DEVELOPMENT OF A FRAMEWORK TO STUDY AND ENHANCE THE FEASIBILITY OF AN ABSORPTION REFRIGERATION SYSTEM FOR SPACE COOLING IN MALAYSIA

RASHVIN A/L RAVINDRANATHAN

UNIVERSITI TEKNOLOGI MALAYSIA

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RASHVIN A/L RAVINDRANATHAN

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ABSTRACT

The global rise in energy demands has become a prominent issue that requires urgent intervention. This is largely due to the surge in greenhouse gas emissions, which could result to a global warming predicament. Moreover, from research studies, it is observed that air-conditioning and refrigeration systems are one of the biggest contributors to this increase in energy needs. Therefore, alternative solutions to conventional air conditioning systems are required in combatting this issue. One being through the implementation of an absorption refrigeration system which utilizes GHG free working fluids (zero emission of greenhouse gases). However, this system is yet to be widely commercialized due to its poor technical and commercial feasibility. For instance, its low COP value of below one would instead require more electricity to be consumed through the grid, ultimately increasing the GHG output. Now, in this project, methods such as incorporating solar energy to improve the absorption chiller's efficiency and to reduce the energy intake from the grid would be explored in depth. Hence, the main output of this research is to create a framework to study and enhance the feasibility of an absorption refrigeration system in Malaysia. Besides that, to also compare absorption refrigeration from a commercial perspective against current available conventional cooling systems such as the ductless split (direct refrigerant) and air conditioning systems powered by solar electricity. An EXCEL program is used in modelling out the desirable framework due the software's versatility. Next, the framework is applied on a case study of a commercial building (academic centre) to ensure and prove the credibility of the developed framework. Here, a few observations were made based on the study outcome, where, it is seen that by introducing and integrating solar energy to the absorption refrigeration system, the life cycle cost was reduced by half compared to a conventional split air conditioning system. Besides that, it was also concluded that the solar based absorption chiller would provide a higher internal rate of return of **9%** and a reduction in GHG emission of **83.21%**, compared to a solar PV powered air conditioner with values of **6%** and **54.64%** respectively for a study period of **20 years**.

ABSTRAK

Peningkatan permintaan tenaga global telah menjadi isu penting yang memerlukan campur tangan segera. Ini sebahagian besarnya disebabkan oleh lonjakan pelepasan gas rumah hijau, yang boleh mengakibatkan masalah pemanasan global. Selain itu, daripada kajian penyelidikan, didapati bahawa sistem penyaman udara dan penyejukan adalah salah satu penyumbang terbesar kepada peningkatan keperluan tenaga ini. Oleh itu, penyelesaian alternatif kepada sistem penyaman udara konvensional diperlukan dalam memerangi isu ini. Salah satunya adalah melalui pelaksanaan sistem penyejukan penyerapan yang menggunakan cecair kerja yang tidak melepaskan sebarang gas rumah hijau ke alam sekitar. Walau bagaimanapun, sistem ini masih belum dikomersialkan secara meluas kerana kebolehlaksanaan teknikal dan komersialnya yang lemah. Sebagai contoh, nilai COP sistem penyejukan penyerapan adalah rendah (< 1) dan akan mengakibatkan lebih banyak tenaga elektrik untuk digunakan melalui grid. Justeru, dalam tesis ini, kaedah seperti pengunaan tenaga suria untuk meningkatkan kecekapan penyejuk serapan dan mengurangkan pengambilan tenaga daripada grid akan diterokai secara mendalam. Hasil utama penyelidikan ini adalah untuk mewujudkan rangka kerja untuk mengkaji dan meningkatkan kebolehlaksanaan sistem penyejukan penyerapan di Malaysia. Selain itu, sistem penyejukan penyerapan juga akan dibandingkan dengan sistem penyejukan konvensional dari perspektif komersil. Program EXCEL digunakan dalam penyelidikan ini dalam memodelkan rangka kerja yang diingini. Seterusnya, rangka kerja diguna pakai ke atas kajian kes bangunan komersial (pusat akademik) bagi memastikan dan membuktikan kredibiliti rangka kerja yang dibuat. Di sini, beberapa pemerhatian dibuat berdasarkan hasil kajian, di mana, dilihat bahawa dengan memperkenalkan dan mengintegrasikan tenaga suria kepada sistem penyejukan serapan, kos kitaran hayat telah dikurangkan kepada separuh berbanding sistem penghawa dingin split konvensional. Di samping itu, juga disimpulkan bahawa penyejuk serapan berasaskan solar akan memberikan kadar pulangan dalaman yang lebih tinggi sebanyak **9%** dan pengurangan pelepasan GHG sebanyak **83.21%**, berbanding dengan penghawa dingin berkuasa solar PV dengan nilai **6%** dan **54.64%** masing-masing untuk tempoh pengajian selama **20 tahun**.

