AIR-CONDITIONI ULTANEOUS CONTROL OF SE HEAT FOR BUILDING ENERG MALAYSIA

A dissertation

by

AZIZUDDIN BIN ABD AZIZ

Submitted in fulfillment of the requirements for the degree of

DOCTOR OF ENGINEERING

Graduate School of Human-Environment Studies

Kyushu University

2014

Abstract

Buildings in tropical countries such as Malaysia are exposed to excessive amount of solar heat during daytime occupancy. In addition to that, the outdoor air contains excessive humidity due to the nature of the climate. Air-conditioning system is the main energy consumer of the buildings, more so with the requirement of the full 12 months cooling period in the country. The increasing demand of energy due to its status as a developing country puts Malaysia in a critical situation in terms of building sustainability. Another quandary associated with tropical environment is the indoor thermal comfort due to the high humidity. The usage of normal air-conditioning system means that the room has to be overcooled in order to bring down the humidity. Unfortunately, the low temperature set-point technique is neither comfort cautious nor energy friendly. There is an option to solve the humidity problems by the use of the outdoor air treatment system which neutralizes the incoming fresh air into the room. However, high equipment cost renders the system unfavorable in Malaysia. Therefore, the viable solution to the high latent load requires an innovative system that is affordable, runs at relatively low energy consumption yet be able to provide satisfactory indoor thermal comfort. In the research, a new air-conditioning approach termed Dual AHU (air handling unit) system is proposed to be the answer. The simplicity in arrangement and control setup ensures that the system can be reasonably priced. On top of that, it can be designed as an add-on configuration to the existing air-conditioning. The function of Latent AHU in the proposed system is to remove moisture from the conditioned room up to the desired humidity level and in the process the room temperature is also fractionally reduced. The Sensible AHU completes the task by removing the remaining sensible heat so that the room temperature is maintained at the required set-point. By reducing the relative humidity to 50%, a much lower value than that of the normal air-conditioning could offer, room temperature of the new system is shifted higher to 26°C in order to reduce the energy consumption. However, thermal comfort of the occupants has not been compromised. The performance of the proposed system is evaluated through simulation approach. The result shows that the new system could offer energy savings of between 10.2 to 13.6% in constant-air-volume configuration and between 10.7 to 13.2% in variable-air-volume configuration compared to normal air-conditioning system. The procedure to design of the proposed system using manual calculation and psychrometric chart is also being clarified. In addition, the possibility to retrofit the new system into existing air-conditioning system is explained at the end of the research.

Table of Contents

Chapter 5
Performance of the Proposed Air-conditioning System

Chapter 6
Design Method

Chapter 7
Conclusion

List of Figures

List of Tables

CHAPTER 1

Introduction

1.1 Overview of Malaysian energy scenario

As one of the leading developing countries in Asia, Malaysia's urban growth is on the rise and could be physically seen by the rapid increase of rural buildings and premises in the cities across the nation. In the middle of the 80's, the country has taken a major step by switching from its traditional agricultural income to industrial sector to boost its economy. Figure 1.1 shows the gross domestic product (GDP) of Malaysia since the year 2000 [1]. The establishment of Asean Free Trade Zone is another factor of economic rise in South-east Asia.

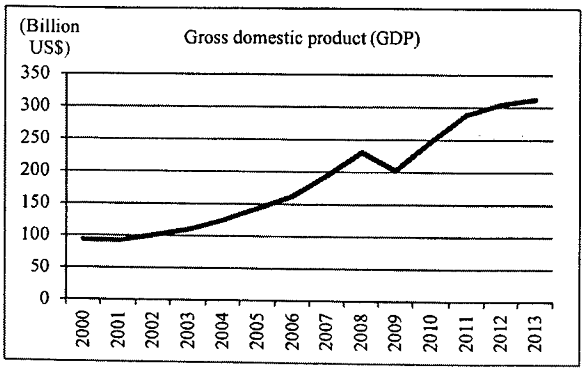

Fig. 1.1: GDP of Malaysia

The rise in economy brings another development in terms of population. Figure 1.2 shows the population growth in Malaysia. With better household income, the size of family has increased as a higher standard of living seems affordable to the masses. As of 2013, the population has clocked 29.7 million [2].

