EFFECT OF HEAT GENERATED BY OUTDOOR CONDENSING UNIT OF AIR-CONDITIONING SYSTEM TOWARDS THE SURROUNDING ENVIRONMENT: A CASE STUDY USING GREEN LEAVES PLANTS

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ABSTRACT

Air-conditioning systems work by transferring heat from indoor spaces to the outdoors and thus the generation of hot air by air-conditioning systems can indeed complicate energy efficiency, and the substantial amount of heat released from these systems can contribute to the aggravation of the global warming effect. The first objective of this study was to investigate the effect of heat generated by outdoor condensing units of air-conditioning systems on the surrounding environment. The second objective of the study was to investigate the reduction of carbon footprints by comparing the heat generated by the two different brands of outdoor condensing units (i: Evoair and ii: Control). By conducting such a study and disseminating its findings, this paper contributes to proposing a better environmentally friendly air-conditioning system for supporting Environmental, Social, and Governance (ESG) initiatives and working towards mitigating the global warming effect. In order to accurately measure the temperature increase in the vicinity of outdoor condensing units during operation, three different types of green leaf crops (Brassica rapa subsp. chinensis, Brassica oleracea var. alboglabra and Ocimum basilicum) were selected to measure the change in microclimate effects. These crops were cultivated in two separate greenhouses receiving exhaust from two different outdoor condensing units for 9 hours/day for a duration of 55 days. The evaluation factors included seed germination rate (%), crop survival rate (%), plant height, number of leaves and dimension of leaves. In conclusion, this study concluded that the air produced by Evoair's outdoor condensing unit, which is lower in temperature is more environmentally friendly and favourable for the growth of green plants compared to the hot air produced by Control's outdoor condensing unit.

Keywords: *Outdoor condensing units of Air-conditioning system, Carbon footprint, Heat stress, global warming effect, Environmental, Social, and Governance (ESG).*

INTRODUCTION

An air conditioning (AC) system is necessary to maintain room temperature and humidity for residents' thermal comfort. The residents' thermal comfort can improve their wellness and working performance [Lan et al., 2011 Fan et al., 2019]. Outdoor air temperature especially in urban areas is affected by building materials and the anthropogenic heat emitted from buildings and automobiles. As the surrounding environment gets hotter, the use of air-conditioners is bound to increase. But powering AC units requires energy, and the cooling process ejects heat into the surroundings, which has an adverse impact on the environment. The substantial amount of heat released from air-conditioning systems, especially in densely populated urban areas with a high concentration of these units, can contribute to the heat island effect. The heat island effect can lead to increased energy demand for cooling, elevated health risks for residents, and a higher overall carbon footprint (You et al., 2023). By 2050, researchers expect the number of air conditioners on Earth to multiply to 4.5 billion (IPCC, 2022).

In general, AC absorbs heat to cool the indoor air temperature of buildings and at the same time releases heat into the surrounding outdoor space, which is considered “waste heat”. The waste heat released from air conditioners into the urban area is significant, accounting for more than one half of the sensible heat from the surface during the summer (Ohashi et al., 2007). Research by Salamanca et al, (2014) reported that AC systems increased the mean air temperature over 1^0C (or equivalent to 274.15 K) in some urban locations. Releasing waste heat into the ambient environment increases cooling demands. In 2007, Ohashi and research group from the Okayama University of Science in Japan found that ACs can raise temperatures in downtown Tokyo by as much as 0.94^0C (or equivalent to 256.48 K). Singh et al. (2022) concluded that AC systems contribute up to 1.4 °C to urban heat in Singapore. In short, air conditioning urgently needs an upgrade to reduce the waste heat in the atmosphere. Many investigations have been conducted based on climate models, meteorological models, canopy models etc. to investigate the heat stress patterns and the waste heat from air conditioning to the environment (Ohashi et al., 2007; Fischer et al., 2010; Jay et al., 2019). These models are comprehensive but time consuming and expensive.

From the problems stated above, there’s a need to investigate the effect of heat generated by outdoor condensing units of air-conditioning systems on the surrounding environment and propose a better environmentally friendly air-conditioning system for a more comfortable and safe living environment. In this study, we focus on the direct effect of the air released from the AC outdoor condensing units on the growth of green leaf plants. The only manipulated variable in this study was the brand of outdoor condensing units installed in the greenhouse. This work aims to provide insights to the public about the effect of heat generated from AC outdoor condensing units on the environment.

