Invited Paper

RESEARCH ON GREENHOUSE APPLICATION IN THE TROPICS

Herry Suhardiyanto[1] and Yayu Romdhonah[2]

ABSTRACT

Studies on greenhouse technology for tropical conditions show significant progress in the last decade. Several concepts of adapted greenhouse structure have been proposed by scientists in order to provide optimum environment for the growing plants inside. This paper reviews on some studies concentrated on improving the performance of greenhouse structure for tropical conditions. It presents some information on the design, material selection and the construction of several proposed greenhouses. It is hoped to give helpful information for future research as well as be implemented in commercial greenhouses in the tropics.

Keywords: *greenhouse, natural ventilation, structural design, tropics.*

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INTRODUCTION

The growing of plants in greenhouses is essentially subtropics phenomenon. It is not, however, a new phenomenon in the tropics. Greenhouses have in recent years become widely used for crop production in tropical countries whether for vegetables, fruit or ornamentals. However, little information on greenhouse design for the tropics has been the problem for greenhouse growers.

In the early years, greenhouses in the tropics were simply built exactly like the subtropics without local climate consideration. Temperate greenhouses i.e. quonset or tunnel type structure and glass-covered greenhouse were used commercially. Quonset type structures are actually meant as cold frames for nursery purposes in the subtropics while glass-covered greenhouses are used since glass is the most effective transmitter of solar light and heat. With abundant solar radiation in the region, they resulted in high greenhouse air temperature causing plant stress that eventually reduced the crop yield. Otherwise, active control like exhaust fans and fogging system had to be used to maintain the desired air temperature and humidity inside the greenhouse.

The concept of greenhouses is to overcome climatic disadvantages and provide the optimum environment growth for the plants inside. Their ability to do this efficiently depends upon location, structure and arrangement. With specific climatic conditions such as: high temperature, abundant solar radiation, heavy rain and wind load, temperate or subtropics greenhouses are not suitable for tropical conditions. They have to be adapted in order to provide the optimum

[1] Department of Agricultural Engineering, Bogor Agricultural University, 16680, herrysuhardiyanto@ipb.ac.id

[2] Alumna of Undergraduate Study Program, Department of Agricultural Engineering, Bogor Agricultural University, 16680, dona_tep@yahoo.com

conditions for the plants inside.

Up to 1997, studies on greenhouse structures that are suitable for tropical conditions were very limited. One of few studies was carried out by Kamaruddin in 1995. He proposed an adapted greenhouse called insect-proof rain shelter structure for temperate vegetable production in the lowlands. But only after in 1999 studies on the effect of these structures in producing the suitable indoor climate were carried out. In the last decade, studies on greenhouse design for tropical conditions show significant progress and resulted in some proposed greenhouse structures for this region. Several investigations on the use of the adapted greenhouse have also been carried out. The authors believe that the findings are important for greenhouse growers in the tropical region.

This paper reviews some studies concentrated on improving the performance of greenhouse structures in general included thermal studies, ventilation studies, and studies on the design (shape, dimensions, and roof configuration). It presents the concepts of adapted greenhouse structure, some information on the design, material selection and the construction of several proposed greenhouses for tropical conditions. In this paper, some of the proposed greenhouses are named by the scientist who conducted the research for practical consideration. It is hoped to give helpful information of structural design and technology for future research as well as be implemented in commercial greenhouses in the tropics.

PRINCIPLES IN DESIGNING TROPICAL GREENHOUSE

Thermal Models

Therr[illegible] greenhouse are [illegible] 2006 [illegible] predict air exchange rate and internal microclimate (air temperature and humidity) in two identical adapted greenhouses in Thailand. He used simplified greenhouse model i.e. the greenhouse is assumed as a solar collector. A good correlation (R^2 between 0.72 and 0.89) was obtained at any greenhouses covered with different net sizes.

Another thermal study was conducted by Suhardiyanto *et al.* (2007a) using the general greenhouse model as proposed by many researchers (e.g., Kimball, 1973; Bot, 1983; Takakura, 1989; Wang et al., 2000). The greenhouse system is divided into four sub systems i.e. cover, inside air, floor surface and soil layer. The crop inside were not modeled in this study. The novelty part is that incident angle of the sun was considered in the greenhouse heat balance. The heat balance model was used to predict the temperature of the inside air. The results showed a good agreement with the measured air temperatures.