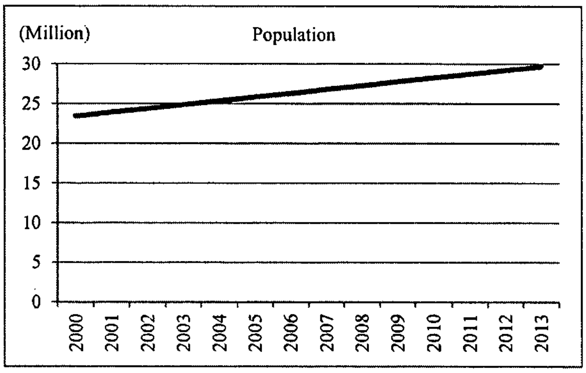

Fig. 1.2: Population of Malaysia

However, the nation's economy development has resulted in the increase of energy consumption of the whole country as well. There are growing concerns amongst the public about the energy use in Malaysia and its implications to the environment. The country is indeed in a critical situation in terms of building sustainability. As the air-conditioning system is the main energy consumer of office buildings, it is important to find new methods to reduce its energy consumption. In order to tackle this issue, the implementation of effective energy conservation and management system needs to be carried out accordingly. Also, efforts are greatly needed to reduce the energy demand through innovative strategies.

The overall energy consumption for Malaysia is shown in Figure 1.3 [3]. It is observed that since 1980, the rate had increased steadily until the last report of 2012. In other words, the people of Malaysia are consuming more and more energy at a higher rate than before. This scenario is due to the attempt of reaching a higher standard of living among the occupants. Actions must be taken to curb this trend as it will increase the level of carbon dioxide emission in the country as well.

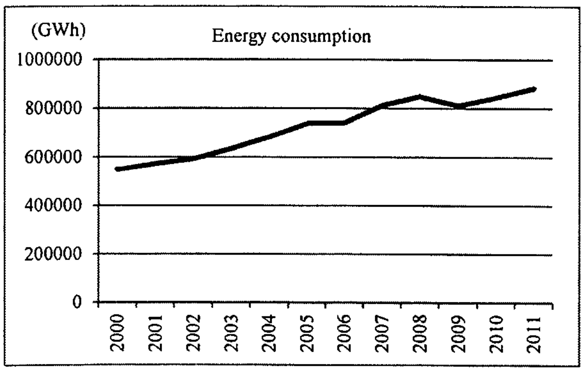

Fig. 1.3: Energy consumption of Malaysia

Another useful indicator of energy use is the office and residential buildings consumption in the country as shown in Figure 1.4 [3]. Obviously the demand for energy supply from building sector has also intensified in Malaysia. While it is understandable that a developing nation should have an increasing trend of energy usage, attempts should be made to reduce the rate of increase as low as possible. In addition, as the air-conditioning system is certainly the main consumer of energy in these buildings, the focus on maintaining building sustainability through efficient air-conditioning system should always be the main agenda. Hence it is very important to consider new measures for energy conservation in the country.

