Research Article

Monitoring Experimental Conditions in a Melon Greenhouse: Impacts on Human Comfort and Plant Growth in Tropical Climate

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Abstract

Greenhouses in tropical climates are designed to passively control the environment, protecting plants from pest and extreme climate condition, which has become increasingly important due to climate change. This research aims to monitor a melon greenhouse's environment in a tropical climate to understand light intensity, pollutants and climate conditions. Indoor and outdoor conditions of melon greenhouse were real-time monitored by Vantage VUE model, DAVIS weather station, PM2.5 meter and noise meter. The findings showed that peak light intensities reached at 135,600 lux outdoors and 32,050 lux indoors at noon, with an average light transmittance of 38%. Additionally, PM2.5 levels remained stable around 26-30 μg/m³, and sound levels decreased from 60 dB in the morning to 45 dB at noon. These pollution levels did not impact the farmer and the indoor melon in winter season. However, other seasonal periods need to be monitored for long term adaptation and climate change mitigation. These research findings will support greenhouse design for human comfort and plant growth, focusing on optimizing temperature and humidity conditions. IoTs mechanisms and devices were proposed as having high cost potential for monitoring sensor, networking process, comparative and reliable data collection for further next step of greenhous greenhouse integration. Lastly, upcycled transparent roof from LDPE were suggested to be continually used with minor development or plug-in devices for increasing light shade during the mid-daytime.

Keywords: Greenhouse; Melon Farm; Tropical Climate Monitoring

1. Introduction

Greenhouse's agriculture has become more popular as climate change and environmental condition control. For international greenhouses, the main purpose has mainly identified environmental control from extreme climate conditions and energy saving. For example, in Beijing, the greenhouse can be used for thermal comfort and energy saving purposes by integrating transparent polycarbonate sheets. This transparent material can balance temperature at night by increasing ambient temperature averagely 3.9 °C in greenhouse (Xu et al., 2020). Also, the results of Computational Fluid Dynamics (CFD) simulation with plant consideration in greenhouse demonstrate 2-3 °C (31.68%) higher air temperature compared to unmerged plant case (Xu, et al., 2022).

In terms of economic concern of greenhouse farming, productivities are based on local climate conditions, construction design and controlled systems. Not only to guarantee the profit from greenhouse productivities, it is possible to save cost for watering and in-used energy. For commercial tomato farms in Norway, a greenhouse with day and night energy-controlled systems provided doubled net financial return (NFR) higher than only night energy-controlled system greenhouse (Naseer, et al., 2021). In addition, there were some research proofs for positive attitude of vertical farming (VF) (Ares et al., 2021) and high potential of indoor vertical farms (IVFs) to minimize carbon emission within 2-year return rate business plan (Avgoustaki & Xydis, 2021).

In case of winter climate, greenhouses normally resist outdoor cold condition by IoTs system and insulated materials which can save more in-used energy for controlling climate. Whereas, in Thailand's tropical climate, greenhouse structure and materials are designed for pesticide control. Illuminance and light transmittance of material are considered in terms of suitable intensity for plant growth and increase in indoor ambient temperature. Also, some automated watering systems can be applied in case of large farming area.

Based on Thailand gross domestic products (Office of Agricultural Economics. Agricultural Economic Report, 2019), the boundary of this research points to feasible plants especially salad vegetables, tomatoes and melons. To scope central location of Thailand, the main greenhouse productivity for melon farm is more popular and has higher networking potential. Consequently, this research aims to monitor ambient environment in melon greenhouse case compared to outdoor climate conditions. Those dynamic changes of climate possibly affect the growth rate of the plant and human comfort condition. Also, based on in-used recycled Low-Density Polyethylene (LDPE) plastic materials, the opportunities are probably investigated for promoting future innovation for greenhouse's climate adaptation and sustainability.

2. Literature Reviews

Before explaining all literature contents, it is necessary to clarify research framework of reviews as shown in Figure 1. The framework also illustrates how different factors and studies are connected.