MATERIALS AND METHODS

Greenhouse and ACs setup

Two small-scale greenhouses with dimensions of length x width x height: 1.25m x 2.5m x 2.0 m were constructed as shown in Figure 1 and located in an open area beside the Faculty of Engineering and Green Technology, Kampar, Perak, Malaysia, with the coordinates of 4.338830 101.143051. Two different brand outdoor condensing units (i: Evoair and ii: Control) were connected through pipes to the nearest room where these two different brand air conditionings were located. During this period, the average duration of daily sunshine was approximately 6-7 hours (METMalaysia - Malaysia's Climate).

Figure 1: Two green houses were constructed to receive hot air/heat generated from the two different brand’s condensing unit (i) Evoair, (ii) Control

Preparation of green leaves plants

Thai Basil (*Ocimum basilicum*), Hong Kong Kai Lan (*Brassica oleracea var. alboglabra*) and Pak Choy (*Brassica rapa subsp. chinensis*) were selected as the green leaf plants in this study. These plants are the most popular leafy vegetables in Asia (Cartea et al., 2010). Apart from its economic importance, it is also known for its health benefits. Pak Choy contains beneficial phytochemicals, provitamin A, vitamin C, minerals, and fibre (Acikgoz, 2016). The demand for and awareness about the importance of vegetables for a healthy diet are increasing. For each crop, six pots of soil are prepared: three pots to be put in the greenhouse that houses the Evoair outdoor condensing unit, and another three pots to be put in the greenhouse that houses the control of the outdoor condensing unit. 1.500 kg of soil was weighted using a 3-decimal point balance. Seeds were then being planted into the soil at a height of around 2 cm down the soil. Three seeds were distributed evenly in the pots in the shape of a triangle. Lastly, the seeds were being watered and left to germinate. Obvious impurities, such as dried branches and dried leaves, were being picked out during the process. The pots were being placed in positions as shown in Figure 2 in both greenhouses.

Figure 2: Plants pots arrangement in greenhouse
(Upper deck: Hong Kong Kai Lan; Lower deck left: Pak Choy; Lower deck right: Thai Basil)

Fertilization
During this study, commercial fertilizers were applied twice to each pot. In each application, 20 granules of fertilizers were added to each pot. These fertilizers were placed at the edges of the pots so that the nutrients could gradually reach the crops. This is to avoid fertilizers contact with the crops directly, which causes the desiccation of roots.

Irrigation process
Crops were watered according to the soil moisture level of the respective pot. Soil moisture level was kept at 20.0%. A soil moisture meter (Extech Instruments: M0750) with a precision of 1 decimal place was used for soil moisture measurement.

Monitoring and data recording
Relative humidity (Rh, %) and temperature (ºC) were monitored. Two temperature and sensor sensors (Traceable: 6525/6) were placed in the greenhouses, respectively to monitor these parameters.

The growth of the crops in each pot was observed daily and the photos of the crops were captured at 1700 daily.

During the sprouting stage, the seed survival rate was being observed and recorded. At the end of the project, data such as plant height, number of leaves, fruit bore, sizes of fruits, and dimensions of leaves were recorded and compared.

Equations

Equation 1 (Stephen, n.d), equation 2 (Ababa, 2020), equation 3 and 4 (Byju's, 2022) were used for data analysis.

$$Seeds\ germination\ rate\ (\%) = \frac{Number\ of\ seeds\ germinated}{Total\ number\ of\ seeds\ in\ each\ pot}\ x\ 100\% \quad \text{Eq.1}$$

$$Crops\ survival\ rate\ (\%) = \frac{Crops\ surviving}{Total\ number\ of\ crops\ in\ each\ pot}\ x\ 100\% \quad \text{Eq. 2}$$

$$Average\ relative\ humidity\ (\%) = \frac{\Sigma\ Relative\ Humidity}{Number\ of\ relative\ humidity}\ x\ 100\% \quad \text{Eq. 3}$$

$$Average\ temperature\ (^{\circ}C) = \frac{\Sigma\ Temperature}{Number\ of\ temperature} \quad \text{Eq. 4}$$

RESULTS AND DISCUSSION

Vegetation growth

Plant height was selected as one of the evaluation factors in this study. Plant height is a major determinant used in agriculture for the vertical growth and developmental abilities of plants. Besides that, plant height also reflects the capability of the plant for light competition.