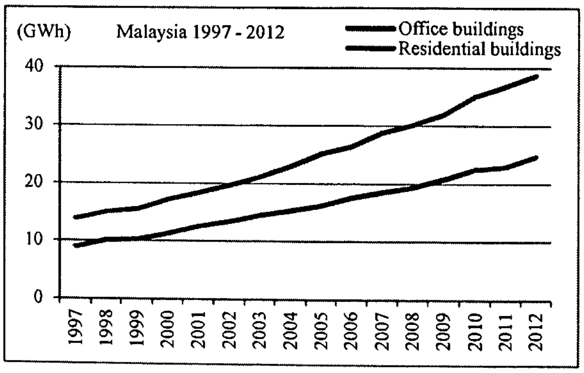

Fig. 1.4: Building energy consumption

1.2 Impact of indoor temperature to building energy consumption

The indoor temperature of most office buildings in Malaysia reveals a concerning scenario. The measured indoor temperature presents a relatively low value based on observation reports [4-5]. The findings revealed that the general temperature set-point is around 22-23.5°C which in turn gives a measured relative humidity of around 45-65%. The cause of problem is the typical design of air handling unit being used in most premises that does not dehumidify enough moisture unless the temperature is brought down to a low set-point. The low temperature set-point of air-conditioning system is one of the reasons of high building energy consumption.

1.3 Indoor thermal comfort of tropical buildings

Tropical climate or equatorial climate usually found very close to the 0° equator line. As shown in Figure 1.3, the climate is located in South America, Central Africa and Southeast Asia. Malaysia is one of the countries experiencing tropical climate which is hot and humid throughout the year.

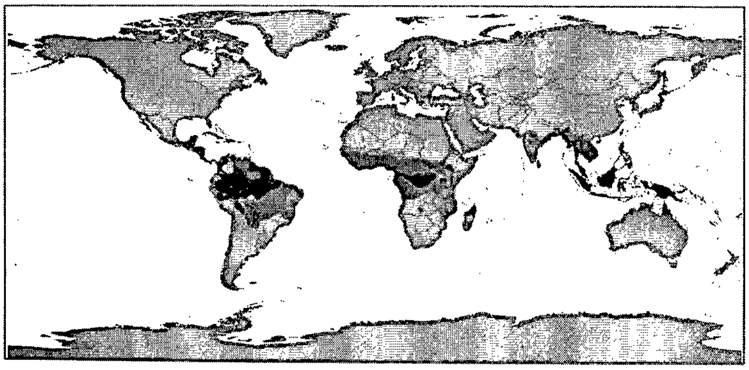

Fig. 1.3: Tropical climate of the world [6]

Figure 1.4 shows the outdoor condition of Kuala Lumpur [7]. The Malaysian temperature has a relatively low fluctuation and settles around 31°C while the relative humidity is rather consistent and averages around 75%. Apparently, there is no winter season in the climate.

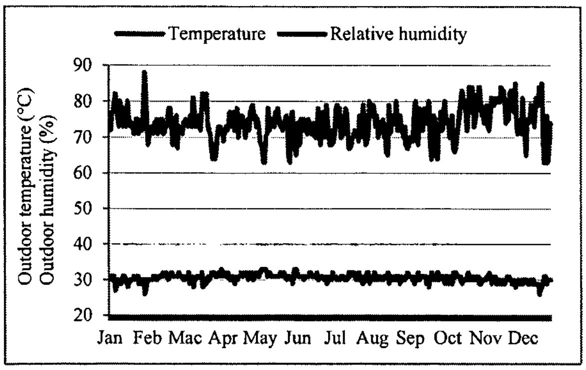

Fig. 1.4: Outdoor condition of Kuala Lumpur

In short, buildings in the country are exposed to excessive amount of solar heat during daytime occupancy. In addition to that, the outdoor air contains excessive humidity due to the nature of the climate, more so with the requirement of the full 12 months cooling period in the country. Due to the high humidity condition, it is a customary practice for the air-conditioning temperature to be set at a relatively low value in order to increase the dehumidification rate. As a result, cold indoor condition occurs which causes the occupants to feel thermally uncomfortable inside the buildings.

The high humidity has an adverse effect to thermal comfort as the human body normally cools itself by perspiration. The evaporation process absorbs heat from the body. However, a higher relative humidity reduces the evaporation rate because of the higher vapor content. In tropical countries such as Malaysia, human sweat will only evaporate into the air at a relatively low rate. As a result, one will feel much hotter than the actual temperature. In office buildings, the unsatisfactory condition of thermal comfort would affect the occupant productivity, which will have a direct impact on the nation development.