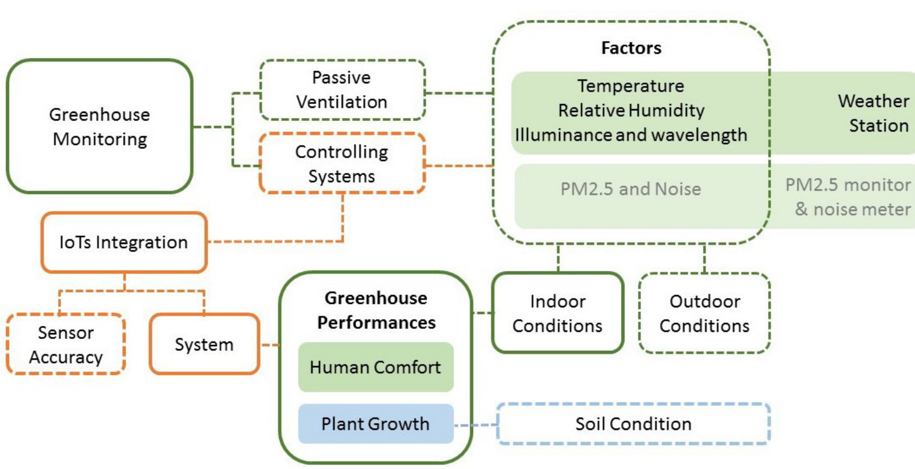

Figure 1. The framework of literature for greenhouse studies.

The key aspects of contents can be listed as follows: Greenhouse Monitoring, Weather Station, Human Comfort, Plant Growth Condition and Soil Condition. To understand better greenhouse performance, overall key climate factors need to be clarified how those factors affect human comfort and plant growth.

2.1. Greenhouse Monitoring

Greenhouse weather variable monitoring involves the continuous monitoring of temperature, humidity, light intensity, and other environmental variables inside a greenhouse. This monitoring is essential for optimizing plant cultivation and increasing production efficiency. Several articles discuss the use of wireless sensor networks (WSNs) for greenhouse monitoring. Suman et al. (2020) report the use of WSNs with wireless sensor nodes to monitor temperature and humidity in a greenhouse. Asha Bharathi et al. (2024), presents a greenhouse monitoring system based on a wireless sensor network that collects data on temperature, humidity, light intensity, and other variables. Elio et al. (2019) propose the use of low-cost sensors and data storage and processing cards to monitor the microclimate of a greenhouse. Anagu et al. (2023) describes a vegetable greenhouse monitoring system that includes sensors for temperature, humidity, light, soil humidity, and soil temperature. These papers provide insights into different approaches and technologies for greenhouse weather variable monitoring.

To focus on optional Internet of Things (IoT) mechanism preparations and communications for greenhouse, the acceptable data loss rate between sensor and gateway is approximately 1.5% and those between gateway and server is around 0.4% (Wang et al., 2020). To improve the reliability of temperature data in smart greenhouses, three key steps in wireless sensor network (WSN) process were considered in different keys. The first step of data collection should rely on sensors and filters. After collecting data, the second step of the fusing process depends on the intersection algorithm when the last step of the synthesis stage should reflect the learning machine algorithm (Xia et al., 2022). Monitored cameras can be additionally integrated to system algorithms to automatically count insect pests with 93% accuracy compared to manual counting approach (Rustia et al., 2020). If applying technological items in monitoring system, perhaps, different approaches can increase accuracy of data.

For an Automated Climate Monitoring System (ACMS) in greenhouse, climate condition can be based on temperature, humidity and light intensity (Weldeslasie et al., 2021) which should be adequate information for multi-purposes of comparing, analysis and optimizing between in-used energy and emission (Li, et al., 2021). Based on farming activities, remote Internet of Things (IoTs) from mobile phones was proved to be an assistive feature (or mature feature) for inclusive groups of elderly and disable by addressing activities and making decisions easier (Loukatos et al., 2021). The remote controlling approach can respond inclusive society and increase higher value to greenhouse. However, in small to medium farming greenhouses, feasible cost of system should be concerned before actual investment.

Overall greenhouse monitoring reviews describe environmental factors, tools and data collection processes which can be adapted into this research experiment. With a clear understanding of the methods, the next session can explore the results and their implications of weather station for greenhouse agriculture.