Natural Ventilation Rate

New designs for improving greenhouse ventilation were also proposed and evaluated using computer and experimental models. Kamaruddin (1999) made a major breakthrough with natural ventilation studies of tropical greenhouses. He used direct measurement with tracer gas method to measure ventilation rate. He provided information of [illegible] rates due to stack e[illegible] and the [illegible]. The study [illegible] rate can be [illegible] temperature [illegible] direction, [illegible] opening [illegible] between the [illegible]

[illegible] through the [illegible] through the top [illegible] (1999) noted that some of the flow left above the neutral level in the bottom opening if the neutral level intersected the opening. However, if wind was dominant (wind effect), the height of the neutral level changed thus resulted in change in the position of air inlet and outlet of the greenhouse.

Though it was not proposed for tropical greenhouse, natural ventilation guidelines including minimum ventilation opening area of 20% of greenhouse floor area have been outlined by Connellan (2000). But, this study has given valuable information for greenhouse growers in the tropics.

Ventilation configuration for an adapted greenhouse has been studied recently by Harmanto (2006). It was found that the combination of sidewall and roof openings played an important role in providing better air exchange rates in naturally ventilated greenhouses under humid tropical conditions. He proposed minimum ventilation area of 60% of total surface floor area is necessary to maintain a favorable microclimate and air exchange rate in the adapted greenhouse.

Suhardiyanto *et al.* (2006) conducted an analysis of natural ventilation for modification of a steep-type (roof slope of 45°) standard peak greenhouse in Bogor district, Indonesia. A computer program was developed to calculate the neutral pressure level and natural ventilation rate of the greenhouse. Five alternatives of modified and two alternatives of newly designed greenhouse were investigated. An alternative of modified greenhouse design was selected according to the highest natural ventilation rate at the lowest cost (Suhardiyanto *et al*, 2006). The modified greenhouse with the roof slope of 30° gave a better inside microclimate. The difference between outside and inside air temperature has decreased to 3 °C with its previous one. (Suhardiyanto *et al.*, 2007b).

Structural Design

Most of greenhouses in tropical region are used for hydroponics system. Akyas, et al. (2004) reported that there was a need to harden the floor and to install screen-wall to protect the crop from air and soil borne disease and pest without causing increase in air temperature and humidity. To lower the air temperature, they first altered the growing structure from "joglo" type to Piggyback type. The result of modifying the growing structure showed, however, that the air temperature was still too high.

The concept of tropical greenhouses has recently been proposed and tested. The greenhouse was designed to be a relatively simple structure, easy to construct, and low in maintenance cost. The material for building up the greenhouse should be locally available with relatively longer period of life use (mostly about 3-5 years). A naturally ventilated greenhouse is mostly common practice to meet these requirements. In addition, the ventilation opening area should be maintained as large as possible in order to achieve an internal air temperature close to the ambient temperature (von Zabeltitz, 1999), and the vents are covered with insect-proof net.

Recently, Harmanto (2006) conducted evaluation of net greenhouses for tomato production in the tropics and gave recommendation on ventilation configuration. He studied the effect of insect-proof nets on air exchange rate and internal microclimate. Three kinds of insect-proof nets i.e. 40-mesh (anti-leafminers), 52-mesh (anti-whiteflies) and 78-mesh (anti-thrips) were investigated. The best results in crop performance, total production and fruit quality were noted in 52-mesh houses. Thus, it was proposed as appropriate nets for the adapted greenhouse in the humid tropics.

Little information is available for roof configuration studies in tropical region.

Campen (2004) applied Computational Fluid Dynamics (CFD) to find a favorable design for Indonesian conditions. CFD has made thermal analysis possible to be conducted for a virtual prototype greenhouse. He investigated four different greenhouse designs. The ventilation rate and the maximum air temperature inside the greenhouse have been used to evaluate the designs. The results showed that the design without an opening in the top has the highest ventilation rate and the lowest maximum temperature in case of wind due to aerodynamics. In case of no wind the climate in the design without top ventilation is slightly worse than in the other designs. Increasing the length of the greenhouse reduces the ventilation for this design. In addition, the insect gauze reduces the ventilation by more than 50%.

