OPTIMIZING ALTERNATIVE WIND POWER FOR ENERGY EFFICIENT BUILDING DESIGN IN TROPICAL HOT-HUMID CLIMATE OF MALAYSIA

By

HIRDA LAILANI BINTI KHALID

Thesis submitted in fulfillment of the requirements
for the Degree of
Masters of Science

UNIVERSITI SAINS MALAYSIA

AUGUST 2012

ACKNOWLEDGEMENTS

Alhamdulillah, for the strength and courage You given me, this thesis finally has been completed in two years. Throughout the years, I have worked with a great number of people who have contributed in many ways. It is a pleasure to express my gratitude to those people in my humble acknowledgement.

Foremost, I would like to record my deepest gratitude to my main supervisor, Associate Professor Dr. Ar. Abdul Malek Abdul Rahman for his supervision, advice, and guidance from the very early stage of research through the entire period of study. As well as giving me the extraordinary experiences throughout the works that have been carried out. Above all, he has provided me encouragement and support in various ways. For that, I am indebted to him more that he knows.I would like to express my sincere gratitude to my co-supervisor, Dr. Yusri Yusup from School of Industrial Technology, USM for his great supervision and crucial contribution especially in technical part of research. I am truly grateful in every possible way and hope to keep our collaboration in the future.

Manythank our supplier and technical consultant, En. Mohd. Jamil Kassim and En. Muhd.Fadli Mohd. Tap from Kemuning Saintifik Sdn. Bhd for technical consultancy and material supply. Not forgetting, Mr. Chow Kok Chean from iWind Energy (M) Sdn. Bhd for his assistance and his valueable advice on VAWT used. I gratefully acknowledge the staffs of School of Housing, Building and Planning; En. Md. Noh Sohaimi and En. Zulkifli from HBP General Workshop and En. Faizal Md. Nasir and Ms. Nurandlia Mohamad Koldaie from Environmental Laboratory for their technical aid and collaborations while doing the experimental studies. Not forgetting, friends that contributed formal and informal in this research.

Special appreciation goes to USM Fellowship Scheme and Research Creative Management Office (RCMO) for the financial assistance and funding since 2010. Thank you for putting a trust and invested on this research.

Last, but not least, to **MY PARENTS**, there are always no perfect words to express my deepest gratitude on what you had given me. Therefore, beside the Almighty, the love in family bonding shows it all. **THANK YOU**.

TABLE OF CONTENTS

PART II- EXPERIMENTAL STUDIES

CHAPTER 3: RESEARCH METHODOLOGY

CHAPTER 4: RESULT AND DISCUSSION

LIST OF FIGURES

APPENDICES

A. Appendix A: Result of monitoring

B. Appendix B: List of publication

LIST OF TABLES

LIST OF PLATES

LIST OF ABBREVIATIONS

AC	Air-Conditioning
ACEM	Association of Consulting Engineers Malaysia
BAWT	Building-Augmented Wind Turbine
BIPV	Building-Integrated Photovoltaic
BIWT	Building-Integrated Wind Turbine
CFC	Chlorofluorocarbons
CH_4	Methane
CO	Carbon Monoxide/ Carbon Oxide
CO_2	Carbon Dioxide
EE	Energy Efficiency
EERE	Energy Efficiency and Renewable Energy
GBI	Green Building Index
GHG	Greenhouse Gases
HAWT	Horizontal-Axis Wind Turbine
HBP	School of Housing, Building and Planning
HCFC	Hydrochlorofluorocarbons
HFC	Hydrofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
IPS	Institute of Postgraduate Studies
LWSWT	Low-wind Speed Wind Turbine
NEP	National Energy Policies
NO_x	Nitric Oxide/ Nitrogen Dioxide
PAM	Pertubuhan Akitek Malaysia/ Malaysian Institute of Architects

RE	Renewable Energy
RES	Renewable Energy Sources
SO_x	Sulfur Oxide
UHI	Urban Heat Island
VAWT	Vertical-Axis Wind Turbine

LIST OF SYMBOLS

rpm	Rotation per minute
V	Voltage (Volts)
P	Power (Watt)
I	Current (ampere)
R	Resistance (Ohm)
f	Frequency (Hz)
C_p	Coefficient of wind turbine performance
ρ	Air density
A	Swept area of the blades (m^2)
v	Wind velocity (m/s)