Meanwhile, the research on thermal comfort in Malaysia has been reported several times in the past. Basically, the study was on the satisfaction level of the occupants in office buildings based on thermal key parameters. Most of the reports brought up the issues of low temperature set-point in the rooms. Sometimes, the chilling situation was unbearable to the occupants that they requires additional layer of clothing to warm themselves.

It is surprising to find out that the research pertaining to humidity comfort is lacking in Malaysia. Almost all of the thermal comfort investigation was mainly focused on indoor temperature while giving little attention in humidity. As a result, no data is available on neutral humidity value and its comfort range. The lack of research reflects the low level of awareness in Malaysia on humidity comprehension. The explanation on the low temperature set-point is much to do with the humidity level in the room. The humidity is too high inside the building that the temperature has to be set to a very low value. By utilizing such technique, the humidity level is brought down and the damp condition is eliminated. But the consequence is that the room is overcooled and it affects the indoor thermal comfort.

1.4 Cost of existing dehumidification system

The effort to overcome humidity problem leads to the innovative method of separate latent cooling. Outdoor air treatment system is a proven design to overcome the humidity challenge by curing the ventilation air separately before it enters the condition room [8-9]. While the system is certainly effective in doing its job, one thing that provides a huge drawback is the equipment cost. The multi-mechanism that exists in the desiccant system renders high initial expense from the procurement point of view. Unlike normal air-conditioning setup, the outdoor air treatment system consists of equipment and sub-components that is unfamiliar to most installation service provider in Malaysia. As a result, the erection process requires a relatively higher budget than that of normal air-conditioning. The high price tag associated with the system may still be affordable to the building owners in developed countries. But for the investors in currently developing nations such as Malaysia, extra financial provisions for the initial cost is a major concern thus causing the outdoor air treatment system unfavorable.

1.5 Past research on building energy conservation

Attempts to reduce building energy have been initiated for decades. For instance, Mosolly et al. [10] examined the optimal control strategies of variable air volume air-conditioning system. The optimization problem for each control strategy was formulated based on the cost of energy consumption and constrained by system and thermal space transient models. Simulation results indicated that 30.4% of energy savings could be achieved. The popular method of desiccant cooling has developed numerous enhancements in order to refine the system. Kinsara et al. [11] proposed the $CaCl_2$ solution to be used as the liquid desiccant. The moist solution leaving the dehumidification packed bed was dried or re-concentrated in another packed bed, called the regeneration packed bed, and then recirculated back to the dehumidification packed bed. Simulation results showed that the proposed system consumed only about one third of the energy used by a conventional air-conditioning system.

On the other hand, Niu et al. [12] researched the possibility of combining the desiccant cooling with chilled-ceiling system. With such combination, temperature and humidity control were decoupled by using desiccant wheel for moisture removal and ceiling panels for temperature control. Simulation results indicated that the proposed system could save up to 44% of primary energy consumption compared to conventional constant-air-volume type of air-conditioning system. Innovative design of desiccant system leads to the creation of a hybrid design by Ghali [13] as the regenerative heat needed by the desiccant wheel was partly supplied by the condenser dissipated heat while the rest was supplied by an auxiliary gas heater. Simulation results revealed that the new system could offer a savings of US$418.39 for a gas cost price of US$0.141/kg. The payback period appeared to be less than 5 years. Mumma [14] took the initiatives to study outdoor air pre-conditioning equipment that utilizes passive desiccant wheels, sensible heat exchangers and deep cooling coils. The dedicated outdoor air system was then compared to 5 other configurations. Simulation results clearly showed that the proposed system could offer significant energy savings compared to conventional air-conditioning.