ADAPTED GREENHOUSE STRUCTURES FOR TROPICAL CONDITIONS

Based on the principles in designing tropical greenhouse, some recommendations have been made by researchers on adapted greenhouse structures for tropical conditions.Crop protection structures for the tropics have been developed in Malaysia by Malaysian Agricultural Research and Development Institute (MARDI). The structure has transparent plastic roofing, insect screen sidewall covering and a simple structural frame. It is being used widely in Malaysia since 1995 (Kamaruddin, 1995).

In Indonesia, piggy back structure (Figure 1) that allows large ventilation area is mainly used for commercial crop production while adapted tunnel type with continuous roof vents is used in Thailand. Several proposed greenhouse structures for tropical conditions are:

1. Early MARDI structures (1995)

The early MARDI structures were the rain shelter, the insect-proof structure, and a combination of rain shelter and insect-proof structures. These structures were then widely being used in Malaysia to replace the temperate greenhouses which are not suitable in the tropical conditions (Kamaruddin, 1999).

Rain shelter consists of structural frames, open side walls and transparent polyethylene film roofing, while the insect-

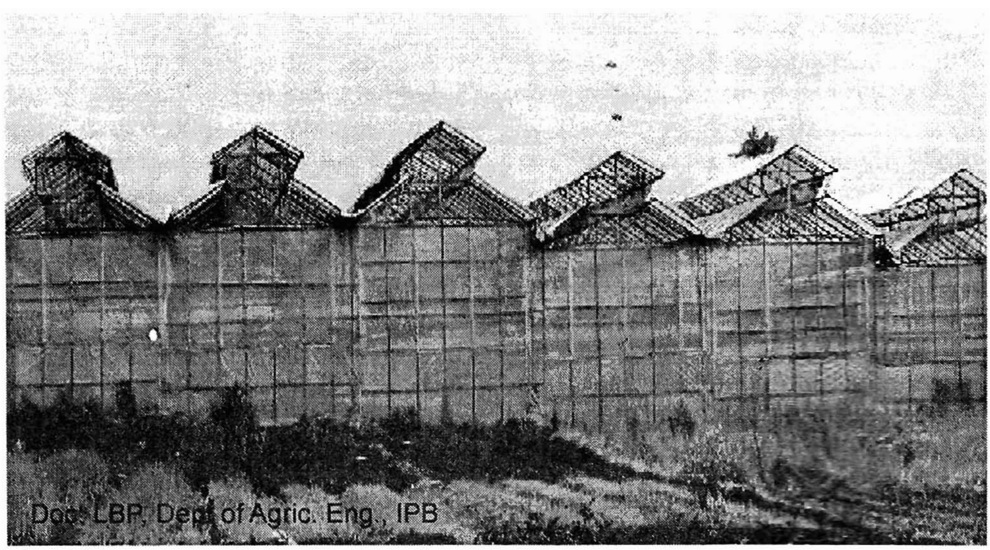

Figure 1. A multi-span piggy back structure with polyethylene film cover

Table 1. Dimensions of Naturally Ventilated Tropical Greenhouse Structures (Kamaruddin, 2006)

Structure	Length (m)	Width (m)	Height (m)	Volume (m^3)	Floor area (m^2)	Cover area (m^2)
Single-Span	50	10	4.5	2300	500	600
Double-Span	50	20	4.5	4600	1000	1200
Triple-Span	50	30	4.5	6900	1500	1600
Quadruple-Span	50	40	4.5	9200	2000	2400

Source: Kamaruddin, R. and S.A.F. Mohammed. 2006. Natural ventilation by stack effect in multi-span tropical greenhouse structures. Journal of Tropical Agriculture and Food Science. (in press) Reference No.17/2006.

proof structure was entirely covered with polyethylene insect screen and the combination of both was called the insect-proof rain shelter (IPRS) (Pictures of MARDI structures can be seen in Kamaruddin, 1999). The standard dimension and geometry of the structures varied according to particular requirements. Studies showed that the differences between inside and outside average air temperature (min-max), soil temperature, relative humidity (8.30 a.m. to 2.30 p.m.) and shade under IPRS were 1.0-3.0C, 1.0C, 2.1-3.2% and 30-43% respectively. The structures have been proven technically feasible and economically viable for Capsicum, celery, Chinese cabbage, tomato, cabbage and cauliflower production (Kamaruddin, 1999).