2.2. Weather Station

The support of climatic service is necessarily organized by government and implied to urban scale research (Dumas, et al., 2021) especially public structure of system, agricultural process, urban greenhouses and resilience research in Philippines and Thailand (Delina et al., 2020). All system availability of environment analysis was proved to affect failure at the root of the Photo Voltaic (PV) power plant and financial investment in Thailand (Ketjoy et al., 2022). Also, sharing sources of weather station data are actively collected and Doppler measurement adequately accurate for grape farms in the USA (Gibbons et al., 2022). Real time monitoring data from weather station is basically used as a based accurate result to compare with simulation results for examples EnergyPlus weather (Wang W. et al.., 2021), Global Energy Forecasting Competition (GEFCom) (Moreno-Carbonell et al.., 2020) and other sharing sources (Gibbons et al., 2022). To validate data collections, central data pools are important for city research, farming, and energy project in places especially in the Philippines, Thailand, and the USA.

For tropical climate greenhouse, it is possible to install weather station with other manual meters to combine all environment data of indoor and outdoor ambient monitoring and validate data with central weather data. Having examined the weather data collection, the next session will discuss human comfort factors and plant condition in tropical climate.

2.3. Human Comfort and Plant Growth Conditions

Human comfort is a multifaceted concept influenced by several factors, including temperature, humidity, wind flow, clothing, noise levels, and acoustic preferences. Numerous studies have developed models and methodologies to analyze and optimize human comfort.

For instance, Enfan et al. (2021) proposed a model utilizing variable precision fuzzy rough sets to examine the relationship between meteorological elements and human comfort. Prageeth et al. (2020) introduced a methodology to collect subjective feedback on comfort preferences using micro ecological momentary assessments. This data was then used to create classification models for preferences related to thermal, light, and noise conditions.

Plants have been shown to positively impact indoor thermal comfort. This is achieved through reductions in relative humidity and CO2 concentrations, as well as the stabilization of surface temperatures (Meng et al., 2022). Additionally, blue light has been found to influence plant morphology and yield in vertical farming systems, particularly for crops like watercress (Qian et al., 2022). Light intensity and wavelength also play a crucial role in different stages of plant growth. For example, in a naturally ventilated greenhouse, radiation transmittance significantly increased during cloudy conditions (Saadon et al., 2021). Moreover, improvements in daylight glare probability (DGP) by 94.5% have been shown to enhance human visual comfort in such environments (Yang et al., 2021).

Regarding chemical factors, seasonal variations can affect the quality of crops, such as melons, particularly in terms of volatile organic compounds (VOCs) or aroma emissions (Zarid et al., 2020). The production of these compounds can be stimulated by metabolites, but certain chemicals like forchlorfenuron, a type of VOC, have been linked to increased health risks for consumers (Wang et al., 2021).

In this research on greenhouse conditions, key factors affecting both human comfort and plant growth will be monitored, including temperature, relative humidity, and illuminance. However, the measurement of specific light wavelengths and VOCs falls outside the scope of this study. Future research on greenhouse environments is encouraged to incorporate these factors, as they are critical for optimizing both human comfort and plant growth outcomes.

2.4 Soil Condition

Thermal comfort and plant growth factors can directly affect soil's nutrition and health, for example, the effect of high temperature and low relative humidity can increase evaporative rate of the soil water. Then some supportive reviews are listed in this session.

Soil's nutrition is another factor to be controlled in agricultural studies in which weather and indoor air condition always affects indoor air humidity, temperature, soil's pH content, micronutrient (Dash et al., 2021). For modelling and simulation processes, soil temperature and climatic environment are correlated together (Goldoni et al., 2022), especially temperature and humidity (Romanis et al., 2022) as defined by Penman-Monteith equation (Baldocchi et al., 2022). By experimental and calculating comparisons, humidity level directly affects radon (Abd Ali et al., 2019) and organic carbon, but there is no effect on nitrogen level (Oliveira Filho et al., 2022). In simple terms, the health of soil in farming studies is influenced by things like weather, indoor conditions, and soil properties, which are all connected and can affect things like air moisture and soil warmth.