Another relatively new type of air-conditioning system is the variable refrigerant flow (VRF). Zhou et al. [15] developed a new module of VRF and compared its performance against variable-air-volume system and fan coil plus fresh air system. The results through simulation of EnergyPlus program showed that the VRF was able to achieve up to 22.2% of energy savings. Rodriguez Hidalgo et al. [16] carried out an experimental research on solar absorption cooling. An experimental facility with 50 m^2 flat plate solar thermal collectors had been developed for housing air-conditioning application using $LiBr/H_2O$ absorption technology. The results showed that the setup could save the energy cost of 62% compared to normal air-conditioning.

The optimal control strategies for variable speed pumps with different configuration have been investigated by Ma and Wang [17]. The sequence control strategy determines the optimal number of pumps in operation taking into account their power consumptions and maintenance costs. The speeds of pumps distributing water to terminal units were controlled by resetting the pressure differential set-point using the online opening signals of water control valves. The speeds of pumps distributing water to heat exchangers were controlled using a water flow controller. The results showed that up to 32% of pump energy could be saved by the optimal control. Another optimization study of distributed energy resource systems was carried out by Gao et al. [18]. The selected systems were photovoltaic, solar water heating and fuel cell. A genetic algorithm was optimized with the aim to reduce the energy consumption and life cycle costs. Simulation results showed that the methodology could reduce the residential energy consumption and expenses.

Engdahl and Johansson [19] explored the possibility of using the optimal supply air temperature in a variable air volume air-conditioning system. Comparison was made against constant and decreasing supply air temperature. Simulation results show that the optimization offered a significantly lower energy usage. Another interesting research was done by Zhang and Niu [20] on the system combining chilled ceiling with air dehumidification strategies using air handling unit and desiccant cooling. The proposed system was then compared to normal air-conditioning. Simulation results confirmed that the chilled ceiling system has the energy savings potential of up to 47% and 30% for the combination with air handling unit and desiccant cooling respectively.

Control strategies of air-conditioning system were investigated by Mathews et al. [21]. The strategies include air-bypass, reset control, setback control, improved start-stop times, economizer control and carbon dioxide control. Simulation assessment confirmed that the combination of improved start-stop times with air-bypass, reset and setback control was found to be the most efficient with energy savings of up to 66%.

1.5 Research purpose and methodology

Based on the above discussion concerning the increase in building energy consumption as well as the local thermal comfort issues, it is undeniable that the root cause of problem reasonably lies with the air-conditioning system of the building. In Malaysia, the popular type of air-conditioning is the use of chiller and air handling unit with chilled water being deployed as the thermal medium. The existing system consumes high energy due to the use of low room set-point temperature and subsequently the overcooling condition causes the occupants to feel thermally uncomfortable. The situation occurs due to the inability of the cooling coil to remove the sensible and latent loads in the correct proportion in which they occur in the room. It is safe to say that the existing air-conditioning system is not suitable to be used in tropical buildings. There is a way to reduce the humidity by using the outdoor air treatment using the desiccant system, but the cost is too high.

The objective of the research is to propose a new air-conditioning system for Malaysian buildings to overcome the problems typically associated with tropical climate. The new design must be low in cost for to be affordable in developing country such as Malaysia. The design criteria of the new air-conditioning system include humidity control, low energy consumption and minimum equipment cost. The new system should improve the thermal comfort of the occupants and can be retrofitted as an add-on configuration to the existing air-conditioning. It is best to adopt a comparison method between the proposed and existing air-conditioning system so that the advantages and drawbacks could be highlighted. In order to do so, it is deemed necessary to utilize the approach of computer simulation to assists in the evaluation of the new air-conditioning system.

Among other things that are crucial in the analysis is the schematic configuration, control setup, psychrometric process and room conditions in terms of temperature and humidity. The most important aspect is of course the energy consumption of the new system. The knowledge in this research will contribute to the development on building energy sustainability measures through the innovation of the proposed design of air-conditioning system.

1.6 Organization of dissertation

The dissertation consists of 6 chapters. The contents of each chapter are described as follows.

Chapter 1 contains the background of problems related to buildings in hot and humid environment of Malaysia. The purpose of the research is explained and the solution to overcome the problems is described accordingly. The relationship of other chapters with the main objective is also specified here.

