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Environmental patterns under rain shelter for strategic environmental control in a tropical greenhouse

(Corak persekitaran di bawah struktur pelindung hujan untuk strategi kawalan persekitaran di dalam sesebuah rumah hijau tropika)

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Key words: thermal environmental pattern, rain shelter, heat stress, vegetables, tropics

Abstract

The benefits of using protective structures for intensive vegetable cultivation have encouraged studies to provide a better indoor environment for improving crop production performance. Studies by MARDI indicate that the yield of vegetable per unit area is 2–4 times higher in shelters compared to open field production. However, study for the design of the shelters and the indoor microclimate to optimize crop production has received inadequate attention. The protective structures used for vegetable production are rain shelter (RS) and insect proof netted structure (IPNS). This study at MARDI investigated the indoor environment in a netted rain shelter. The shelter incorporated a polyethylene (PE) film roof to eliminate the rain with jack roof to provide natural ventilation and insect proof netting sides to keep out insects. The year long study on thermal environment, measured the air temperature inside and outside the shelter, soil temperature and solar radiation inside the shelter during vegetable cultivation. Thermal environmental patterns under the shelter were developed to determine the levels of environmental comfort and the design of control system to meet crop requirement. The internal environment of rain shelter depends on radiant heat received by the structure. Excessive radiation will cause heat stress to the plants and depress the physiological functions. This excessive heat is important to be determined and removed to improve the indoor environment. The developed environmental patterns can be used to determine the strategic steps in controlling the effects of heat stress and used as guideline in the design of more effective environmental control system.

Introduction

Vegetable production under protective structure has becoming an important sector of agriculture because of the effectiveness in controlling insects and pests, thus increases the productivity and quality of fresh farm products. Studies by MARDI indicate that the yield of vegetables per unit area is 2–4 times higher as compared to open field production (Illias and Rezuwan 1997). The protective structures used for vegetable cultivation are mainly rain shelter with netted sides and netted structure depending on the types of vegetable grown. These structures are used to protect the crops from damage caused by excessive rainfall, insects and other detrimental environmental factors.

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Under this naturally ventilated protective system of crop production, the internal environment is termed as 'modified' because it changes the surrounding factors and protects, to some extent, from negative effects of the environment, but has no control over the environmental parameters. The in-house air environmental condition is highly influenced by the external environment. In a naturally ventilated greenhouse, the quality of in-house air environment is very much determined by the structural design (Aldrich and Bartok 1994). Good structural design would result in betterment of the effective growth environment for crops, particularly air temperature and relative humidity.

Research and development of tropical greenhouses for crop production in Malaysia has been conducted for the last 20 years. However, studies for the verification of an improved design of the structure have been very limited. The characteristics of air environment under the structure have not been well studied to determine the effects on crop production or even for the purpose of natural ventilation design. Therefore, it is important to study the basic characteristics of the in-house environment of a commonly existing structure to improve the future designs of tropical greenhouse systems.

The importance of natural ventilation in structural design is widely recognized. However, the applications in practice have not always been successful. Influencing factors of environment such as the airflow quality besides its quantity, the positions of air inlets and outlets, orientation of the building and structural materials have been shallowly considered. This could be due to lack of understanding on the principles that relates the environment and requirements appropriate to the application of natural ventilation (Hellickson and Walker 1983).

The greenhouse environment considered primary for plant growth includes temperature, light, humidity, CO_2 levels, water and nutrients. The airflow is important by acting as a medium maintaining these parameters in balance by exchanging and refreshing the air environment through natural convection process. The internal environment of a rain shelter is influenced by radiant heat received by the structure and surrounding objects. The amount of heat induced from radiation can sometimes cause stress to the plants and depress the physiological functions.

Effective greenhouse environment can be achieved through design optimization of structure for a better air movement process. It is important to understand the environmental characteristics and inter-relation between the environmental factors and how best the systems could be provided to modify the environment (Kamp and Timmerman 1996). The effects of these environmental factors on plant physiological tolerance and maintaining the vital processes of plant growth are equally important. Plant growth is in the form of two processes: photosynthesis and transpiration, which can be optimized by effective environmental modification (Heijnen 1996). The objective of this study was to characterize the patterns of the internal environment of existing netted rain shelter used for the production of vegetables in the tropical lowlands.