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LIST OF ABBREVIATIONS

AC	-	Alternating Current
CLF	-	Cooling Load Factor
CLTD	-	Cooling Load Temperature Differential
COP	-	Coefficient of Performance
CPC	-	Compound Parabolic Concentrator
DC	-	Direct Current
EES	-	Engineering Equation Solver
ETC	-	Evacuated Tube Collector
GHG	-	Greenhouse Gas
HEX	-	Heat Exchanger
HFC	-	Hydrofluorocarbons
HVAC		Heating, Ventilation, and Air Conditioning
LCCA	-	Life Cycle Cost Analysis
LHS	-	Latent Heat Storage
MUPV	-	Modified Uniform Present Value
NEM	-	Net Energy Metering
O&M	-	Operation and Maintenance Cost
PCM	-	Phase-Change Material
PTC	-	Parabolic Trough Collector
PV	-	Photovoltaic
RE	-	Renewable Energy
SARS	-	Solar Absorption Refrigeration System
SDG	-	Sustainable Development Goal
SEDA	-	Sustainable Energy Development Authority
SHS	-	Sensible Heat Storage
SIR	-	Savings to Investment Ratio
SPB	-	Simple Payback Period
SPV	-	Single Present Value
TES	-	Thermal Energy Storage
TETD	-	Total Equivalent Temperature Differential

TFM	-	Transfer Function Method
UNDP	-	United Nations Development Programme
UPV	-	Uniform Present Value
XCPC	-	External Compound Parabolic Concentrator

LIST OF SYMBOLS

Q_e	-	Heat absorbed from space
Q_g	-	Heat required by generator
W_p	-	Work done by pump
T_e	-	Evaporator Temperature
T_g	-	Generator Temperature
T_a	-	Ambient Temperature
$T_{m,coll}$	-	Average Internal Fluid Temperature of the Collector
a_0	-	Optical Efficiency
a_1	-	Linear Heat Loss Coefficient
a_2	-	Quadratic Heat Loss Coefficient
G	-	Solar Irradiance
η_{coll}	-	Collector's Efficiency
$Q_{out,coll}$	-	Heat Output Per Area
β	-	Collector's Inclination Angle
d	-	Distance between Solar Collectors
ε	-	Solar Incident Angle
W_{coll}	-	Width of Solar Collector
L_{coll}	-	Length of Solar Collector
W_b	-	Total Width of the Rooftop / Flat Ground
L_b	-	Total Length of the Rooftop / Flat Ground
W_e / L_e	-	Space between the Collector to the Edge of the Rooftop / Flat Ground
Row_{max}	-	Maximum Number of Rows
$Collector_{max}$	-	Maximum Number of Collectors per Row
A_{max}	-	Required or Available Area for the Solar Collector Installation
A	-	Surface Area of HEX
Q	-	Heat Duty of HEX
U	-	Heat Transfer Coefficient
C_B	-	Base Cost of HEX

C_p	-	Purchase Cost of HEX
I	-	Initial Investment Cost
Repl	-	Replacement Cost
Res	-	Residual Value of System
E	-	Total Electricity / Energy Cost
W	-	Total Water Cost

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Global energy demands have increased exponentially due to the growing population and rapid urbanization. Additionally, it has been determined that commercial and residential buildings are the primary energy consumer, which accounts for 40% of the total energy. This trend is expected to increase by the year 2030, achieving an overall value of 50% (Hassan, Zin, Majid, et al., 2014). In Malaysia, approximately 13% of the total energy and 54% of electricity is consumed by buildings. The electricity consumption breakdown is summarized as shown in Table 1.1 (Hassan et al., 2014).