Chapter 2 contains the initial phase of the study to grasp the current situation in Malaysia in terms of the effort towards building sustainability. The study focuses on the existence of guidelines pertaining to low energy building, the design approach of air-conditioning system and the incentives to encourage the implementation of green buildings. It is observed that the guidelines and standard on energy efficient buildings have been established with clear instructions. However, a new design method of air-conditioning is deemed necessary to be introduced as the current practice tends to design a system with a low temperature set-point. The support from the government of Malaysia is evidence through the incentives offered to building owners and potential buyers of the office and house unit inside a certified green building.

Chapter 3 contains a field study to comprehend the current situation of room condition and air-conditioning system in Malaysia. In the exercise, the measurement of indoor temperature and relative humidity was performed inside 3 different office buildings in the suburban area. The types of chiller and air handling units commonly being used also being studied during the walk through. The thermal measurement device recorded the data round-the-clock for several days of observation. The data are eventually compared with existing comfort zones defined by recognized standards in Malaysia. It is observed that most of the occupants were not thermally comfortable in the measured rooms. Therefore, it is necessary to find a new room condition which is more suitable for buildings in hot and humid environment.

Chapter 4 contains the research solution by proposing a new air-conditioning system to resolve the problems faced by Malaysian buildings. The first step is to define a new room condition with a comfort zone that utilized less energy consumption. The design requirements in terms of humidity control and low equipment cost are also explained as well as the necessity to use 2 air handling units in the system. The design concept of the new air-conditioning configuration is described with the assistance of related figures. The control method of temperature and humidity is also being clarified in this chapter.

Chapter 5 contains the most important section in the research which is the performance analysis of the proposed air-conditioning system. In the study, simulation approach is adopted in order to confirm that the control method is able to operate under the tropical climate. Since the new system is designed to work on 2 air handling units (AHU), it is necessary to evaluate the suitable AHU size ratios. The simulation results show that the new system is indeed be able to run under the constant-air-volume and variable-air-volume configuration. The limitation due to the range of AHU size ratios has also being identified. It is observed that the mixture of supply air between the 2 AHUs has resulted in a slight difference of temperature and humidity of the room. However, the thermal comfort of the room has not been compromised. It is also observed that the proposed air-conditioning system could offer energy savings of up to 11.4% compared to normal air-conditioning system.

Chapter 6 contains the design method of the new air-conditioning system using manual calculation and psychrometric chart. The design procedure is explained step-by-step for the application of a new building. For the existing building, the new system can be designed as an add-on configuration to the existing air-conditioning system. The method of retrofitting is also explained in this chapter.

Chapter 7 concludes the whole research and provides some recommendations for future works.

Figure 1.5 shows the research flow of the dissertation.