Materials and methods

Two units of tunnel shaped jack roofed rain shelters at MARDI Research Station, Jalan Kebun were used in the study (*Plates 1–3*). Each unit had a planting area of 6 m x 20 m, with a height of 3.5 m at ridge opening along the structure. The main frame of rain shelters was constructed with galvanized iron (50 mm dia. G.I pipes), covered with polyethylene (PE) plastic sheets roof (3.0 μm) and insect-proof netted sides (mesh 32). A few varieties of high value sub-temperate vegetables were selected and grown under the rain shelter using soil culture. These included chili, cabbage, chinese kale, mustard, cauliflower and long beans. Crop maintenance and other agronomic practices were

Plate 1. The rain shelter used in the study

Plate 2. Inside view during planting bed preparation

Plate 3. Inside view during crop production test

managed accordingly as recommended by horticulturalists.

The thermal environment under the rain shelters were studied for 12 months using a battery powered data logger. The environmental parameters were closely monitored, which include the air temperature (day and night) inside and outside the rain shelter, relative humidity (R.H), day-length, root-zone temperature and CO_2 concentration level. Daily data was collected in 1-hour interval and analysed. The relevant environmental patterns under this specific rain shelter with netted-sides were developed. Three environmental patterns were developed: the external air temperature (at 2.0 m height), the internal air temperature for every 1.0 m airspace strata above ground and solar irradiation patterns.

The air temperatures and relative humidity were determined by standard metrological sensor, soil temperature determined by soil-temperature probe and irradiation by a solarimeter. Three units of air temperature sensor were placed centre to the rain shelter at different heights: 1, 2 and 3 m above ground (A.G) respectively, measuring the internal air temperature of specific air strata. One unit was placed outside the rain shelter at 2.0 m in height measuring the external air temperature. The internal solar irradiance was measured by solarimeter placed at the centre of the rain shelter at 2.0 m in height (A.G).

Results and discussion

Study of thermal environment characteristics under the insect proof rain shelters were carried out for 12-month period with three rotational vegetable cropping. Three environmental patterns were developed to be used to determine the level of environmental comfort and the design of control system to meet the crop requirements. The three environmental patterns were environmental temperature pattern, stratified internal air-temperature pattern, and net solar irradiation pattern inside the rain shelter.

Environmental temperature pattern

Figure 1 shows the mean values of three environmental temperatures: the outside air temperature (T_{ao}), inside air temperature (T_{ai}) and the root bed temperature (T_r). The two parameter inputs, T_{ao} and T_{ai} were very important as they influenced one another and determined the effectiveness of in-house environment. These environmental patterns represent general characteristics of

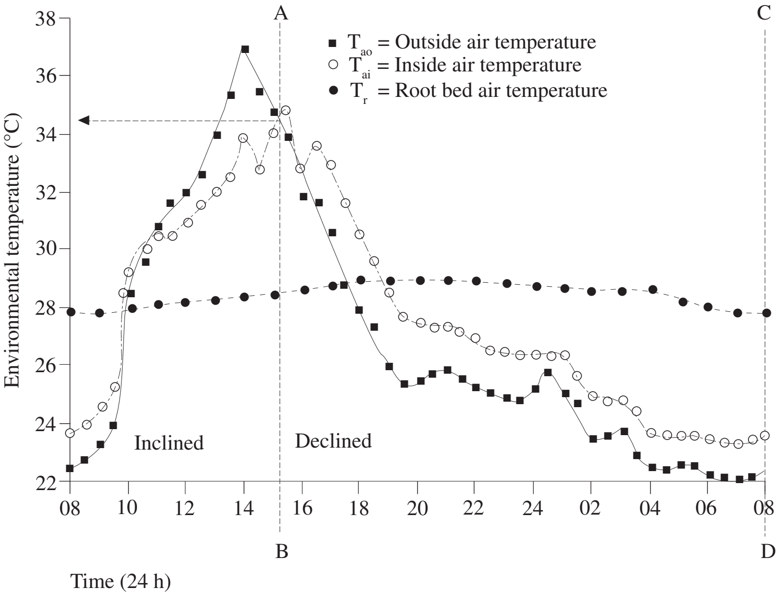

Figure 1. Daily environmental temperature patterns under a naturally ventilated rain shelter in lowland tropic

the selected parameters which can be used as references in systems design and for agronomic management.

