# TECHNO-ECONOMIC ANALYSIS IN OPTIMISATION OF HYBRID AIR-CONDITIONING SYSTEM COMBINING CHILLED WATER STORAGE AND SOLAR WATER HEATER

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## SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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**STUDENT'S DECLARATION**

I hereby declare that the work in this 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 or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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# ABSTRAK

Penyelidikan ini merupakan kajian hibrid penyaman udara yang menggabungkan sistem konvensional mampatan wap, tangki simpanan air sejuk dan sistem pemanas air solar di kawasan tropika. Sinaran matahari tahunan pada iklim tropika dapat dieksploitasi untuk tujuan penyejukan. Sistem penghawa dingin solar adalah menarik untuk diterokai di rantau Asia Tenggara kerana terdapat sinaran matahari sepanjang tahun. Tenaga solar adalah bersih dan tidak memudaratkan alam sekitar. Oleh itu, usaha membangunkan penghawa dingin solar dengan cara berkesan boleh memberi pulangan yang baik kepada manusia sejagat. Pengenalan sistem pemanas air solar dalam sistem mampatan wap yang sedia ada di bangunan perpustakaan UMP memberi hala tuju baru dalam pembangunan projek-projek tenaga boleh diperbaharui terutama di institusi pengajian tinggi. Isu utama penghawa dingin hibrid solar adalah input yang tidak stabil kerana perubahan cuaca harian. Sebagai sebuah negara yang lembab dan panas, sinaran matahari boleh menjadi sangat berguna pada awal tahun dan berubah secara mendadak ketika musim tengkujuh pada hujung tahun. Oleh itu, idea untuk mengekalkan penghawa dingin hibrid solar boleh dilaksanakan dengan memasang penyimpanan haba tenaga untuk menyimpan tenaga untuk kegunaan keesokan hari. Tangki simpanan air sejuk merupakan contoh penyimpan tenaga yang bagus dari segi ekonomi. Sinaran matahari yang dikumpul boleh digunakan untuk menggerakkan unit penyerapan penyejukan. Air sejuk akan dialirkan melalui Unit Pengendalian Udara pada kegunaan keesokannya. Sebarang kekurangan daripada sinaran matahari akan dibantu oleh unit pemanas tambahan. Model komponen hibrid ini akan menjadi bahagian yang paling penting untuk mendapatkan hasil yang optimum dari segi penjimatan ekonomi dan alam sekitar. Data cuaca di Pekan dicatatkan sepanjang tahun daripada stesen cuaca mini di Fakulti Kejuruteraan Mekanikal. Data-data ini digunakan untuk menentukan beban penyejukan pada bangunan perpustakaan UMP. Kaedah Radiasi Masa adalah kaedah yang dipilih berdasarkan ASHRAE 2009. Penggunaan data yang direkodkan seperti data cuaca dan profil bangunan perpustakaan UMP akan digunakan untuk menentu ukur beban penyejukan. Hasil daripada pengiraan beban penyejukan secara purata akan digunakan untuk menentukan saiz tangki simpanan air sejuk yang optimum. Dengan memanipulasikan saiz tangki, perbezaan suhu dan waktu operasi; menjadikan semua ini faktor yang baik untuk mendapatkan penjimatan kepada ekonomi dan alam sekitar. Semua operasi dijadualkan pada waktu malam untuk mendapatkan faedah daripada kadar elektrik bukan pada waktu puncak di bahagian komersial. Seterusnya, penilaian ke atas alam sekitar menggunakan faktor pelepasan karbon dioksida daripada standard Agensi Tenaga Antarabangsa pada tahun 2015. Analisis kadar pulangan merupakan salah satu analisis ekonomi yang digunakan dalam penyelidikan ini. Kesimpulannya, dengan saiz tangki yang optimum dan operasi strategi yang berkesan, bil elektrik tahunan dapat dijimatkan sehingga RM405,470.00 dan penjimatan pelepasan gas karbon dioksida sebanyak 296,637 kg$CO_2$e/kW. Penyelidikan ini dapat membantu meningkatkan lagi amalan rekabentuk serta pemasangan system penyaman udara hybrid dinegara-negara beriklim tropika agar dapat mengurangkan penggunaan bahan api fossil serta pengurangan emisi gas rumah hijau dimasa akan datang.