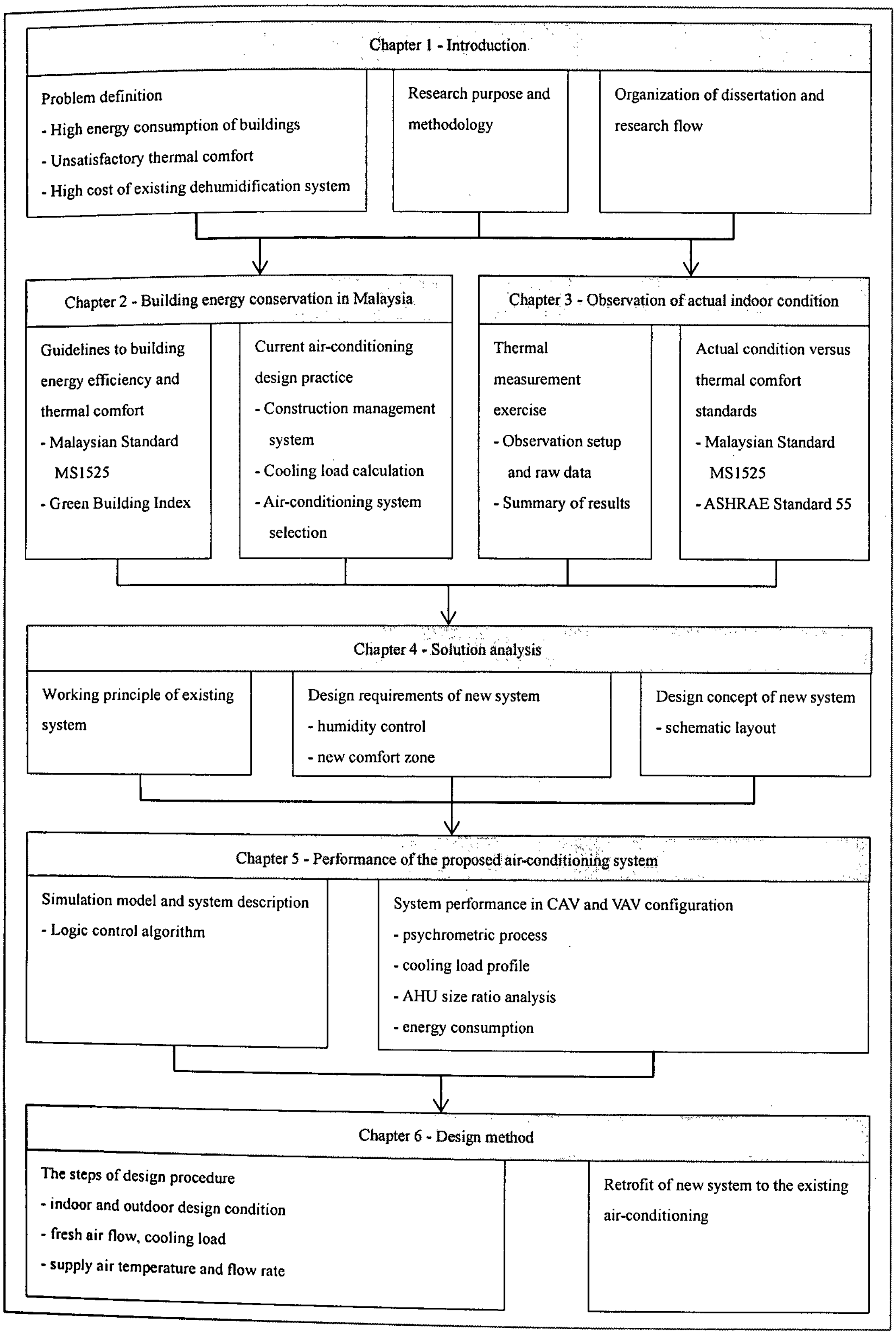

Fig. 1.5: Research flow

References

[1] Central Bank of Malaysia, Annual Report 2013, Bank Negara Malaysia, http://www.bnm.gov.my, accessed on September 10, 2014.

[2] Population and demography, Department of Statistics Malaysia, http://www.statistics.gov.my, accessed on September 10, 2014.

[3] Energy Commission of Malaysia, Statistics of Malaysian Energy Information Hub, http://meih.st.gov.my/statistics, accessed on September 10, 2014.

[4] Y.H. Yau, A preliminary thermal comfort study in tropical buildings located in Malaysia, International Journal of Mechanical and Materials Engineering, vol.3, no.2, pp.119-126, 2008.

[5] R. Sulaiman, S.N. Kamaruzzaman, S.P Rao, M. Pitt., The environmental performance of air-conditioning systems in heritage buildings in tropical climates, Journal of Surveying, Construction & Property, vol.2, no.1, pp.75-80, 2011.

[6] The Weather Channel, Koppen-Geiger climate classification, http://uk.weather.com, accessed on September 10, 2014.

[7] Malaysian Meteorological Department, Weather data report of Subang Kuala Lumpur, Petaling Jaya, Malaysia 2013.