Line A–B was drawn to show the changing phases of heat movement between the outside and inside environment, which results in inclined and declined of the environmental temperatures under the shelter. The outside air temperature (T_{ao}) was at its lowest value of 22 °C (0700 h), started to increase from 0800 h and reached the maximum value of 37 °C at 1400 h. The increase rate was calculated to be 2.14, and reached the maximum value earlier than the inside air temperature (T_{ai}). While, the inside air temperature (T_{ai}) increased at the rate of 1.10 and reached the maximum value of 35 °C at 1530 h. From 1400 h to 1930 h, the T_{ao} declined sharply with a rate of 2.20, but after 1930 h it decreased at a slower rate (0.33).

The outside air mass receives direct radiation, which heated the air in multiple magnitude, as compared to the inside air mass which receives a large potion of diffuse radiation. It creates an unbalanced thermo-potential between the outside and inside environment. When T_{ao} increased at a faster rate, it resulted in a temperature difference (ΔT) and caused the heat to flow into the internal environment (inflow). Between 1000 h and 1515 h, the outside environment became a heat source and the inside environment as a heat sink until an isothermal occurred (1515 h) with a value around 34.5 °C. At this point, the process of heat built-up was continuing, and caused the increase in T_{ai} and became critical when there was no proper aeration before the air flow started to reverse (outflow). This environmental pattern showed that the heat flow changed at about 1500 h, where the inside air temperature was higher than outside ($T_{ai} > T_{ao}$) and took ≥ 18 hours from 1600 h to about 1000 h the next morning.

The inside air temperature (T_{ai}) started at its lowest value of 23.5 °C (0700 h), increased and reached the maximum value of 35.0 °C at 1530 h. The rate of increased in T_{ai} was 1.35 and the maximum temperature was achieved by 2 hours, later than the one achieved in T_{ao}. From 1600 h,

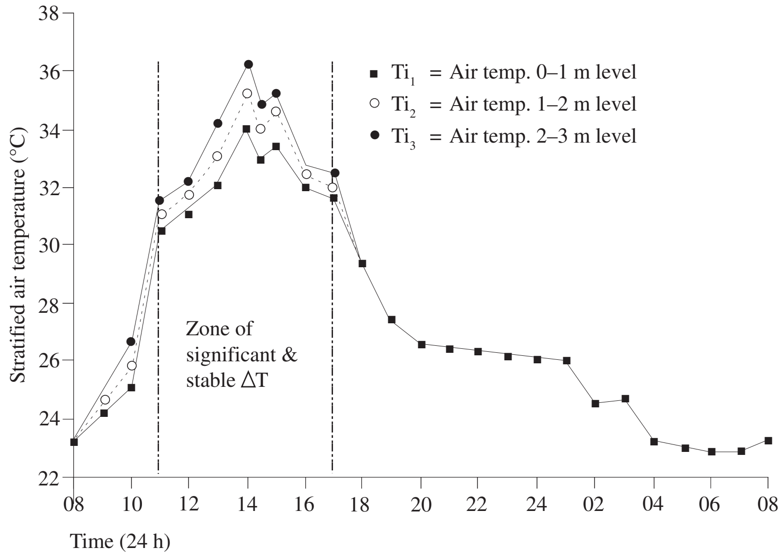

Figure 2. Inside air temperature patterns measured at every 1.0 m space strata from ground under a naturally ventilated rain shelter

the T_{ai} decreased but the values were higher than the T_{ao} for the rest of the time until 1000 h the next day. This phenomenon occurs due to the heat that is retained in the structure and dissipated by the crops during respiration at night. The root bed temperature (T_r) was stable throughout the day, i.e. between 27 °C and 29 °C.