Another point of soil condition is the pupal stage of melon growth, which is sensitively infected from fungicide and can be effectively controlled by B. bassiana JEF-350 (Li et al., 2021). Higher acidic conditions can also block bacterial disease and slag fertilisation can improve soil quality and reduce risky severity of melon field (Ferreira Preston et al., 2021). Spanish melons were proved to have an increased fruit maturity affecting positively the level of fatty acids in particular glucose, fructose, citrate, amino acids and polyphenols (Tristán et al., 2022). While Fe and Mg level can reduce K nutrition and other metal oxidations negatively impact colour and lower level of soil nutrients (Makiel et al., 2022). One of the more significant findings to emerge from this review is that Melon plants grow better when a special fungus is used to protect them from disease, and certain soil treatments can make them healthier and taste better. Farmers can preserve the level of soil moisture to keep fungus alive by using recycled plastic covers or rice straw from agricultural waste.

There were some water-used effects of soil salinity to melon growth during 15-30 days period, but melon genotype Galia F1 was high salt tolerance (Sarabi & Ghashghaie, 2022). Also, Nitrate (NO3-) and mineral N in soil were proved to affect soil's salinity and water in European countries which did consequently link to melon and pepper crop yields in 2005-2006 (Soto et al., 2018). What emerges from the results reported here is that all environmental factors directly affect human comfort and each growing state of plants. In this research, monitoring the air's ambient condition is the top priority for greenhouses with passive ventilation. Additionally, monitoring other dynamic pollution changes can help us prepare for the future and offer further recommendations. Having explored the key aspects of greenhouse monitoring, we now turn to the methods used to collect and analyze environmental data in greenhouses.

3. Methodology

To accomplish the research objectives, a representative of small melon greenhouse, ranging from 700 to 1,600 sq.m., in central Thailand was selected from 57 cases (Likitswat, 2021; Wongwatcharapaiboon, 2022) before investigating indoor and outdoor environments. The structure of the greenhouse is depicted in Figure 2 with dimensions of 6 m in width, 20 m in length and 5 m in height. A weather station was set a height of 1.5 m for monitoring outdoor condition, while indoor meters were placed at the same height (Wongwatcharapaiboon, 2022).

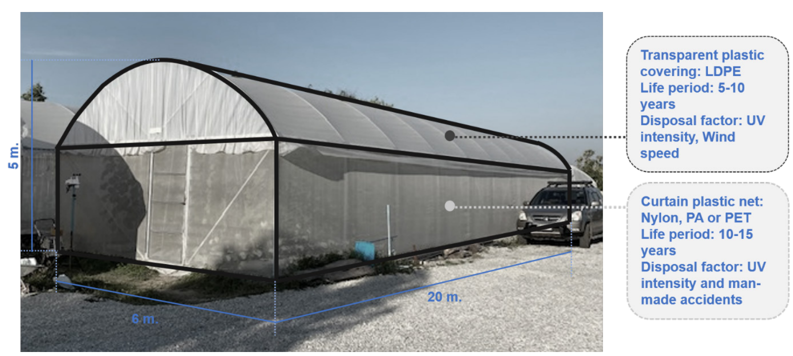

Figure 2. Sampling melon greenhouse, Supatra Melon Farm, Saraburi (Wongwatcharapaiboon, 2022).

Figure 3. Weather station set for outdoor monitoring, Supatra Melon Farm, Saraburi.

The greenhouse construction utilized selective materials such as transparent LDPE plastic for roof covering and nylon plastic netting for ventilated curtain walls. Although LDPE has been found to provide lower light transmittance compared to recycled Polyethylene Terephthalate (PET), LDPE was considered preferable due to its positive effects on indoor light intensity and wavelengths conducive to plant growth (Wongwatcharapaiboon, 2022). However, it is important to note that the light transmission ratio of the transparent recycled LDPE plastic should be taken into account, as the calculated light transmission, influenced by outdoor and indoor weather stations, may be affected by the plant canopy. This canopy effect could potentially lead to fluctuating light transmission results.