MENGOPTIMUMKAN TENAGA ANGIN ALTERNATIF BAGI REKABENTUK BANGUNAN BERKECEKAPAN TENAGA DALAM IKLIM PANAS LEMBAP TROPIKA DI MALAYSIA

ABSTRAK

Terletak berhampiran garisan Khatulistiwa, Malaysia mempunyai kelebihan besar iaitu tenaga solar di mana kebanyakkan kita menggunakan kelebihan tersebut dengan menjana elektrik menggunakan panel fotovoltaik. Walau bagaimanapun, angin di Malaysia adalah terhad, tidak tetap dan sering tenang menyebabkannya tidak boleh disandarkan sebagai tenaga alternatif dan untuk digunakan sebagai pengudaraan semulajadi ruang dalaman bangunan. Oleh itu, kebanyakkan rakyat Malaysia menggunakan sistem penghawa dingin untuk mencapai keselesaan terma dan secara tidak langsung menghindari pencemaran udara. Bangunan moden yang berpenghawa dingin secara keseluruhannya akan menyebabkan fenomena pemanasan bandar atau *"urban heat island"* (UHI) di mana fenomena umum ini menyebabkan suhu bandar-bandar besar adalah lebih tinggi berbanding kawasan luar bandar, lantas menyumbang kepada masalah pemanasan global. Darip dibiarkan terbazir, gas ekzos yang dikeluarkan daripada unit kondenser alat penghawa dingin yang kebiasaannya terletak di kawasan luar bangunan berpotensi sebagai sumber alternatif untuk menjana tenaga angin. Sumber ini adalah cukup untuk menjana tenaga elektrik melalui penggunaan turbin angin menegak berskala kecil. Turbin ini terkenal dengan dengan ciri-ciri *"omni-directional"* yang menjadikannya jenis yang paling sesuai untuk digunakan di kawasan angin berkelajuan rendah. Kebanyakkan angin ekzos daripada unit kondenser mempunyai halaju lebih daripada 5.0 m/s dan amaun tersebut sudah cukup untuk menjana elektrik

mengikut kajian literasi yang telah dibuat. Melalui kondenser yang telah dipilih, dengan halaju diantara 8.0 m/s hingga 9.0 m/s, sebanyak seminimum 87.0 Watt dijangka dapat dijana mengikut spesifikasi yang telah diberikan oleh pihak pengilang. Sebagai ahli di dalam Protokol Kyoto, ia adalah inisiatif Malaysia untuk meneroka tenaga alternatif ini dalam segala bentuk yang mungkin. Oleh itu, kajian ini dijalankan bagi meneroka sejauh mana angin atau pergerakan udara dapat menyumbang dan dapat digunakan dengan lebih baik bagi kawasan angin berhalaju rendah seperti Malaysia.

OPTIMIZING ALTERNATIVE WIND POWER FOR ENERGY EFFICIENT BUILDING DESIGN IN TROPICAL HOT-HUMID CLIMATE OF MALAYSIA

ABSTRACT

Located near the Equator, Malaysia has a great advantage of solar energy as it abundantly available and people making use of it using solar photovoltaic to generate electricity. Malaysian wind however is light, variable and calm making it unreliable as an alternative energy and too low to naturally ventilate indoor spaces. As the result, most Malaysians resorted to use air-conditioning systems to achieve thermal comfort thus avoiding polluted air. The modern fully air-conditioned buildings are creating urban heat islands hence contributing to global warming. Instead of being wasted, the exhaust air releases from the condenser unit located outdoor is potentially becoming the alternative source in wind power generation and sufficiently generates power using the small-scale Vertical-axis Wind Turbine (VAWT). It is a well-known type for its *Omni-directional* character which is the most suitable type to be used in low-wind speed condition. Most of exhaust air of condensers that have been measured are more than 5.0 m/s and it is sufficient to generate electricity according to literature review. The chosen condenser which has wind velocity in ranges of 8.0 m/s to 9.0 m/s is expected to generate a minimum power of 87.0 W as referring to specification from the manufacturer. As a member of Kyoto Protocol, it is one of Malaysia's initiatives to explore whatever form possible as an alternative energy to meet the protocol requirements. Therefore, this research explores to what extent can wind or air movement be contributively and be better utilized in the low-wind speed regions such as Malaysia.

