1	0.0	9.4
1 AGW mixed	30.2	5.5	0.7	0.2	5.7	0.0	0.4	6.1
2 AGW mixed	30.9	5.6	0.0	0.0	5.6	0.0	0.9	6.5
1 PGW mixed	29.8	7.9	1.1	0.4	8.3	0.0	0.0	8.3
2 PGW mixed	29.2	7.0	1.7	0.6	7.6	0.0	0.0	7.6
1 PGW single	30.3	7.8	0.6	0.2	8.0	0.0	0.0	8.0
2 PGW single	29.7	6.8	1.2	0.4	7.2	0.0	0.0	7.2
1 AGW single	30.9	5.6	0.0	0.0	5.6	0.0	0.4	6.0
2 AGW single	30.9	5.3	0.0	0.0	5.3	0.0	0.9	6.2

4 Conclusion

The findings from these studies highlight key approaches to optimizing energy consumption and indoor environmental quality. The first study demonstrates how door configurations influence electricity use by affecting air movement and room temperature stability. Outward-opening doors with air curtains result in the highest energy consumption 0.80 kWh and 0.78 kWh, while sliding doors with air curtains significantly reduce energy use 0.40 kWh due to less air movement. Vestibule sliding doors without air curtains provide the most efficient outcome, with a consumption of 0.16 kWh. The research indicates that vestibule doors without air curtains are 59% more energy-efficient compared to single doors with air curtains. It is conclusive with Wang and Zhong [16] that air curtains are associated energy losses through building entrances under mild pressure differences. Sliding doors also outperform outward-opening doors by 49% in terms of energy efficiency. However, further research is needed to explore the impact of air pressure on energy consumption. In the second study, improving indoor air quality while minimizing energy consumption in classrooms was the focus. The study identifies alternatives that maintain CO_2 levels below 1,106 ppm, ensuring good air quality. Active green walls (AGW) showed the most significant improvement, saving between 23% and 29% of energy compared to a no-green-wall option while also reducing CO_2 concentration by 35%. Passive green walls (PGW) offered moderate energy savings of 1% to 14%, depending on the configuration. Two active green walls with Epipremnum aureum plants were found to be the optimal solution for classrooms, improving air quality while reducing energy consumption by 26%. Estupiñan et. al. [17] found that Epipremnum aureum has high efficiency for elimination of CO_2 indoors. As a result, it is conclusive to the same direction with other researches. Both studies underscore the importance of selecting optimal configurations—whether through door types or green walls—to achieve energy efficiency and environmental quality. While both strategies yielded positive results, they address different facets of energy efficiency. Door type and air curtain usage primarily target the reduction of air leakage and thermal comfort in commercial settings, whereas active green wall systems focus on improving indoor air quality and lowering energy consumption in educational environments. When combined, these two strategies offer a comprehensive approach to building energy efficiency and indoor environmental quality.

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