Table 1.1 Energy Consumption in Malaysia

Region	Industry (GWh)	Commercial (GWh)	Residential (GWh)	Transportation	Agriculture	Total
Peninsular	45,357	34,696	21,536	241	344	102,174
(Share, %)	44	34	21	0	0	100
Sarawak	5,554	2,026	1,657	-	-	9,237
(Share, %)	60	22	18	0	0	100
Sabah	1,504	1,923	1,516	-	-	4,943
(Share, %)	30	39	31	0	0	100
Total	52,414	38,645	24,709	241	344	116,353
(Share, %)	45	33	21	0	0	100

Source: Tenaga (Hassan et al., 2014)

Electricity is generally used for cooling, heating and lighting purposes for both residential and commercial buildings (Birkha Mohd Ali, Hasanuzzaman, Rahim, et al., 2021). Ihara, Gustavsen, and Jelle (2015) had identified that energy consumption due to cooling and heating comprises of 45% of the office buildings. It was also observed that cooling systems in residential buildings (Malaysia) consume more than 1500 kWh (n=243) of electricity annually as illustrated in Figure 1.1 (Kubota, Jeong, Toe, et al., 2011). The importance of cooling systems and their high energy usage due to Malaysia's hot climate is further discussed in a study conducted by Hassan et al. (2014). From here, it can be surmised that air conditioning and refrigeration systems (cooling) are two of the major electrical energy consumers in Malaysia.

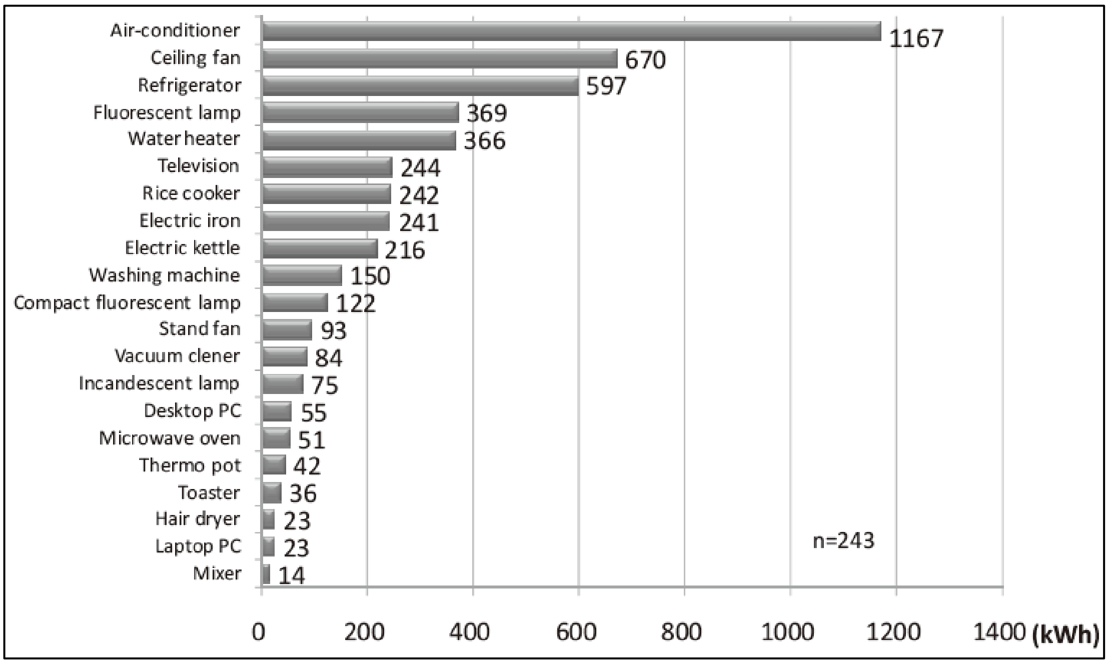

Figure 1.1 Annual Electricity Consumption for a Selected Study Area

Moving on, electricity is mostly generated through the burning of fossil fuels (coal, natural gas), which results to the release of greenhouse gasses (GHGs). Meanwhile, GHGs are the main contributor towards the increase of Earth's temperature. Therefore, the higher the electricity usage, the larger the amount of greenhouse gasses emitted, leading to a global warming crisis. In fact, Malaysia is currently listed as the 24th highest GHG emitter globally. As of today, a ductless split air conditioner is widely used in Malaysia. The operating principle of this system is depicted in Figure 1.2, where a refrigerant is utilized as its working fluid. It should be noted that many of the refrigerants used such as R410A and R22 tend to release hydrofluorocarbons (HFCs), a type of greenhouse gas (Saidur, Sattar, Masjuki, et al., 2009). In other words, a split air conditioning system is a perfect GHG emitting instrument.