CHAPTER 1: INTRODUCTION

1.1 ISSUES AND PROBLEM STATEMENTS

1.1.1 Global warming and climate change

Climate change is defined when there is a change in the state of the climate that can be identified by changes of weather conditions persisting for extended period mostly attributed from human activities direct or indirectly (IPCC, 2007). The evidence shows the average global temperatures increasing moderately with significant amounts since the 20th Century (Time for Change, 2009; Pitts, 2004). It was first identified in the 1960s and people are struggling to sustain the world with whatever solutions that are left.

One of the major causes of global warming is the excessive emission of global greenhouse gases (GHGs). GHGs contain gases such as CO_2 and CH_4 which have the ability to trap excessive sunlight which increases the global temperature. This scenario is similar like a glass dome that traps some amount of gases; therefore it also has been referred as "Greenhouse Effect" (Gervokian, 2006).

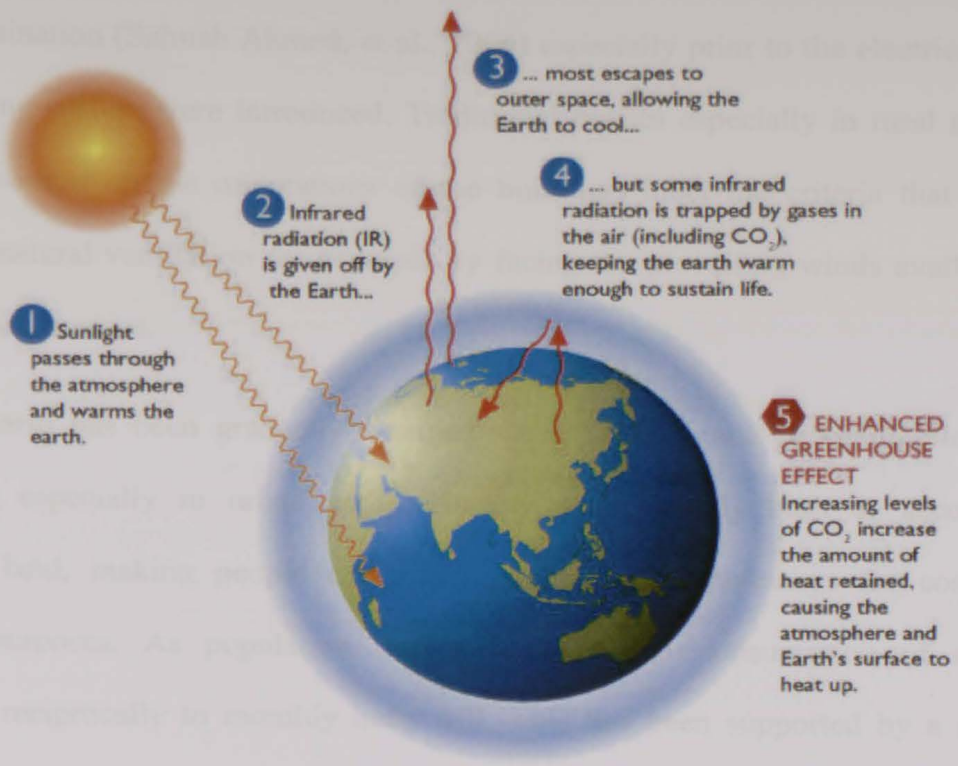

Figure 1.1: A diagram on how greenhouse effect is created (NSW Gov., 2011)

1.1.2 Malaysia climate and the use of air-conditioning systems

Being located near the Equator (4° 0' 0" N / 102° 0' 0" E) Malaysia's weather is classified as hot-humid Equatorial (www.met.gov.my, 2009). It is well-known for the extreme weather which is hot and humid throughout the year with copious of rain. The availability of light winds, year-round warm and pleasant weather with constant temperatures and high humidity make outdoor living is much desirable decades ago (Furturarc, 2010). Therefore, people rely solely on natural ventilation for comfort purposes by having many openings in their houses such as doors and windows in the living rooms, a chimney in the kitchen, and slits near the roof to allow air circulation and

also illumination (Salmah Ahmed, et al., 2006) especially prior to the electrical lighting and cooling system were introduced. Traditional houses especially in rural areas were built by setting up the orientations of the buildings meet the criteria that favor the effective natural ventilation for example by facing the prevailing winds available from land and sea breezes.