The need to study the thermal environment in a controlled volume such as a greenhouse is to understand the process of heat flow between the outside and inside environment in order to strategize the environmental control mechanism that should be provided. In this case, the external environment became a heat source and the internal environment as a heat sink from morning to 1500 h, thus the heat flowed from outside to inside or warmed the internal environment. Both T_{ao} and T_{ai} became one value (34.5 °C) at about 1515 h, in which no energy flowed between the inside and outside. It is the transition period and becomes the most stressing part of the day if no artificial vent is provided.

After 1530 h, the heat flow started to reverse from inside to outside environment, in which T_{ai} remained higher than T_{ao} between 0.5–2.5 °C for the next 18 hours. At night the breakdown of sugar through respiration is taking place and plants dissipate heat and CO_2 into the internal environment, which contributes to the higher values of T_{ai} compared to T_{ao}.

Stratified internal air temperature pattern

In this study, the inside air temperature (T_i) was divided into three space strata with 1.0 m each and designated as T_{i1}, T_{i2} and T_{i3} (*Figure 2*). This is used to determine the temperature gradient (if it exists and when it occurs) under the rain shelter, which is useful in the design of natural ventilation and other environmental control applications.

A temperature gradient existed within 6–8 hours, from 0900–1700 h. The marginal temperature gradient started from 0900 h, increased at 1100 h and became significant and stable in the afternoon (1400 h) but decreased thereafter until evening (1700 h). The highest temperature gradients were at 1400 h, i.e. during the peak radiation of the day with magnitude about 1.2 °C (each

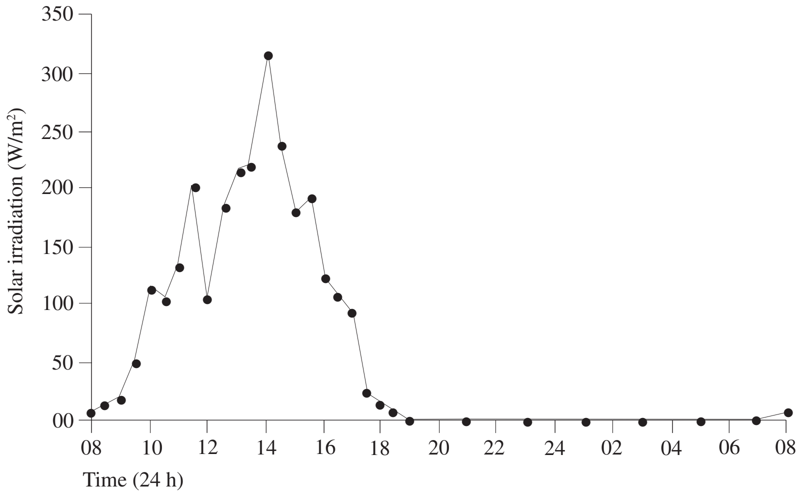

Figure 3. Net solar irradiation pattern under the rain shelter in lowland tropic

level) from the lowest to the highest air space strata.

The total temperature difference (ΔT) between ground and the ridge was 2–3 °C, enough to cause a natural convection to take place that provides a minimum ventilation rate. In late evening and at night, there was no temperature difference in the T_{i1}, T_{i2} and T_{i3}. In this situation the temperature gradient did not exist. As a result, natural convection i.e. the process of airflow caused by temperature difference did not occur and thus, heat could not be dissipated out of the structure and the inside temperature (T_{ai}) remained higher than the outside (T_{ao}).

This internal air temperature characteristic reveals that temperature differences are important to induce minimal ventilation rate during calm conditions or when the wind is very low. Therefore, during the peak radiation period (1200–1500 h) it is important to provide assisted ventilation system. Otherwise if a natural ventilation is used, the design of ventilation rate should be based on wind-induced ventilation rather than the thermal buoyancy effect.

