AIR-CONDITIONING SYSTEM WITH SIMULTANEOUS CONTROL F SENSIBLE AND LATENT HEAT FOR BUILDING ENERGY CONSERVATION IN MALAYSIA

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AIR-CONDITIONING SYSTEM WITH SIMULTANEOUS CONTROL OF SENSIBLE AND LATENT HEAT FOR BUILDING ENERGY CONSERVATION IN MALAYSIA

A dissertation

by

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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.

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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.

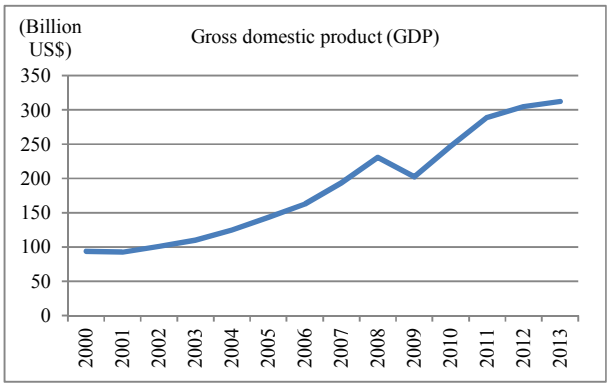

Fig. 1.1: GDP of Malaysia

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].

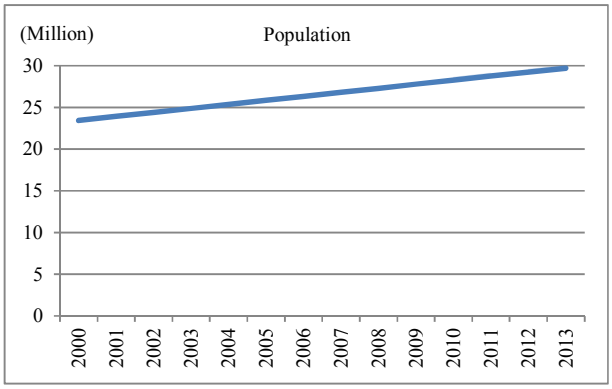

Fig. 1.2: Population of Malaysia

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.

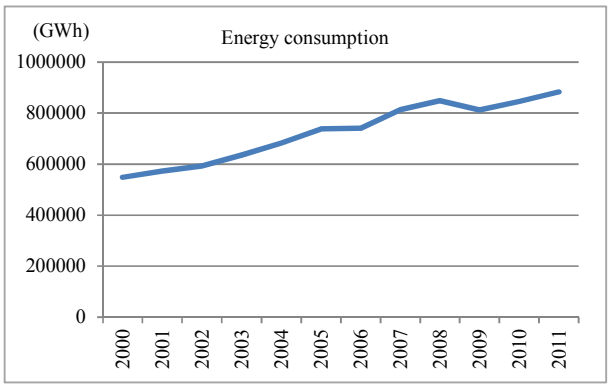

Fig. 1.3: Energy consumption of Malaysia

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.

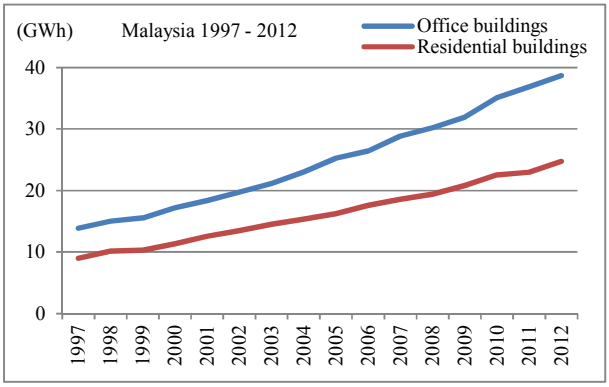

Fig. 1.4: Building energy consumption

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.

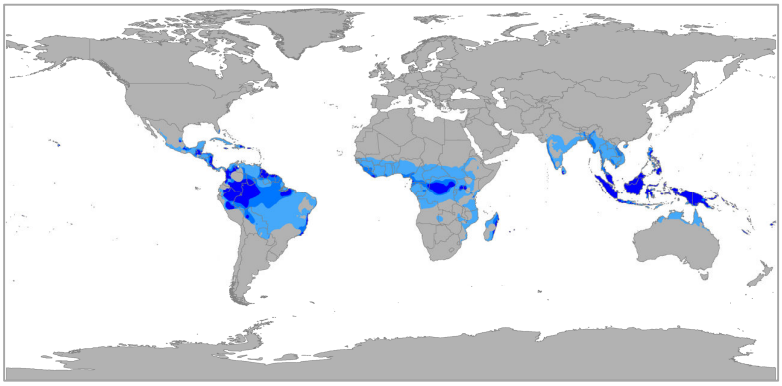

Fig. 1.3: Tropical climate of the world [6]

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.