The second and third evaluation factors are the dimensions of the leaves and the number of leaves. The dimensions of the leaves represent the area of the leaves. As the formula for area is length multiplied by width, the length and width of the largest leaves on the plant were measured and recorded. The area of leaves is very significant as leaves are one of the most important organs in plants. The functions of leaves are to carry out photosynthesis by intercepting light, absorbing the raw material of photosynthesis, which is carbon dioxide, and releasing oxygen as a product of photosynthesis. Furthermore, leaves are the site where evapotranspiration happens. When evapotranspiration occurs, water vapor lost will build up pressure that will aid the plant in absorbing water from the ground (Jia el at., 2018). More leaves will increase the total leaf area, which will increase the area of evapotranspiration and photosynthesis sites.

Vegetation growth of Thai Basil (*Ocimum basilicum)*

As shown in Figure 3, the first basil seed germinated on observation Day #3 and the others germinated one after another. The highest seed germination rate and crops survival rate were observed in Pot #1 with 66.7% as shown in Table 1. The seed germination rate and crop survival rate from all 3 pots (Control) were 33.33%. Basil leaves from Pot 2 measured the highest plant height (76 cm) and had the highest number of leaves (131). Overall, the growth of basil seeds was fast and was very healthy throughout the whole observation period.

Figure 3: Growth stages of Thai Basil (*Ocimum basilicum)* in Evoair's greenhouse and Control's greenhouse.

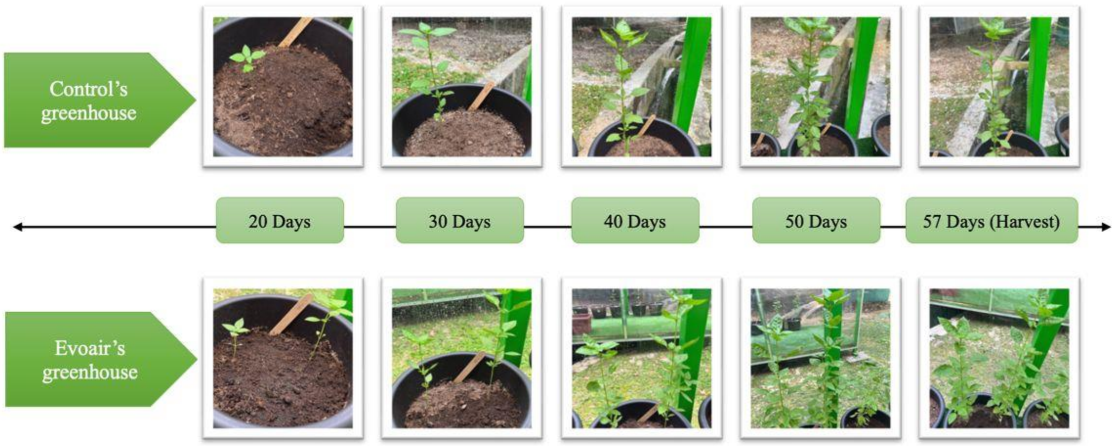

Table 1: The growth of Thai Basil (*Ocimum basilicum)* measured using different parameters.

Parameters		**Evoair**			**Control**	
Pot number	1	2	3	4	5	6
Seeds germination rate (%)	66.67	33.33	33.33	33.33	33.33	33.33
Crops survival rate	66.67	33.33	33.33	33.33	33.33	33.33
Height of plants (cm)	54	76	73	54	57	57
	61					
Number of leaves	90	131	93	80	88	109
	93					
Dimensions of largest leaf of each	7 x 4	7.5 x 4.5	7 x 4.5	5.5 x 3x5	4.5 x 3	4.5 x 3
crop (length, cm, x width, cm)	5.5 x 4					

Vegetation growth of Hong Kong Kai Lan (*Brassica oleracea var. alboglabra*)

One of the Kai Lan seeds germinated on observation Day #3 and the others germinated one after another. The growth of Kai Lan was noticeable initially, however, the growth rate decreased from Day #16.