This greenhouse structure supports the production of approximately 300-340 Japanese melons within a 70-75 day growth period. Previous studies on weather stations, with data collections similar to those conducted at climate stations (Weldeslasie et al., 2021), gathered data on key environmental factors such as temperature (Song & Park, 2021), light intensity (Yang et al., 2021), relative humidity (Sudprasert & Jaroensen, 2021), and CO2 concentration (Meng et al., 2022). To validate previous findings, the greenhouse's temperature (measured with an accuracy of ±0.5°C and a range of -40°C to 70°C), relative humidity (±2% RH with a range of 0% to 100% RH), wind speed (±0.5 m/s across a range of 0 to 50 m/s), and light intensity (±10 lux, with a range from 0 to 200,000 lux) were measured using the 'Vantage VUE model, DAVIS weather station' as shown in Figure 3.

Furthermore, an indoor monitoring station was established at a height of 1.5 m above the ground and positioned centrally between two plant beds, as shown in Figure 4. During the monitoring process, only one researcher was present to minimize the effect of human body heat on the readings (Zhu & Feng, 2021). Quantitative data were collected over three days, but the report will focus on the data from one mid-day period. All instruments recorded data every 30 minutes during daylight hours only.

Throughout the monitoring period, planting soil nutrition, humidity, and watering schedules were consistently managed using agricultural nylon bags for the melon plants. The next section will present and discuss the results from the collected quantitative data.

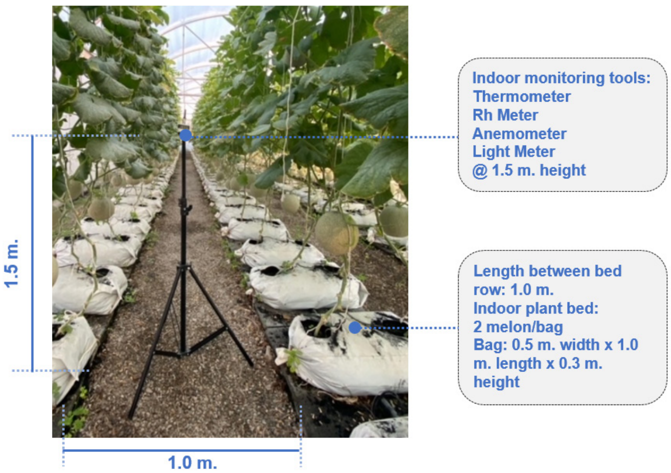

Figure 4. Indoor monitoring set in melon greenhouse, Supatra Melon Farm, Saraburi .

4. Results and Discussions

With regard to the monitoring process, the set of data collections shall demonstrate temperature, relative humidity, light intensity, light transmittance, PM2.5 concentration and sound, respectively. To compare indoor and outdoor conditions of a greenhouse environment, simple linear graphs present daytime monitoring results from the weather station as shown in Figures 5-7. The monitoring was conducted over a 3-day period, with data from the 8th of December 2021, being presented in the report as it represents the most stable conditions during the monitoring period. From Figure 5, temperature and relative humidity were monitored in real-time during the daytime in December 2021. There were insignificant differences between indoor and outdoor conditions of temperature and relative humidity when using a ventilated net for light wall material. Both indoor and outdoor temperatures slightly increased from 20 oC to reach the peak at approximately 40 oC at 12:00 o'clock. Also, the trends of temperature and relative humidity were opposite during

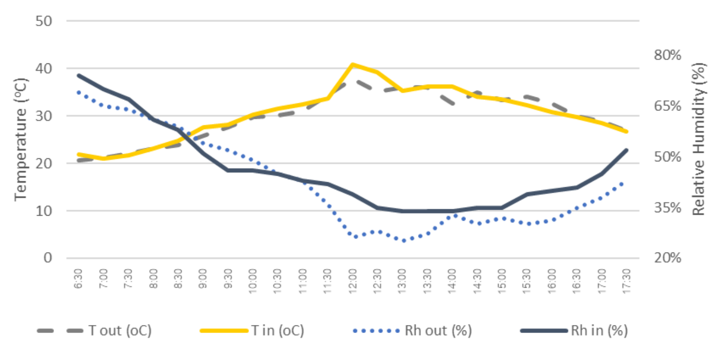

Figure 5. Temperature and Relative Humidity Monitoring Results.