2. NVTGS (Naturally Ventilated Tropical Greenhouse Structures)

Kamaruddin et al. (2006) reported that Naturally Ventilated Tropical Greenhouse Structures were designed and constructed at Malaysian Agricultural Research and Development Institute (MARDI). The design considered engineering code of practices, plant physiological and

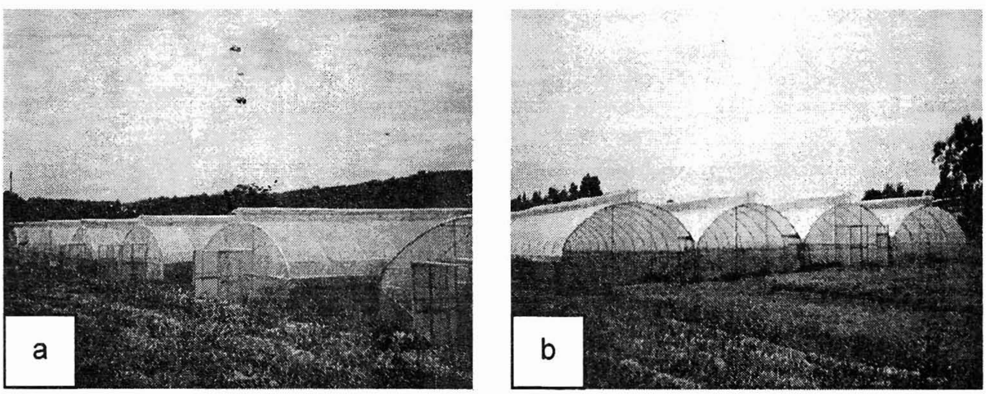

Figure 2. Naturally ventilated tropical greenhouse structures. (a) Single-span greenhouse (b) Quadruple-span greenhouse. "Reprinted from Journal of Tropical Agriculture and Food Science. (in press) Reference No.17/2006, Kamaruddin, R. and Faisal Mohammed Seif Al-Shamiry. Natural Ventilation by Stack Effect in Multi-Span Tropical Greenhouse Structures, with permission from the author."

agronomics requirements. The single-span of the structure was made 50 m long x 10 m wide x 4.5 m high which has straight side walls and tunnel roof shape with jack-roof. Moreover, the double, triple and quadruple spans were also constructed in the prefabricated and modular form. Figure 2 shows the typical types of the structures. All structures were made of galvanized steel frame, transparent polyethylene film (180 m thick) roofing and polyethylene insect-screen (800 m mesh) side cladding. The dimension of the greenhouse structures is presented in Table1.

3. Insect screen houses

Insect-exclusion screen houses have become popular among growers because they reduce the need for pesticide application and cost much less than greenhouses. The structure is very simple and has flat roof. Figure 3 shows the structure of a commercial screen house in Indonesia.

4. J.B. Campen Structure

The design was intentionally proposed for Indonesian conditions. Greenhouses in Indonesia are built to protect the crop from heavy rain and insects. The walls of the greenhouse are open or covered by insect gaze. A new design has been developed with an aerodynamic top opening. This design proved to function with and without wind. It is currently being tested in Indonesia (Campen, 2004).

DISCUSSION

The primarily function of a greenhouse in the tropical region is to protect plants from excessive solar radiation and heavy rain. Work on thermal models has been very limited. Most of the work were done as to study the effect of natural ventilation to the inside microclimate. The model still contains 'lumped' heat sources and/or sinks. However, experimental evidence confirms that current model predictions of mean temperatures are good. For a passive environmental control, ventilation openings (sidewalls and roof) have become essential for tropical greenhouses. A well designed naturally ventilated greenhouse will provide acceptable air temperature conditions and better microclimate.