Compared to the other two types of crops (Thai basil and Pak Choy) planted in this study, the growth of Kai Lan is significant (Figure 4) The seed germination rate and crop survival rate for all the pots placed in the Evoair greenhouse were 100% (Table 2). In addition, the vegetation growth measurement from pots placed in Evoair greenhouse showed a better growing appearance compared to Control. As shown in Figure 2, the pots of Kai Lan were placed closest to the outlet of the outdoor condensing unit of both greenhouses. It is hypothesized that the hot air generated from the control outdoor condensing unit retarded the growth of Kai Lan.

Figure 4: Growth stages of Hong Kong Kai Lan (*Brassica oleracea var. alboglabra)* in Evoair's greenhouse and Control's greenhouse.

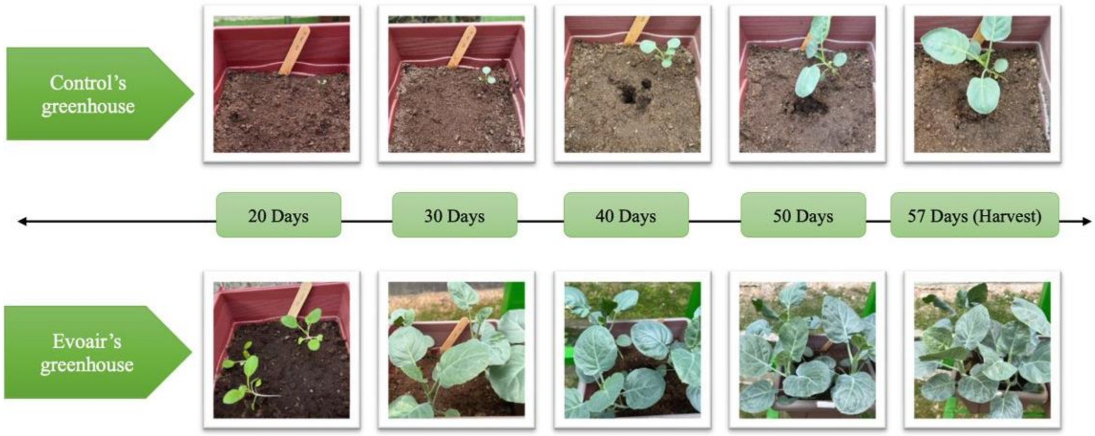

Table 2: The growth of Hong Kong Kai Lan (*Brassica oleracea var. alboglabra*) measured using different parameters.

Parameters		**Evoair**			**Control**	
Pot number	1	2	3	4	5	6
Seeds germination rate (%)	100	100	100	33.33	100	0
Crops survival rate	100	100	100	33.33	100	0
Height of plants (cm)	20	21	26	6	14	-
	17	19	18		14	
	20	7	20		10	
Number of leaves	9	8	8	6	7	-
	8	6	9		8	
	9	9	12		11	
Dimensions of largest leaf (length,	11 x 10	13 x 12	10 x 9.5	5 x 4.5	5 x 4.6	-
cm, x width, cm)	10 x 10	10 x 8.5	8.5 x 8.5		5 x 5	
	10 x9	3.5 x 3	12 x 12.5		5 x 4	

Vegetation growth of Pak Choy (*Brassica rapa subsp. chinensis*)

Among all three crops planted, Pak Choy was observed to be the easiest type of crop to germinate. Seven seeds of Pak Choy germinated on the observation Day #2. Pak Choy was the only crop to achieve a 100% germination rate in all pots (Table 3).

The height of the plants for all pots from Evoair's greenhouse is within the range of 6-10 cm while the range of height is 4-6 cm for all pots from Control's greenhouse. The number of leaves recorded for the pots from Evoair's greenhouse is 11 leaves: the lowest from Pot # 3, and 15 leaves the higher from Pot #1. The highest number of leaves growing in Control's greenhouse was 8. The growth of Pak Choy in the Evoair greenhouse was relatively healthy compared to the one in Control's greenhouse.