# ABSTRACT

This thesis is a research report representing a study of hybrid air-conditioning combining vapour compression system, chilled water storage and solar water heater system in the tropical region. Yearly, solar radiation in the tropical climate promises potential exploitation of solar energy for cooling purposes. Solar air-conditioning system can be attractive to explore in the South East Asian region because of the abundance of solar radiation throughout the year. Solar energy is clean and provides no harm to the environment. Thus, development in solar air-conditioning in respective ways can give a good return to society. The main component in hybrid solar air-conditioning is the solar water heater system. Introduction of solar water heater system in the existing vapour compression system in the UMP library building can provide a new direction in the development of renewable energy projects especially in higher learning institutions such as Universiti Malaysia Pahang. The main issue of hybrid solar air-conditioning is the intermittant input because of the variation in daily weather conditions. As a hot and humid country, solar radiation can be useful in the early part of the year but turns less useful during the monsoon season towards the end of the year. Thus, the idea to sustain the hybrid solar air-conditioning can be supported by installing thermal energy storage (TES) to store energy for later use. The best and most economical TES is chilled water storage (CWS). Harvested solar radiation can be used to feed absorption chiller and this chiller mainly functions to chill the water. The chilled water will be distributed through the Air Handling Unit (AHU) for the following day's usage. Any discrepancy of solar radiation should be covered by a supplementary unit of auxiliary heater. Modelling the hybrid component would be the most important part to get an optimum result in terms of economic and environmental saving. Weather data in Pekan was recorded yearly using the mini weather station installed by the Faculty of Mechanical Engineering. These data were used to determine the cooling load of UMP library building. Radiant Time Series (RTS) method was chosen according to ASHRAE 2009 by using the recorded local weather data and the UMP library building physical profiles. Result of the average cooling load was used to determine the optimum sizing of the chilled water storage tank. Manipulating the water tank size, the temperature difference and the operation hours can be good factors to get fairly good savings in economic and environmental terms. All operations were scheduled during night time in order to gain benefits on the off-peak electricity rate under Commercial Group. The environmental assessment was done using $CO_2$ emission factor from International Energy Agency (IEA) Standard in 2015. The Payback Period analysis was used to determine the economic benefits. In conclusion, with optimum sizing and operation strategy the yearly billing of the building can be reduced up to RM405,470 and $CO_2$ emissions can be reduced up to 296,638 $kgCO_2e/kW$ for the UMP library building. This research work can contribute to more incorporation of design and installation of solar air-conditioning hybrid systems in tropical countries in future to help reduce dependency of fossil fuels and reduce emissions of greenhouse gases to the atmosphere.

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# LIST OF SYMBOLS

| | |
|---|---|
| $A$ | Area ($m^2$) |
| $C$ | Specific heat of water (kJ/kg.K) |
| $c_0, c_1$ | Conduction Time Factor |
| $F_u$ | Usage Factor |
| $F_s$ | Service Allowance Factor |
| $G$ | Global radiation |
| $K$ | Energy loss rate of tank |
| $N_p$ | Number of people |
| $q_s$ | Sensible heat gain |
| $q_l$ | Latent heat gain |
| $q_\theta$ | Hourly conductive heat gain for the surface, W |
| $q_{i,\theta}$ | Heat input for the current hour |
| $q_{i,\theta-1}$ | Heat input n previous hour |
| $Q$ | Heat gain |
| $Q_{pl}$ | Heat input for people (latent) |
| $Q_{ps}$ | Heat input for people (sensible) |
| $Q_l$ | Total latent heat |
| $Q_c$ | Cooling load |
| $Q_{ch}$ | Capacity of chiller |
| $\Delta T$ | Temperature difference |
| $t_a$ | Ambient temperature |
| $t_m$ | Temperature of heat transfer fluid |
| $t_{e,\theta-n}$ | Sol-air temperature |

| | |
|---|---|
| $\eta$ | Volume efficiency of tank |
| $\eta_0$ | Efficiency of collectors |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| AHU | Air Handling Unit |
| ANN | Artificial Neural Networks |
| ARD | Abiotic Resource Depletion |
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| ATES | Aquifer Thermal Energy Storage |
| CCHP | Combined Cooling Heating and Power System |
| CDM | Clean Development Mechanism |
| CER | Certified Emission Reduction |
| CFC | Chlorofluorocarbons |
| CLTD/CLF | Cooling Load Temperature Different / Cooling Load Factor |
| COP | Coefficient of Performance |
| $COP_{ch}$ | Coefficient of Performance for the Chiller |
| CTES | Chilled Thermal Energy Storage |
| CTS | Conduction Time Series |
| CWS | Chilled Water Storage |
| ETC | Evacuated Tube Collectors |
| ESFG | Energy Sustainability Focus Group |
| FME | Faculty of Mechanical Engineering (UMP) |
| GNA | Gordon-Ng Model |
| GWP | Global Warming Potential |
| HB | Heat Balance |
| HCFC | Hydrochlorofluorocarbons |
| HFC | Hydrofluorocarbons |
| HTF | Heat Transfer Fluid |
| HVAC | Heating, Ventilation and Air-Conditioning |
| IEA | International Energy Agency |
| IHG | Internal Heat Gain |
| ITS | Ice Thermal Storage |
| JPPH | Jabatan Pembangunan dan Pengurusan Harta |
| LHG | Latent Heat Gain |

| | |
|---|---|
| LSM | Local Standard Meredian |
| MPR | Multivariable Polynomial Model |
| PCM | Phase Change Material |
| RMSE | Root Mean Square Error |
| RTS | Radiant Time Series |
| SACE | Solar Air-Conditioning in Europe project |
| SHG | Sensible Heat Gain |

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