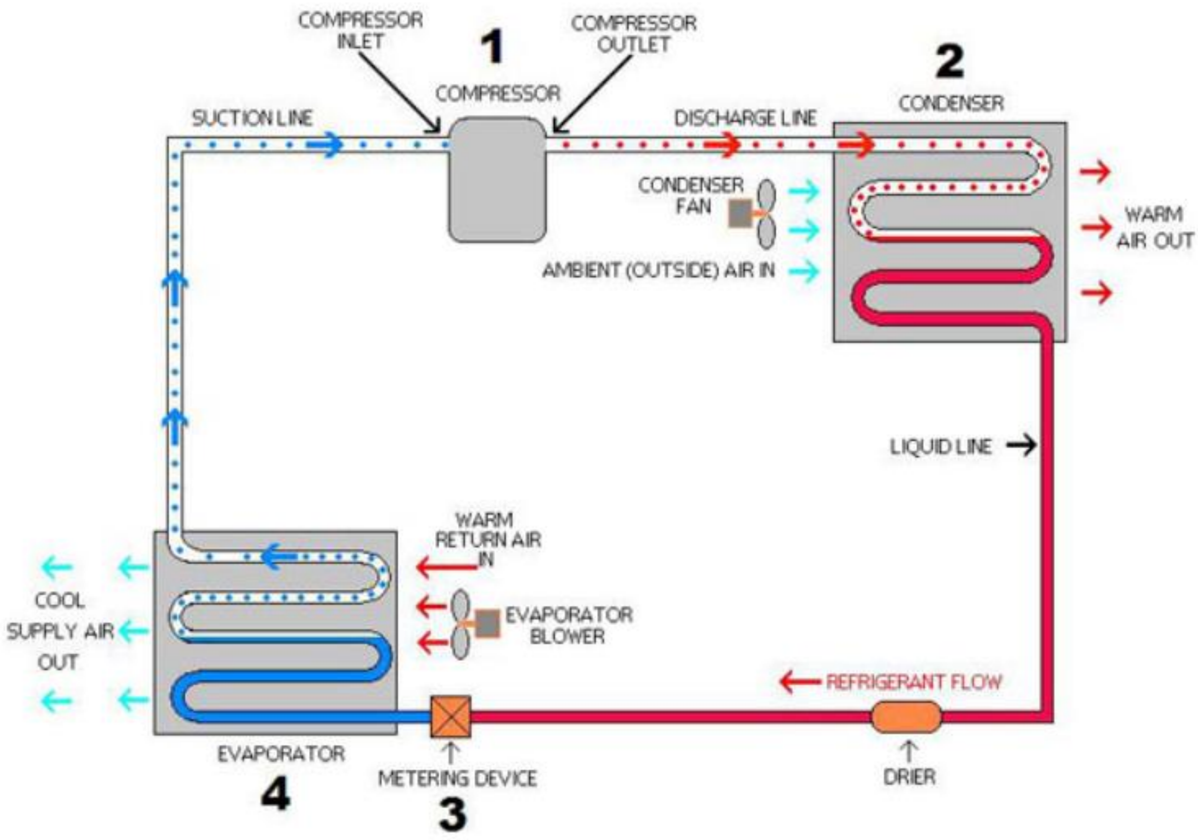

Figure 1.2 Split Air Conditioning System

Currently, there are 2 possible directions in combatting the above issue. The first is by minimizing heat gains and maximizing the application of natural heat sinks within a building itself (Karlsson, and Moshfegh, 2006). While, the second is to develop renewable energy technologies such as the solar absorption refrigeration system (SARS). SARS operates primarily on solar thermal energy and uses a GHG-free working fluid (e.g. water or lithium bromide). Therefore, apart from being a clean system, it is also suitable to meet the rising energy demands, particularly for space cooling. Despite this, SARS is not widely commercialized due to its poor cost and technical feasibility compared to a split air conditioning system.

