UNIVERSITI PUTRA MALAYSIA

MODELING OF EVAPORATIVE COOLING SYSTEM FOR NATURALLY-VENTILATED TROPICAL GREENHOUSES

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By

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Natural ventilation in tropical greenhouse is a common method for ventilation which gives higher inside temperatures compared to the outside temperatures. This type of ventilation is not enough to reduce high temperature inside the structure in low land areas. Thus the requirement of cooling is increased. Use of fossil fuel to run the cooling fans are not economically viable due to increasing fuel cost and greenhouses are not always located near the electrical grid. The objectives of this research was to study the inside microclimate of the greenhouse, the natural ventilation of the greenhouse, the evaporative cooling system by means of misting fans and to study the use of photovoltaic (PV) as an alternative energy source to cool down the greenhouse. This study presents the theoretical and experimental results of the in-house microclimate, ventilation rate induced by stack effect, wind effect and combination of both stack and wind effects for naturally ventilated single and multi-span tropical greenhouses, effect of height and plants on inside temperature and ventilation rate. Ventilation rate induced by the stack effect was found to increase with increasing temperature difference between inside and outside of greenhouse

structures according to power law, with an index of 0.5. The wind effect ventilation rate was found to increase linearly with increasing outside wind speed. Ventilation rate inside single span structure (smaller floor area) was higher than in multi-span structure. This was due to that the fast movement and air exchanges in single span structure. However, the bigger floor area gives higher in-house temperatures. Inside temperature and outside wind speed were calculated to verify the mathematical models which were developed. This method was used because of the difficulty to use tracer gas method in porous large scale greenhouse structures. The comparison between calculated and measured inside temperature showed there was no significant difference between them. The effect of height on ventilation rate is also crucial in greenhouse design. The ventilation rate increases with the increasing height (distance between the middle of the side opening and the middle of the roof opening) of the structure. Ventilation rate inside the house with plant was found lower than inside the house without plant. This was due to the temperature difference between inside and outside structure. Evaporative cooling by means of misting fans in single span was also presented in this study. Four misting fans were used to cool the greenhouse. They were installed two meters above ground with two fans near the southern sidewall and two fans in the middle of the greenhouse operating from 10:00 am to 16:00 pm daily. Data was collected from three rows with total 57 points inside the greenhouse. The distance between points was 2.5 m along the length of the greenhouse. The data was processed using GIS (Geographic Information System) to model the inside temperature and wind speed. The temperature inside the greenhouse with fans was found to be lower than that without fans, while the inside relative humidity of the air was found to be higher in the greenhouse with fans than that without and the outside. However these values of relative humidity lie at the optimum value that is less than 90% which do not give negative effect on the plants inside the structure. Based on the results, the contours and 3D maps of the in-house temperature and wind speed distribution in the single span greenhouse were developed. The efficiency of misting fans was lower than the previous studies. This was due to the usage of misting fans in porous naturally ventilated greenhouse, while the previous studies were carried out in closed greenhouses and glasshouses. Photovoltaic (PV) hybrid system design and simulation was discussed in this study. The results show that PV system would be suitable to supply electricity to cover the load requirement without purchasing energy from grid, and the battery state of charge was found to be in the range of 75-100%.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMODELAN SISTEM PENYEJUKAN PENYEJATAN BAGI RUMAH-RUMAH HIJAU TROPIKA PENGUDARAAN SEMULAJADI