This scenario has been gradually changed when land is now becoming limited and expensive especially in urban areas. Houses were densely built to accommodate available land, making people depending on electrical appliances for cooling and lighting purposes. As population grows, demand and consumption of electricity increased reciprocally to monthly hefty bill. This has been supported by a statement from Buttgen (2002), a General Manager of Copthorne Hotel, Tanjung Bungah, Penang in which the air-conditioning solely takes up nearly 70% of the electricity bill in most hotel buildings. Moreover, according to Yeang (1999), a notable Malaysian architect in green building, the modern fully air-conditioned high rise buildings are consumed more than 75% of the total energy consumption.

When most people resort to use air-conditioning systems to cool the buildings, this will aggravate the environment that leads to urban heat island. Malaysia has been experiencing a dramatic increase in usage of air-conditioning which is expected to be higher in the future (Mahlia, 2001; Masjuki, et al., 2001) thus resulting the heat-island intensity in selected cities in Malaysia in the ranges from 2 K to 7 K (Sham, 1991). Heat-island intensity is a measure of the magnitude of urban heat island (Voogt, 2004) that can be higher during the day due to solar heating.

Buildings are responsible for producing over half of all climate change emissions (Roaf, et al., 2005) with 25% globally and 50% for individual countries. The modern fully air-conditioned building that is known as the late 20th century phenomenon, is increasing the cities temperature and becoming urban heat islands. The CO_2 emissions from air conditioning systems have become one of the largest driving forces for climate change around the world (Roaf, et al., 2005) and it has been increasing since the 1980s (EIA, 2006). Thus, the IPCC has been targeted and indicated that building-related emissions could be reduced by about 40% by 2010, and by about 60% by 2020 by using market encouragement and taking a longer term view, the savings from reduced fossil fuel use will outweigh the costs of implementing measures (Pitts, 2004).

Air-conditioning can be referred as self-contained electromechanical devices that cooling the space by providing conditioned air (Gevorkian, 2006). The process is accomplished when energy is added through electricity of natural gas combustion or other energy sources (Hinrichs, 2006). As shown (Fig. 1.2), air-conditioning is a process when air out-side the building inclusive of air discharged from the exhaust is sucked and cooled before being discharged into the occupied space. Exhaust air which contains heat and *Hydrofluorocarbons* (HFCs) or *Hydrochlorofluorocarbons* (HCFCs) or *Chlorofluorocarbons* (CFCs) will be released through the condenser unit that located outside the building. Previously, air-conditioning systems contained CFCs that were harmful and endangering the ozone layer. Currently, with introduction of new refrigerants HFCs which is more environmental-friendly had effectively reduced ozone depletion but there are many systems still use HCFC refrigerants that contribute to depletion of the ozone layer.

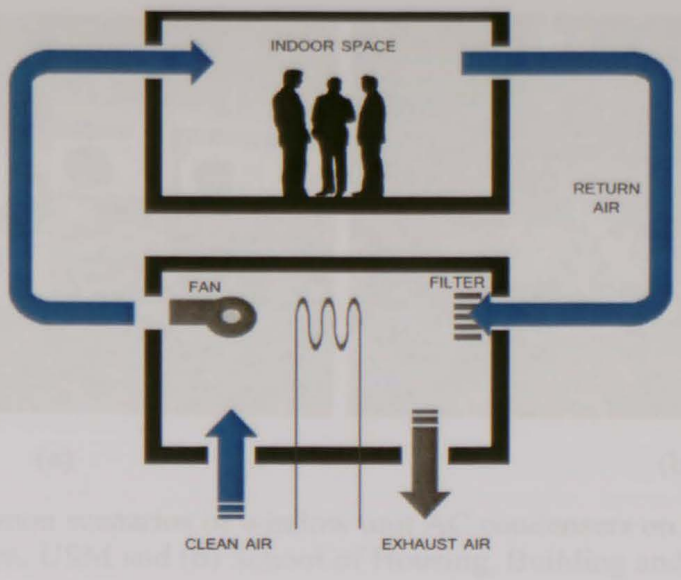

Figure 1.2: The cycle of exhaust air in an air-conditioning condenser unit

The ugly scenarios from the use of window unit AC systems on the building facades can be seen as showed in Plate 1.1. It normally will destroy the building aesthetical value if the juxtaposition of the condensers is not proper integrated with building design. If the condensers are properly integrated with the building design to maintain the aesthetical façade, wastage of the exhaust air can be tapped to generate wind power by small-scale vertical-axis wind turbine (VAWT). Since natural wind is very limited and unpredictable in Malaysia, this research has a wide potential as a pilot study in optimizing wind power in low-wind speed areas by using alternative way.