Apart from Kai Lan, Pak Choy pots were being placed second closest to the outlet of outdoor condensing units (Figure 2), which were directly under the outdoor condensing units. From the observation of the vegetation growth, Pak Choy crops can provide a relatively persuasive display reflecting the quality of air released by the outdoor condensing units (Figure 5). Evidently, the Pak Choys in Control's greenhouse were not able to survive, even though they achieved a 100% of seeds germination rate. Unlike the ones in greenhouse of Evoair which apparently had firm leaves and a uniform color and could be harvested (Figure 3 and 4).

Figure 5: Growth stages of Pak Choy (*Brassica rapa subsp. chinensis*) in Evoair's greenhouse and Control's greenhouse.

Table 3: The growth of Pak Choy (*Brassica rapa subsp. chinensis*) measured using different parameters.

Parameters	Evoair			Control		
Pot number	1	2	3	4	5	6
Seeds germination rate (%)	100	100	100	100	100	100
Crops survival rate	66.67	66.67	100	33.33	100	0
Height of plants (cm)	10	8	6	4	6	-
	9	11	12		4	
			14		3	
Number of leaves	15	13	11	8	8	-
	15	13	12		7	
			11		7	
Dimensions of largest leaf (length, cm, x width, cm)	11.5 x 9	10 x 7	9.5 x 8	3.5 x 2.5	2.5 x 3	-
	9.5 x 9	7 x 6	7 x 5		2 x 2	
			9 x 7.5		2.5 x 2.5	

In general, the results from this experiment showed that the plant heights of all the green leaf plants that grew in Evoair's greenhouse were taller than the plants that grew in Control's greenhouse. In addition, it can be observed that the number of leaves on most of the plants that grew in Evoair's greenhouse outnumbered the plants that grew in the Control's greenhouse. Aside from that, the area of leaves of the plants in the greenhouse of Evoair was bigger than the plants that grew in the greenhouse of Control. This observation was significant for the plants (Kai Lan) which were located closest to the outlet of the condensing unit. This indicates that Evoair's greenhouse is more favorable for plant growth.

Microclimate changes in the greenhouses

In this study, the soil moisture was maintained at 20%, so no water stress was observed from the plants [Zheng et al., 2013]. The outdoor condensing units channelling to the greenhouses were in operation from 0830 to 1730 daily during the weekdays. To successfully grow crops in a greenhouse, temperature, and humidity must be controlled. The readings of relative humidity and temperature were recorded daily before the air-conditioning was turned on and switched off as shown in Table 4.

The relative humidity recorded from the Evoair's greenhouse was in the range of 77 to 93%, while the relative humidity recorded from the Control's greenhouse was in the range of 63 to 76%. Relative humidity is defined as the ratio of the actual water vapor content to the saturated water vapor content at a certain temperature and pressure. Relative humidity is an important factor in agriculture as it directly affects the water relation to plants [Lysenko et al., 2023]. The plant growth rate significantly increased with the increased relative humidity, as this condition can maintain the photosynthesis process and lower the evapotranspiration process by keeping the stomata open [Chia & Lim, 2022]. Furthermore, relative humidity causes indirect effects to plants such as leaf growth, carbon dioxide uptake and, pollination rate etc.

As humidity is directly related to temperature, maintaining an optimal relative humidity level is essential. The optimal relative humidity level for many plants is around 85±2% in the day [Chia & Lim, 2022]. If the humidity level increases or drops, the plant's physiological processes are likely to slow down, causing slower growth and lower quality yield.

High temperatures have an adverse effect that impacts root growth by decreasing cell division in the root meristem [González-García, 2023]. In general, the optimum range of temperature for maximum plant growth is 18ºC to 25ºC. Any temperature outside the range might cause the crop to be unable to complete its normal biological cycle and unable to reach its maximum yield. Besides, direct influence on temperature includes the opening or closing of the stomata of the plants, which are very essential processes of photosynthesis, transpiration, and respiration of crops (Jiang et al., 2023). The temperature difference between these two greenhouses was insignificant at 10 minutes before the AC was turned on in the morning at 0830. However, based on the temperature recorded 10 minutes before the ACs were turned off, the temperature difference between the greenhouse of Evoair and control was 3.97 ºC. It can hypothesize that the outdoor condensing unit connected to the Evoair's AC not only releases less heat but also lowers the surrounding temperature inside the greenhouse.