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Kajian ini mengemukakan keputusan eksperimen dan teori di dalam mikro-cuaca, kadar pengudaraan oleh kesan tindakan longgokan (stack), kesan angin dan kombinasi kedua-dua longgokan dan kesan angin untuk satu pengudaraan semulajadi dan rumah hijau tropika pelbagai-rentang (multi-span), kesan ketinggian dan tanaman ke atas suhu dan kadar pengudaraan. Kadar pengudaraan didorong oleh kesan longgokan didapati meningkat dengan peningkatan perbezaan suhu antara di dalam dan di luar struktur rumah hijau berdasarkan peraturan kuasa, dengan indeks 0.5. Kesan udara ke atas kadar pengudaraan didapati meningkat selaras dengan peningkatan kelajuan angina di luar. Kadar pengudaraan di dalam satu rentang struktur (kawasan lantai kecil) adalah lebih tinggi berbanding struktur pelbagai-rentang. Ini disebabkan pergerakan pantas dan pertukaran udara dalam struktur satu rentang. Walau bagaimanapun, luas permukaan lantai yang besar memberikan peningkatan dalam suhu. Suhu dalam dan kelajuan angin di luar telah dikira untuk mengesahkan pemodelan matematik yang telah dibangunkan. Kaedah ini telah digunakan kerana kesukaran dalam penggunaan kaedah gas penyurih dalam skala

besar poros struktur rumah hijau. Perbandingan di antara kiraan dan ukuran suhu di dalam telah menunjukkan tiada perbezaan ketara di antaranya. Kesan ketinggian ke atas kadar pengudaraan adalah sangat penting dalam rekabentuk rumah hijau. Kadar pengudaraan meningkat dengan pertambahan tinggi struktur binaan (jarak antara bukaan tepi di tengah dan bukaan bumbung di tengah). Kadar pengudaraan dalam rumah dengan tumbuhan di dapati lebih rendah berbanding dengan tanpa tumbuhan di dalamnya. Penyejukan sejatan secara semburan kipas berkabus dalam satu span juga dibentangkan dalam kajian ini. Empat kipas berkabus telah digunakan dalam penyejukan rumah hijau. Kipas tersebut telah dipasang dua meter di atas tanah dengan dua kipas berdekatan dinding tepi selatan dan dua kipas di tengah rumah hijau, beroperasi dari pukul 10 pagi ke 4 petang setiap hari. Data dikumpul dari 3 barisan dengan jumlah 57 titik dalam rumah hijau. Jarak antara titik adalah 2.5 m sepanjang jarak rumah hijau tersebut. Data diproses menggunakan model GIS (Sistem Maklumat Geografik) bagi suhu di dalam dan kelajuan angina. Suhu di dalam rumah hijau dengan kipas didapati lebih rendah tanpa kipas, sementara kelembapan relatif udara di dalam adalah lebih tinggi di dalam rumah hijau dengan kipas berbanding tanpa kipas dan di luar. Walau bagaimanapun, nilai kelembapan relatif berada dalam nilai optimum di mana ia kurang dari 90% dan tidak memberikan kesan negatif ke atas tumbuhan di dalam struktur. Berdasarkan keputusan, kontur dan peta 3D bagi suhu di dalam rumah hijau dan taburan kelajuan angin dalam rumah hijau satu rentang telah dibangunkan. Kecekapan kipas berkabus didapati lebih rendah berbanding kajian terdahulu. Ini disebabkan penggunaan kipas berkabus dalam pengudaraan poros semulajadi dalam rumah hijau, sedangkan kajian terdahulu telah dijalankan dalam rumah hijau tertutup dan rumah kaca. Sistem hibrid fotovoltik (PV) dan simulasi juga telah dibincangkan dalam kajian ini. Keputusan telah menunjukkan system PV adalah lebih sesuai untuk membekalkan keperluan elektrik bagi memenuhi beban tanpa membeli tenaga dari grid dan keadaan bateri yang dicaskan adalah dalam julat 75 – 100%.

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I certify that an Examination Committee has met on 07/02/ 2007 to conduct the final examination of Faisal Mohammed Sief Al-shamiry on his doctor of Philosophy thesis entitled "Modeling of Evaporative Cooling System in Naturally-Ventilated Tropical Greenhouses" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously of concurrently submitted for any other degree at UPM or other institutions.

FAISAL MOHAMMED SEIF AL-SHAMIRY

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