(a) (b)

Plate 1.1: The common scenarios of window unit AC condensers on building facades at (a) Dewan Budaya, USM and (b) School of Housing, Building and Planning, USM.

Optimizing the use of alternative energy is one of the main solutions to global warming issue of which many energy policies have been structured. As one of the members of Kyoto Protocol, it is Malaysia's initiatives to reduce global warming based on indigenous resources. Even though the Kyoto target is a relatively small step but it is considered as the first step on a 'ladder of change' (Stankovic, 2009) that moved the world to battle the major problem.

1.1.3 Renewable energy scenarios in Malaysia

Renewable energy (RE) refers to energy resources that occur naturally and repeatedly in the environment and can be harnessed for human benefits (Baharuddin Ali, et al., 2008). The new renewable energy is often based on indigenous resources, has the potential to provide energy services with low or zero emissions of both pollutants and greenhouse gases (Abmann, et al., 2006). Electricity derived from any renewable energy source

(RES) is considered "green" because of the negligible impact on greenhouse gas emission (Rahman, 2003). However, the potentiality to build up or develop the new renewable energy system is different to specific region due to its own location and climatic or weather characteristics.

There has been increased interest in using RE technologies in the urban environment as the directive target has been set up to supply electricity generation by renewable sources, especially after successfully achieved by the Europeans (www.awea.com, 2010). Renewable energy holds the key to future prosperity and a healthy global environment, thus it is considered as a promising way to solve the problem of environmental pollution (Himri, et al., 2008) such as major environmental accidents, water pollution, and maritime pollution. Therefore in Malaysia, besides solar energy, the use of other energies should be emphasized to solve the environmental problems.

For the past few decades, Malaysia has already started implementing new technologies to discover its potential of renewable energy (Siti Khadijah, et al., 2009). RE in Malaysia is still at infancy stage because it has not been commercially explored and implemented by all Malaysian. One of the reasons of this major problem is lack of local expertise, spare parts availability, transportation and inefficient energy management. Therefore, energy policies and regulations should play the important role in achieving the goal of sustainable development in Malaysia. According to the 8th Malaysian Plan (2001-2005) and the Ninth Malaysian Plan (2006-2010), Malaysia is targeting for renewable energy to be significant contributor and for better utilization of energy resources (Zuhairuse, et al., 2009). Thus, The National Energy Policies (NEP) has been

created to guide our future energy sector development based on supply, utilization and the environment.

1.2 RESEARCH OBJECTIVES

Several objectives have been designated to prove the applicability of the hypothesis structured based on the issues discussed earlier. These objectives hold the key of this qualitative study that mostly focused on experiments.

1. To investigate the applicability of VAWT in harnessing exhaust air of air-conditioning condenser unit.
2. To test the efficiency performance of vertical-axis wind turbine (VAWT) in low-wind speed condition that already available in the local market.
3. To prove that exhaust air of air-conditioning system can be an alternative source for low-wind speed condition, thus potentially substituting the unreliable natural wind.
4. To suggest architectural design solutions on integrating or retrofitting the technology to the existing buildings that used air-conditioning systems.

1.3 HYPOTHESIS AND RESEARCH QUESTIONS

Hypothetically the exhaust air releases from condenser unit could be sourced to generate sufficient amount of electricity that can be harnessed by using the small-scale vertical-axis wind turbine (VAWT). Potentially it becomes one of the alternative sources in

optimizing wind power in low-wind speed regions. The limited studies carried out on wind power generation in low-wind speed region were inconclusive, thus require further investigation. Therefore, four research questions have been stipulated as a guideline in achieving the research objectives:

- Q1: Is wind velocity of exhaust air from the standard size condenser sufficient enough as start-up wind speed and cut-in wind speed for the small-scale VAWT?
- Q2: Does the chosen VAWT performs accordingly to manufacturer's specifications under real condition?
- Q3: What are the characteristics of exhaust air distribution that affect wind velocity in generating wind power?
- Q4: How to apply wind power application on building façade of existing and new building?