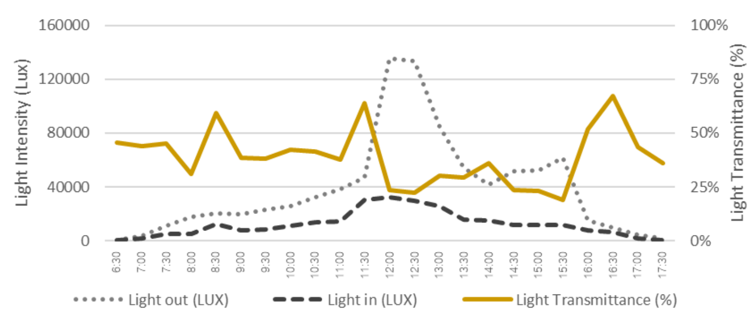

Figure 6. Light Monitoring Results.

the daytime monitoring. Indoor and outdoor relative humidity levels decreased slightly from 35% in the morning time to hit the trough at lower 10% at noon before increasing to 45% in the evening time.

It should be noted that indoor and outdoor temperatures and relative humidity are not significantly different because the ventilated nylon wall allows free heat transfer into the greenhouse. Also, high temperatures directly affect air relative humidity, soil moisture, watering frequency, and quantity for gardening activities. To control soil moisture, covering the surface with a plastic bag is necessary in dry and winter climates.

The chart in Figure 6 reports indoor and outdoor light intensities and light transmittance of the greenhouse during the daytime. It was found that outdoor and indoor light intensities reached their peak at 135,600 and 32,050 lux, respectively, at noon. Light transmittance ranged between 19%-67% and average light transmittance was 38%. Although light intensity for plants is typically indicated in Photosynthetically Photon Flux Density (PPFD, μmol/m²/s), the data in this experiment was recorded in lux and has not been converted to PPFD. Turning to another chart, Figure 7 reports pollutant levels in the greenhouse during the daytime. PM2.5 concentration was stable at around 26-30 μg/m^3, while indoor and outdoor sound levels dropped slightly from 60 decibels at morning monitoring to 45 dB at 10 o'clock.

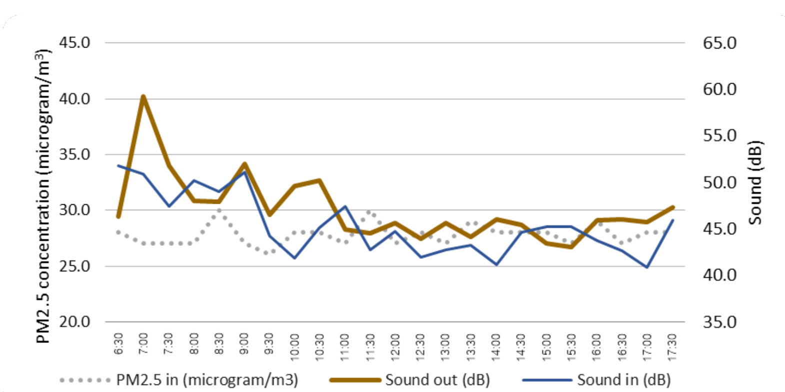

Figure 7. PM2.5 and Sound Monitoring Results.

The factors that correlate with personal comfort lighting include illuminance, temperature, humidity, indoor air speed, and environmental control factors (Weiyu et al.,2020). Additionally, the personal visual comfort model takes into account individual eye pupil sizes, visual sensations, and visual satisfaction in response to various illuminance levels (Lingkai et al., 2019). A study on visual adaptation and comfort found a significant correlation between reaction time and visual comfort, without a significant effect from gender (Jiuhong et al., 2022). Factors that affect visual comfort include illuminance level, brightness ratio, veiling reflections, color, flicker effect, and overall satisfaction.

The aim is to optimize lighting conditions to provide a high level of visual comfort while minimizing energy consumption. By understanding the impact of various parameters on visual comfort, researchers can develop strategies to enhance the quality of lighting and create more comfortable environments for individuals. Suitable visual comfort ranges between 601-850 lux as shown in Table 1, while dissatisfaction was noted in cases of illuminance below 600 lux or above 800 lux (Wijewardane et al., 2018). As a result, both monitored results of indoor and outdoor illuminance strongly exceed 850 lux and do not satisfy users.