The vegetation growth is used to evaluate crops' responses to microclimate change. Green leaf crops are sensitive to water, humidity, temperature, and heat stress [Du, 2017; Alsamir 2021]. It was reported that air temperatures higher than 38–40 °C greatly reduce the photosynthesis rate, stomatal conductance, plant growth, and fruit yield [Shaheen et al, 2016; Liu et al., 2023].

Although overall the recorded temperature from all pots was less than 38 ºC however, the temperature readings recorded from Control's greenhouse were relatively higher with lower humidity which did not favour the growth of green leaf crops [Bhattacharya, 2019].

Table 4: Average relative humidity and temperature readings recorded in greenhouses on weekdays during light period (0830 and 1730).

	Evoair's greenhouse		**Control's greenhouse**	
	Relative Humidity (%)	Temperature (ºC)	Relative Humidity (%)	Temperature (ºC)
10 mins before AC on	85.76	26.58	76.45	27.00
10 mins after AC on	92.72	27.60	63.50	33.10
10 mins before AC off	96.83	28.84	66.47	32.81
10 mins after AC off	77.33	30.51	59.96	32.00

Environmental impact and sustainable direction

In addition, the low heat release capacity of the Evoair's outdoor condensing unit enabled energy savings for the air-conditioning unit which resulted in an estimate of 284 W for a 2.0 horsepower that aligned with the global initiative of lowering the carbon footprint. Based on the GHG protocol for CO_2 equivalent (CDM, 2017), this will indirectly prevent the GHG emissions of 0.17 kg CO_2e (Peninsular Malaysia), 0.15 kg CO_2e (Sabah) and 0.09 kg CO_2e (Sarawak) per unit of Evoair's air conditioning unit as compared to other convention units. Hence, we conclude that the air produced by Evoair's outdoor condensing unit which is lower in temperature is more environmentally friendly and favourable for the growth of green plants compared to the hot air produced by Control's outdoor condensing unit. This positive outcome will surely pave the way for a new and sustainable direction for the air conditioning unit in terms of policy and energy savings. The policy implications of the effect of heat generated by an AC outdoor condensing unit on the surrounding environment could be considered as follows:

1. Use of energy-efficient air-conditioning systems: This study contributes valuable data that could recommend the use of energy-efficient air-conditioning systems that generate less heat and have a minimal impact on the surrounding environment. Policymakers could promote the use of such systems by providing incentives and subsidies to encourage households and businesses to invest in them.

2. Regulation of air-conditioning systems: The data obtained from this study could provide evidence that supports the need for regulation of air-conditioning systems to limit their impact on the environment. Policymakers could use this information to establish guidelines for the installation and operation of air-conditioning systems in different settings to create a natural cooling effect and reduce the heat island effect in urban areas.

3. Promoting urban forestry and reducing carbon in the atmosphere: Trees and plants can grow well with the optimum humidity and temperature, and they serve as a medium to reduce the carbon in the atmosphere during the oxygenic photosynthesis, thus reducing the impact of hot air released from convention AC outdoor condensing units on the environment. Therefore, promoting the use of an environmentally friendly air-conditioning system is an helpful way to mitigate the global warming effect.

4. Educating the public: The data obtained from this study could recommend public education on the impact of conventional air-conditioning systems on the environment. Policymakers could use this information to create public awareness campaigns that encourage individuals and businesses to use air-conditioning systems responsibly and consider the environmental impact of their choices.

CONCLUSION

In this study, the crops were cultivated in greenhouses, absorbing the exhaust heat from the outdoor condensing units for 9 hours/day. Therefore, the conditions of the crops directly reflect the condition of the greenhouses installed with the outdoor condensing unit respectively. Furthermore, the crops in Evoair's greenhouse were thriving compared to those in Control's greenhouse which were barely surviving. Hong Kong Kai Lan (*Brassica oleracea var. alboglabra*) was the most representative crop as it was placed closest to the outlet of the outdoor condensing units. Overall, the policy implications of the effect of heat generated by an AC outdoor condensing unit towards the surrounding environment using green leaf plants highlight the need for sustainable and responsible use of air-conditioning systems to limit their impact on the environment in order to mitigate the global warming effect.

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