[8] K.M. Shank, S.A. Mumma, Selecting the supply air conditions for a dedicated outdoor air system, ASHRAE Transactions, vol.107, part 1, 2001.

[9] S.A. Mumma, K.M. Shank, Achieving dry outside air in an energy-efficient manner, ASHRAE Transactions, vol.107, part 1, 2001.

[10] Mossolly, M., Ghali, K., Ghaddar, N., Optimal control strategy for a multi zone air-conditioning system using a genetic algorithm, Energy, no.34, pp.58-66, 2009.

[11] Kinsara, A.A, Elsayed, M.E, Al-Rabghi, O.M, Proposed energy-efficient air-conditioning system using liquid desiccant, Applied Thermal Engineering, vol.16, no.10, pp.791-806, 1996.

[12] Niu, J.L, Zhang, L.Z., Zuo, H.G., Energy savings potential of chilled-ceiling combined with desiccant cooling in hot and humid climates, Energy and Buildings, no.34, pp.487-495, 2002.

[13] Ghali, K., Energy savings potential of a hybrid desiccant dehumidification air-conditioning system in Beirut, Energy Conversion and Management, no.49, pp.3387-3390, 2008.

[14] Mumma, S.A., Achieving dry outside air in an energy-efficient manner, ASHRAE Transactions, vol.107, pt.1, 2001.

[15] Zhou, Y.P, Wu, J.Y, Wang, R.Z., Shiochi, S., Energy simulation in the variable flow air-conditioning system under cooling conditions, Energy and Buildings, no.39, pp.212-220, 2007.

[16] Rodriguez Hidalgo, M.C., Rodriguez Aumente, P., Izquierdo Millan, M., Lecuona Neumann, A., Salgado Mangual, R., Energy and carbon emission savings in Spanish housing air-conditioning using solar driven absorption system, Applied Thermal Engineering, no.28, pp.1734-1744, 2008.

[17] Ma, Z., Wang, S., Energy efficient control of variable speed pumps in complex building central air-conditioning system, Energy and Buildings, no.41, pp.197-205, 2009.

[18] Gao, X., Akashi, Y., Sumiyoshi, D., Installed capacity optimization of distributed energy resource systems for residential buildings, Energy and Buildings, no.69, pp.307-317, 2014.

[19] Engdahl, F., Johansson, D., Optimal supply air temperature with respect to energy use in a variable air volume system, Energy and Buildings, no.36, pp.205-218, 2004.

[20] Zhang, L.Z., Niu, J.L., Indoor humidity behaviors associated with decoupled cooling in hot and humid climates, Building and Environment, no.38, pp.99-107, 2003.

[21] Mathews, E.H., Botha, C.P, Arndt., D.C, Malan, A., HVAC control strategies to enhance comfort and minimize energy usage, Energy and Buildings, no.33, pp.853-863, 2001.

CHAPTER 2

Building Energy Conservation in Malaysia

2.1 Introduction

The problems of high energy consumption and unsatisfactory indoor thermal comfort faced by buildings in Malaysia have been discussed in the previous chapter. Unsurprisingly, similar problems are also being encountered in other tropical countries due to the hot and humid environment. Since the air-conditioning equipment is the main energy consumer in buildings, more attempts should be focused on the improvement related to the usage and operation of the air-conditioning system. It has also been mentioned that the existing system is found to be unsuitable in hot and humid environment, thus a new air-conditioning system is proposed to be used instead.

Looking from a broader point of view, the successful implementation towards building energy conservation is not intrinsically depending on air-conditioning system alone. The execution has to be supported by all related aspects as shown in Figure 2.1 [1]. According to Al-Mofleh, building energy performance is a function of 3 interrelated factors which is building physical, building system and people behavior. In order to ensure that all factors are working hand in hand, clear guidelines and standards have to be in place for all parties to adhere. Architects and engineers are responsible to come up with the policies in order to achieve to their goals, as far as building sustainability is concerned. Once the guidelines are established, only then the implementation can run in a systematic manner.