The different wavelengths of light are key to the capability of greenhouse space planning and material selection. The ratio of 1 blue to 3 red light transmittances from LDPE material can optimize plant growth benefits, while its visible wavelength transmittance is suited for farmer's vision andthermalcomfort(Wongwatcharapaiboon et al., 2023). However, indoor illuminance is still too intense for long-term planting. This daylighting may cause leaf burning in the early stages of planting. A shading approach is suggested to be applied during the mid-daytime of the winter season. Research on illuminance is also needed during the summer or other seasonal periods for annual planning.

Table 1. Environmental criteria and plant growth condition.

Environment Climate		Human Comfort Zone		Plant Growth Requirements	Other Recommendations
Criteria	Monitoring	Outdoor	Indoor	Indoor	
Temperature	20-40°C	20-29 °C (a)		25-35 °C	
Relative Humidity	10-45%	30-70% (a)		varied	The varied air humidity affects to soil moisture and salinity.
Illuminance	135600-32050 lux	601-850 lux (b)	- Low intensity of light is suitable for all growth process and photosynthesis - 1 blue : 3 red proportion is suitable light for germination, seedling and chlorophyll a & b boosting up (c)		
PM2.5 and Noise Condition	26-30 35 $\mu g/m^3$ 45-60 dB	NAAQ: $\mu g/m^3$ 65 dB	WHO: 25 $\mu g/m^3$	n/a	Possibly increasing VOCs (d-e) in close environment, Soil pH: 6.5-7

(a) (American Society of Heating Refrigerating and Air-Conditioning Engineers, 2017)
(b) (Weldeslasie et al., 2021)
(c) (Wongwatcharapaiboon et al., 2023)
(d) (Zarid et al., 2020)
(e) (Wang Q. et al., 2021)

To discuss human comfort and plant growth, the environmental climate criteria and human comfort zone shown in Table 1 are used to analyze their relationship to plant growth requirements. It is interesting to note that the plant requirements and human comfort climate conditions are quite similar, with both having the same temperature range of 20-40 °C and a relative humidity level of approximately 10-45%. Based on ASHRAE standard of comfort zone, in tropical climate, temperature ranges between 20-29 °C, and relative humidity can be accepted at 30-70% (American Society of Heating Refrigerating and Air-Conditioning Engineers, 2017). This comparison shows that the monitored temperature exceeds the comfort zone during the daytime, while the monitored relative humidity is below the comfort zone. These results are limited to winter experiments in Thailand, where daytime light normally reaches its highest intensity and the temperature is at its lowest for the season.

Additional notes: PM2.5 and noise conditions directly affect human comfort; NAAQs and WHO standards stipulate that they should not exceed 35 $\mu g/m^3$ and 25 $\mu g/m^3$, respectively. There is no direct relationship between PM2.5 concentration and plant growth; however, cloudy conditions can increase the indoor illuminance of a greenhouse. Turning to another note, research has also focused on VOC emissions, which may affect melons and other plants in the same garden bed. This issue was observed close to the harvesting stage of farming (Zarid et al., 2020) which high temperatures during the season can lead to increased VOC concentrations. However, the lack of a VOC meter is a limitation in this monitoring research.

The research process and results may have been limited in scope to the winter season, with passive ventilation and no IoT applications. Further monitoring should consider the annual dynamics of the seasonal climate and other control systems in use. Also, the transparent material was specified as LDPE only, which is suitable for the recycling process and light transmittance (Wongwatcharapaiboon, 2022). PM2.5 concentration and noise monitoring seemed to be surplus to requirements for conditions in Thailand in December 2021. However, the situation with PM2.5 concentration has become more serious each January-March. The potential impact on human comfort and health conditions related to greenhouse air pollution is valuable to monitor and consider for further greenhouse gas studies beyond climate change. In this research experiment, the weather station was limited to monitoring only the on-ground environment. For further research, soil nutrition and conditions should be considered as core factors in greenhouse environment monitoring.