1.4 RESEARCH SCOPE

This research focuses on the study of possibilities of wind power in Malaysia which consist the basic principle of wind energy, the potential of wind power in Malaysia, and wind power technology and its application in low-wind speed condition in order to harness wind as alternative energy to be used in energy efficiency building design. Therefore, there are two types of wind that have been studied in this research; natural wind (Part 1: Theoretical Studies) and fan driven (Part 2: Experimental Studies).

Malaysia is targeting the use of renewable energy by National Policy designated by the government. It is one of the ways to achieve the Kyoto Protocol requirements. Besides solar energy, other renewable energies such as wind energy, biomass, tidal energy, hydro energy and geothermal energy should be optimized as well. In this thesis, wind energy is chosen as alternative energy from issues and literature review done in previous section.

Instead of relying on unreliable natural wind, optimizing wind power in Malaysia can be done by alternative way. Exhaust air from AC systems has been hypothesized to be contributing as alternative source in harnessing wind power. The methods done in experimental study are explained in detail in Chapter 3. The results obtained in experimental study are applied in building designs and will be shown in conceptual diagrams at the end of discussions section in Chapter 4.

It is humbly to acknowledge that this research has not been similarly done by any other researchers based on the thorough literature review collected earlier, therefore it is hard to set the benchmark of this research due to the lack of references on the same topic. The methodology structured in this research is the hybrid methods on the researches done on harnessing wind power from natural wind on potential locations and the laboratory tests on aerodynamic systems.

1.5 SIGNIFICANCE OF STUDY

The study on optimizing wind power for energy efficient building design in low-wind speed condition of Malaysia is significant for several reasons:

- This study responds to the Kyoto Protocol (2002) and Malaysia's Energy Policy starting in the 8th Malaysia Plan (2001-2005), further emphasized by 9th (2006-2010) and 10th National Plan has taken several initiatives to explore and promote the use of renewable energy (RE) as alternative source (Lim, et al., 2006). Under the Energy Efficiency in Commercial Buildings (MS1525), energy efficiency (EE) in built environment has been emphasized (GBI, 2009).
- The integration with building designs is important to promote new architectural term, Aerotecture especially in tropical region. It is defined when the building designs incorporate wind power from the early stage of designing. It is important in commercialization of wind turbine applications on different types of buildings. Furthermore, this study responds to the Green Building Index (GBI) that launched by the Malaysian Institute of Architects (PAM) and the Association of Consulting Engineers Malaysia (ACEM) on integrating energy efficiency (EE) effort in Malaysian buildings by using rating systems based on several criteria (GBI, 2009).

CHAPTER 2: REVIEW OF LITERATURE

2.1 INTRODUCTION

Wind power generation in Malaysia can be considered as a new technology and still in explorations. Lack of technology and references on wind power are due to the unreliable and limited amount of promising wind. Lots of studies have been done by the Westerners but in tropical regions like South East Asia, the studies and available technologies are lagging. The limited studies available were not comprehensively meticulous and supported by research papers to address the shortcomings. Therefore, this chapter discusses and reviews the related literature by analyzing and exploring the alternative way in optimizing wind power in Malaysia.