Net solar irradiation pattern

The incident of solar radiation in the lowland area of the Peninsula (Lat. 1° 16' N to 6° 43' N) was recorded about 10 hours per day, from 0800–1800 h *(Figure 3)*. However, the effective period of solar radiation is less than that, i.e. only about 8 hours (0900–1700 h) on a sunny day and as low as 50% on a rainy day. Although, the duration of solar radiation is only about 8 hours, the flux intensity (irradiation) is excessive for the photosynthesis process. Net solar irradiation is the incidence of solar radiation on a unit surface area that passed through the plastic cladding of the rain shelter. It was measured as the total diffused solar irradiation inside the rain shelter at 2.0 m height above ground. The amount ranged between the lowest 5 W/m^2 and 315 W/m^2 with an average of 165 W/m^2 during the daytime. The incident of peak solar irradiation was at 1400 h with a mean value of 315 W/m^2.

Conclusion

It is important to understand thermal characteristics of the environment under a rain shelter because it affects heat stress and crop performance. The art and knowledge of the phenomena could be used in providing effective solutions to improve the internal environmental condition for crop growth. Three environmental patterns namely environmental temperature, stratified internal air temperature and net solar irradiation were developed. The *environmental pattern* is used to determine the phases of heat built-up and the peak heat stress induced by radiation on the in-house environment. The information is used to provide the control strategies and mechanisms to reduce the heat stress that influenced the physiological processes of the crop. The *stratified internal temperature pattern* is used to determine the minimal air flow and when mechanical assisted ventilation is needed. The *net solar irradiation pattern* is to determine the effective photosynthetic light for crop production under shelters. In naturally ventilated structures such as rain shelters, the main consideration for an effective ventilation system is a good structural design for efficient airflow. This will help keep the internal environment fresh through natural air mass balanced between the inside and outside conditions, thus maintain the in-house environment and provides physiological comfort for crop growth.

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Abstrak
Kelebihan menggunakan struktur pelindung untuk penanaman sayur-sayuran secara intensif mendorong banyak kajian dijalankan bagi menyediakan persekitaran yang lebih baik untuk meningkatkan prestasi pengeluaran. Kajian oleh MARDI menunjukkan hasil pengeluaran sayur-sayuran seunit luas di dalam struktur pelindung meningkat 2–4 kali ganda berbanding dengan pengeluaran di ladang terbuka. Bagaimanapun, kajian untuk reka bentuk struktur pelindung dan iklim mikro di dalamnya bagi mengoptimumkan pengeluaran tanaman kurang mendapat perhatian. Struktur pelindung yang digunakan untuk pengeluaran sayur-sayuran ialah rumah pelindung hujan (RPH) dan struktur jaring kalis serangga (SJKS). Kajian di MARDI ini adalah untuk menyelidik persekitaran di dalam sebuah rumah pelindung hujan kalis serangga. Struktur pelindung ini dibina berbumbungkan film polietilena (PE) untuk nyahhujan dengan bumbung 'jack' untuk pengudaraan semula jadi dan berdinding jaring kalis serangga untuk menghindarkan serangga. Kajian yang dijalankan selama setahun terhadap persekitaran termal, merekod suhu udara di dalam dan di luar, suhu tanah serta pancaran solar di dalam RPH semasa penanaman sayur-sayuran dijalankan. Corak persekitaran termal di dalam struktur dibangunkan untuk menentukan tahap selesa persekitaran dan reka bentuk sistem kawalan untuk memenuhi keperluan tanaman. Persekitaran dalaman sesebuah RPH bergantung kepada haba pancaran matahari yang diterima oleh struktur. Pancaran yang berlebihan akan menyebabkan tekanan haba kepada tanaman dan melumpuhkan fungsi-fungsi fisiologi. Lebihan haba ini perlu ditentukan dan dibuang untuk penambahbaikan persekitaran dalaman. Corak persekitaran yang dibangunkan dapat digunakan untuk menentukan langkah strategik untuk mengawal kesan tegasan haba dan dijadikan panduan dalam reka bentuk sistem kawalan persekitaran yang lebih berkesan.

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