To highlight more opportunities for future sustainability, recycled materials such as transparent LDPE in use can provide adequate light intensity for daytime functions and plant growth. Greenhouse farmers can also use recyclable Nylon and other plastic waste. Another opportunity is to support the local economy by supplying upcycled materials, which can be a fruitful waste resource for local manufacturing businesses. Finally, the social value of local recycled materials and products may increase people's willingness to pay for nature-based solutions and address waste management concerns.

The study's findings underscore the importance of monitoring greenhouse conditions to enhance melon growth and support sustainable agricultural practices in tropical climates. Our research highlights the need for continued innovation in greenhouse design, including the use of upcycled materials, to adapt to and mitigate the effects of climate change. In light of these insights, we now turn to the concluding remarks, which will encapsulate the implications of our findings for future greenhouse farming in tropical regions.

5. Conclusions

According to the research gap, indoor and outdoor conditions of Thai greenhouses need to be monitored for further planning and sustainable application. Then this research aims to monitor a melon greenhouse's environment in Thailand's tropical climate. It examines how the greenhouse structure and materials help control the indoor climate for the purpose of growing melons. The studies use sensors and 'Vantage VUE model, DAVIS' weather station to track temperature, humidity, light, and pollutants outside and inside the greenhouse at a location in Saraburi.

The findings show that, in December 2021, both inside and outside temperatures went up during the day, peaking at 40°C, while humidity dropped and then rose again. The brightest light inside the greenhouse was 32,050 lux at noon, with an average light transmittance reported at 38% of the outdoor condition. Different light colors aid plant growth in greenhouses; however, excessive light can be harmful, necessitating occasional shading. Mid-day illuminance and temperature are too high for indoor conditions, suggesting that future adaptations may include dimming the light with more shading designs and devices. Most of the day, the existing recycled LDPE roof transfers suitable light and heat for plant growth, although the average relative humidity is quite low during winter season monitoring. Furthermore, PM2.5 and noise reports indicated slight air pollution and reduced indoor noise levels throughout the day.

These monitoring factors can be beneficially applied to greenhouse design, recycled material selection, and different thermal comforts (Huang et al., 2020), humidity, air movement, plant growth and climate adaptation in Thai agricultural productivity. Visual comfort is influenced by light intensity, color, reflections, and flicker, with the aim of making lighting pleasant while saving energy. Comfortable light is usually between 601-850 lux; less than 600 or more than 850 lux can cause dissatisfaction among people.

Focusing on climate change conditions, greenhouses in tropical climates are designed to protect plants from pests and extreme heat and light conditions. To highlight greenhouse material selection, recycled transparent LDPE is suggested as roof material, while curtain walls can be flexible materials with a ventilatable concept. Another concern of greenhouse design, balancing environmental factors needs to be planned, for example, low or high temperatures affect relative humidity, soil moisture, soil salinity, soil pH level and plant productivity. With other plug-in devices for soil surface covering, it is possible to reduce the effects of indoor climate change and construction material effects. Using a nature-based approach, optimizing light transmittance and temperature for plant growth through the selection of materials can effectively adapt agricultural practices to changing climate conditions. Also, it is an initial step in agricultural strategy to mitigate the impacts of climate change.

For additional suggestions, the research focused on the winter season, using passive ventilation and did not include IoT technology. Future studies should research the whole year and other control systems, and consider different materials besides LDPE for transparency and recycling. Even monitoring of fine particles and noise was not necessary for Thailand in December 2021, but these factors are becoming more critical from January to March. Future experiments should also examine soil health as it is important for greenhouse environments.

CRediT Authorship Contribution Statement

Jitiporn Wongwatcharapaiboon: Conceptualization; Methodology; Validation; Formal analysis; Investigation; Resources; Data Curation; Writing - Original Draft; Writing - Review & Editing; Visualization; Project administration; Funding acquisition.
Fa Likitswat: Conceptualization; Methodology; Resources; Data Curation; Funding acquisition.
Sudaporn Sudprasert: Conceptualization; Methodology; Resources; Supervision; Funding acquisition.
Saffa B. Riffat: Conceptualization; Supervision.

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