1.2 Problem Statement

In Malaysia, solar absorption refrigeration system (SARS) is proven to be more expensive than a ductless split air conditioner, due to the number of components required, its complexity and the large investment cost incurred in setting up the solar thermal technology (Witmer, 2020). Yet, no methodology has been made to evaluate the techno-economic performance of a solar absorption chiller for different industry or building needs. In addition, the lack of studies comparing the feasibility of SARS against other conventional systems has denied this technology from gaining its well-deserved traction.

Next, the roof of a building is an important location used for the placement of solar collectors. Therefore, if the rooftop area is inadequate, it will affect the total heat generated and storage technology to cater for the maximum cooling load of a building. In fact, with the increasing debate between solar PV versus solar thermal, a comparison of both these technologies on the better use of roof space and energy production would be required. This would help to provide potential users with more options prior to investing their money and time.

Besides that, the intermittent nature of the solar thermal system prevents the continuous use of SARS during unfavorable weather conditions or at night-time, thus either requiring an electrical heater as a backup or a larger thermal energy storage (TES) system if an off-grid solution is desired by the user. This would then increase the overall cost and TES installation space (off-grid scenario). Moreover, the insufficient data pertaining to storage volume or space constraints for the Solar Absorption Refrigeration System (SARS) further adds to the complexity of this RE technology. From the above, several of the main challenges faced by SARS to achieve wide commercialization in Malaysia are thoroughly explained. Solutions to these challenges would be explored in depth through this research study.

1.3 Research Objectives

The primary objective of this research is to develop a numerical tool for evaluating the techno-economic feasibility of a solar absorption refrigeration system, which is to be implemented for space cooling within a commercial building in Malaysia. The sub-objectives of this tool can be broken down as below:

(a) Able to analyze and recommend viable design options for the solar absorption refrigeration system based on the data input provided (e.g. solar collector and absorption system's design parameters).
(b) To compare the solar absorption chiller with a ductless split type air conditioner (direct refrigerant) and a solar PV cooling system, in terms of their cost, greenhouse gas emissions, energy savings and installation space through the use of a case study.

1.4 Research Scope

The research scope includes:

(a) Performing a thorough literature review on various solar thermal technologies, absorption systems and the preferred cooling technologies in Malaysia, to determine the challenges that prevent the development of a viable solar absorption chiller in this country.
(b) Creating a numerical tool using the Excel programme to study the feasibility in implementing SARS for space cooling applications within commercial buildings in Malaysia. Hence, information such as electricity tariff, government incentives and policies would be based on this country.
(c) Gathering data on absorption systems, cooling loads, solar collectors, TES systems, solar irradiance, ambient temperatures and utility systems from online databases, literatures or technology suppliers as case studies to validate the effectiveness of the proposed tool.

(d) Identifying, analyzing and comparing the technical, commercial (e.g. the life cycle cost) and environmental aspects of the solar absorption chiller with both the direct refrigerant (split type) and solar PV powered air conditioning systems for a given study period.

1.5 Significance of Research

During the year 2018, the government of Malaysia made an important decision in the energy field by revising the National Renewable Energy Policy. Through this, Malaysia had set a new goal of achieving 20% renewable energy capacity mix by the year 2025 (SEDA Malaysia, 2019). Besides that, based on UNDP's sustainable development goal (SDG) 7 – affordable and clean energy, all participating countries are to actively invest in solar, thermal and wind energy, to improve energy productivity and ensure its accessibility to all.

Hence, in accordance with the above, this research study is performed to develop a new techno-economic tool in assessing the feasibility of SARS based on different user criteria (e.g. available installation space, on-grid / off-grid system, storage volume). Therefore, by using this tool, a solar absorption refrigeration system can be easily customized, leading to a reduction in cost and improving commercialization opportunities. Moreover, a thorough comparison with other cooling technologies further enhances the credibility of SARS. Finally, this research shall act as a mechanism towards enabling the optimal planning and establishment of the solar absorption refrigeration technology in Malaysia.

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Appendix A Numerical Program - EXCEL

Please refer to the EXCEL file, titled ***"Master Project_Rashvin Ravindranathan"*** for the developed Numerical Tool.