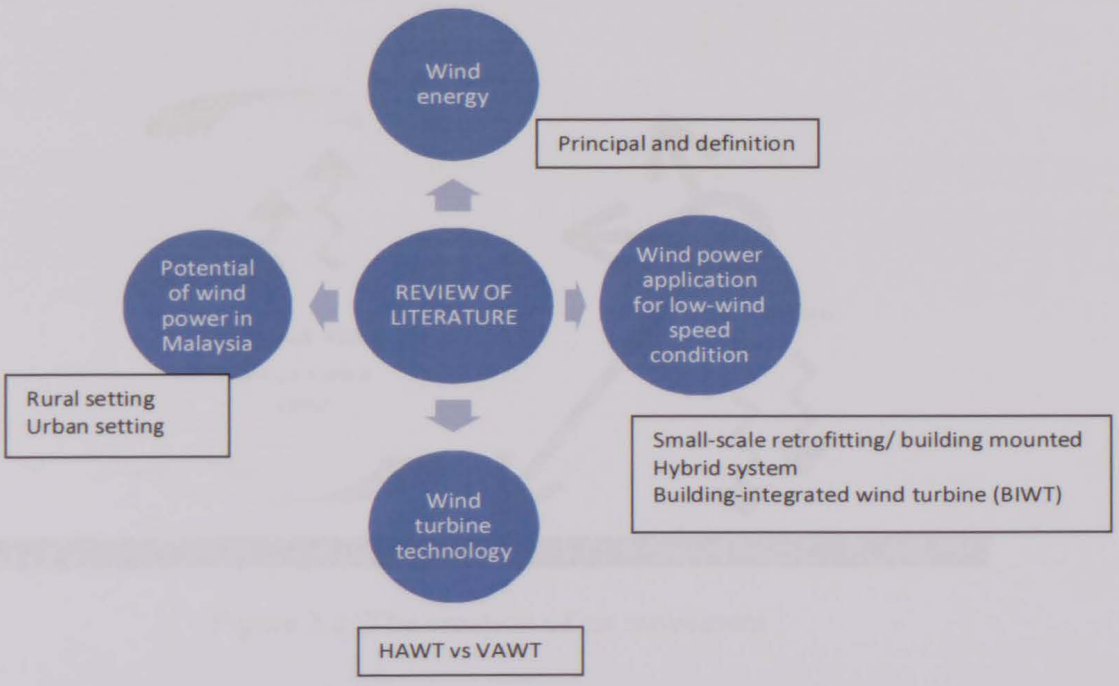

Figure 2.1: Figure of related issues on literature review

2.2 WIND ENERGY

It is imperative in exploring wind power technology to generate wind power, the basic principles of wind energy on how wind is created needs to be understood. Wind is an ancient source of energy created when air moves from an area of high pressure to an area of low pressure. It is a converted form of solar energy as the sun unevenly heats directly the surface of the earth most notably during the day and indirectly at night but also when two different surfaces such as water and land absorb or reflect the heats at different rates (Gevorkian, 2006) (Fig. 2.2). The hot air rises due to this phenomenon and cooler air moves in to fill the void in which it creates the wind. As long as the sun shines, the wind will blow and people will harness it to power their lives (National Geographic, 2009).

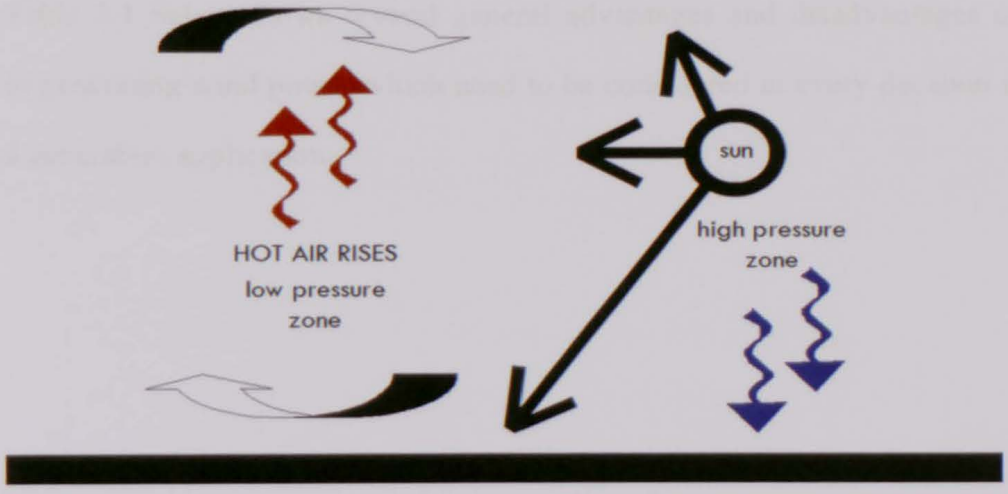

Figure 2.2: The creation of air movement

Even though human being has taken the advantages of wind power for centuries since the ancient civilization of Egypt (proven when people used sail to navigate the Nile River) (www.altenergy.org, 2010), but it generally has been improved significantly since 1970 to generate electricity as a reliable and consistent power (Ackermann & Soder, 2002). Currently, people are aware that wind power is one of the promising new energy sources that can serve as alternative to fossil fuel-generated electricity. Wind power is one of the most environmentally benign sources of energy which does not emit pollutant. According to EERE (2008) wind energy represents as one of the growing renewable energy markets that can add up to its advantages.

Unfortunately, wind is naturally unpredictable and inconsistent energy source compared to other renewable energies such as solar and hydro energy. The unpredictable character of wind is one of the greatest challenges of wind power generation (Gitano-Briggs, 2007). Table 2.1 below shows several general advantages and disadvantages of wind energy in generating wind power which need to be considered in every decision making for wind generation application.