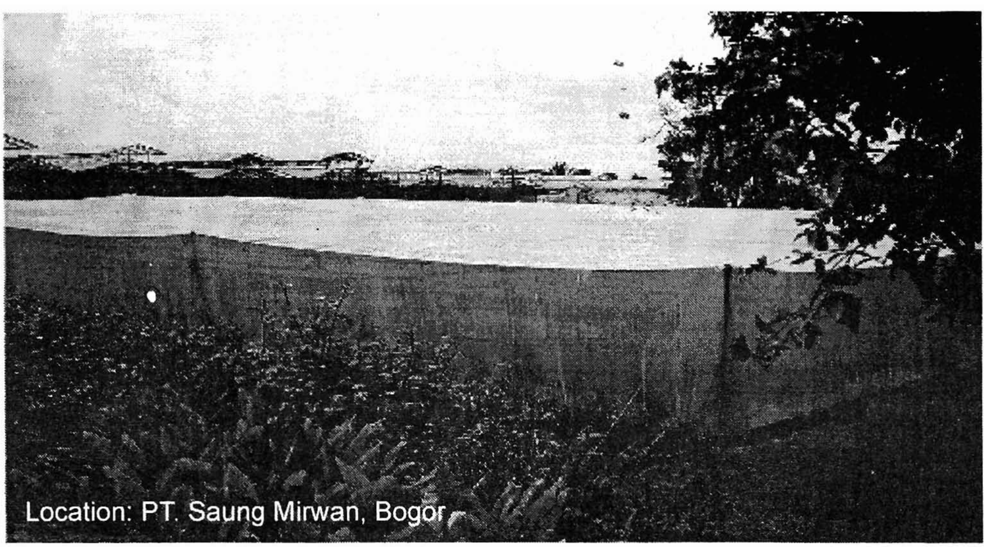

Figure 3. Screen house with flat roof in Indonesia.

The main parameters involved in the cultivation of crop conducted under greenhouse in the tropical region are extreme solar radiation and air temperature. Therefore, the main problem to be solved is reducing the heat load and air temperature inside the greenhouse.

Connellan (2002) stated that if a greenhouse can not prevent the inside air temperature within 5 to 6 °C above outside air temperature, it is considered to be performing poorly in terms of ventilation. This means ventilation configuration is very important for tropical greenhouses.

There have been significant advances in the study of greenhouse ventilation. Analysis of greenhouse ventilation rate is used to evaluate the ventilation efficiency. Natural ventilation system with an appropriate design of the greenhouse is one of possible efforts to overcome the problem since it is economically viable. There is no cost required to operate natural ventilation (Suhardiyanto et al., 2006). A combination of both roof and side wall opening ventilation is then believed to be the answer for tropical greenhouses. This allows better air exchange rate between inside and outside the greenhouse. The best way to achieve this goal is to keep the ratio of ventilation opening to floor area to be as large as possible (von Zabeltitz, 1999). For tropical region, the side wall opening could be opened as much as possible, but the roof vent opening should be limited due to the presence of heavy rain during the rainy season (Harmanto, 2006).

The greenhouse height is also another consideration in developing adapted tropical greenhouse structures. The height of the greenhouse affects the ventilation efficiency by natural ventilation, if vent openings are positioned at the ridge and on side wall. The higher the ridge and the greater the distance between ventilators at the ridge and side wall, the higher are pressure difference. The ventilation efficiency is proportional to the pressure difference (Bot, 1983).

Since the major heat load which must be removed by ventilation is the heat associated with solar radiation, the angle of greenhouse roof need to be considered. Relative humidity is another environmental parameter important in greenhouses. A great deal of condensation often happens at night, if it drips onto the plants the next morning, it can lead to disease problems.

Therefore, the key issue is the reduction of air temperature inside greenhouse to be only some degrees above the ambient temperature. Natural ventilation system with an appropriate design of the greenhouse is one of possible efforts to overcome the problem. A well designed naturally ventilated greenhouse will provide acceptable air temperature conditions and better microclimate. Natural ventilation guidelines including minimum ventilation opening area of 20% of greenhouse floor area have been outlined by Connellan (2000).

RECCOMMENDATION FOR FUTURE RESEARCH

Apart from the considerable progress in research on greenhouses for tropics, there is still a need for a comprehensive computer model to predict greenhouse microclimate. The shape and angle of the roof will affect to the structural design, thus influence the environment of the greenhouse. Studies on the roof design should be made to find out the effect of roof shape and angle to microclimate inside the greenhouse. Information on optical and thermal properties of greenhouse covering material is also need to be investigated.

The development of tropical greenhouse structures is quite significant.

Yet, no greenhouse is ideal. There are always things to do for improvement to provide the optimum environment for the plants inside the greenhouse as the optimal values will depend on the grower's particular crop.

Developments in greenhouse technology for the subtropics should be followed by extensive study on the application in tropical region.

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