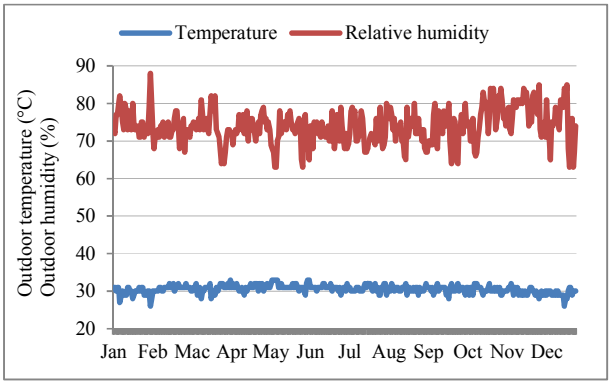

Fig. 1.4: Outdoor condition of Kuala Lumpur

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.

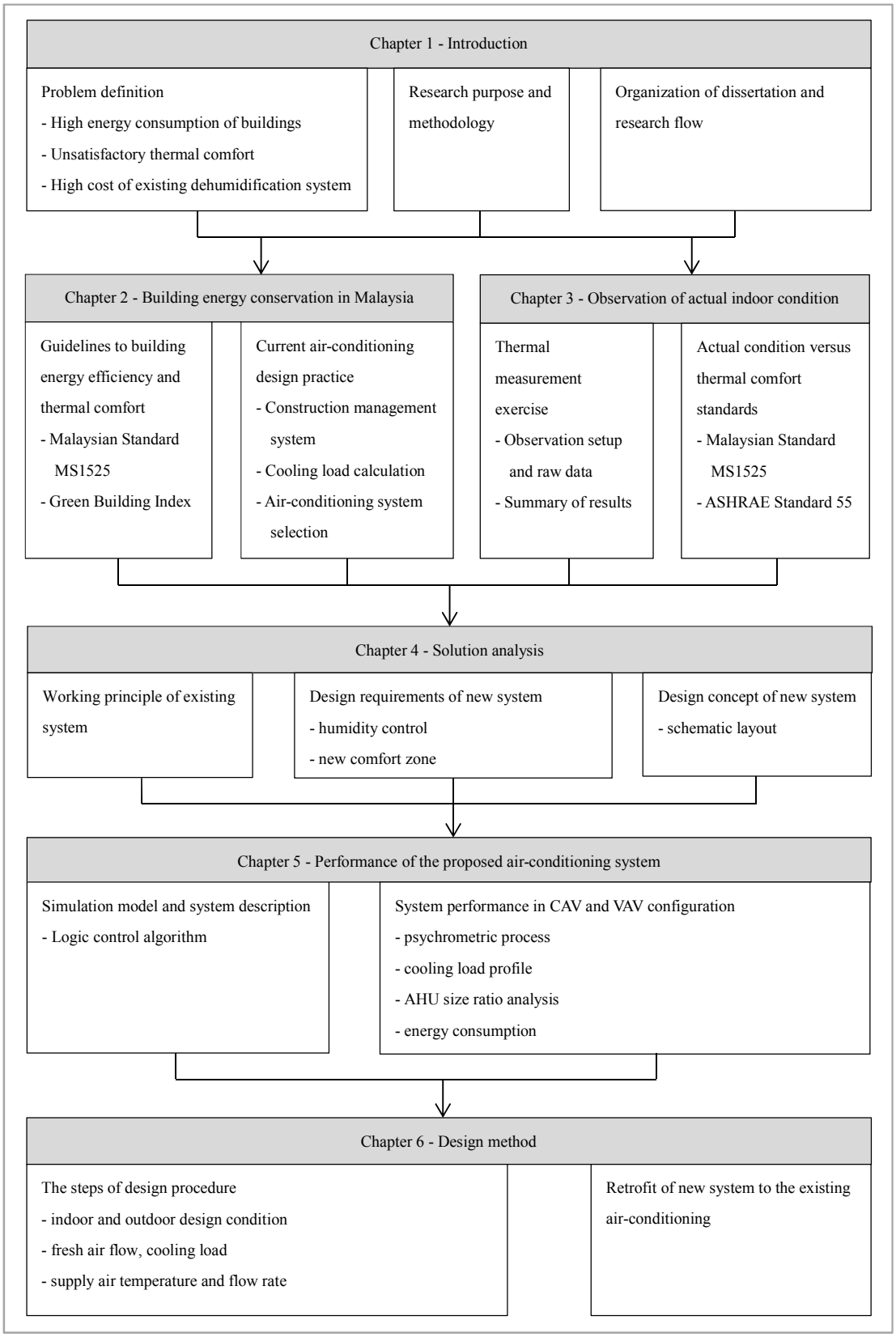

Fig. 1.5: Research flow

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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.

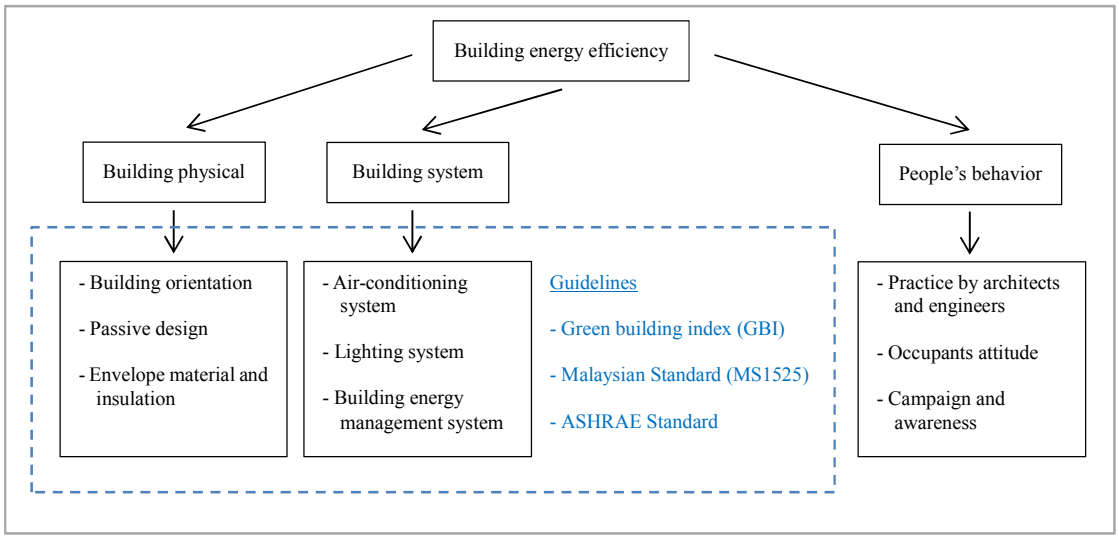

Fig. 2.1: Interrelated factors of building energy efficiency

2.2 Objective

This chapter reviews the current situation in Malaysia pertaining to the goal towards building sustainability. The situation assessment is important to ensure that the proposed air-conditioning system is in line with the country's ambition. Existing guidelines and regulations on building energy efficiency is investigated together with the achievements so far in the country. In addition, the whole practice in designing the air-conditioning system is looked into including the design parameters and the selection criteria. The evidence of success and weaknesses in the practice of the implementation are also revealed in this chapter.

2.3 Initiatives to building energy efficiency in Malaysia

Energy efficiency is the efficient use of energy in a manner that utilizes less energy for producing the same output [2]. In promoting energy efficiency to the public, it is important for the authorities in Malaysia to come up with a strategic guidelines and regulations pertaining to the issue. The analysis will cover on the extent of energy policy towards sustainable building. Whilst some standards are established specifically for energy conservation purposes, other ruling occurs in brief instructions with similar intention.

For instance, there is a clause under the Malaysian Electricity Supply Act 2008 which states that any building installation that consumes 3 million kWh over a period of 6 months is required to engage a registered energy manager for the building. The energy manager is responsible to analyze the energy consumption of the building through continuous monitoring of all system including air-conditioning. In addition, he/she would advise on the development and implementation of measures to ensure efficient management of building energy and to supervise the effectiveness of the actions.

With the aims to provide recommendations to strive for sustainable building, 2 major types of initiatives are established in Malaysia for its architects and engineers. There are Malaysian Standard 1525 and the Green Building Index.

2.3.1 Malaysian Standard MS1525

A significant development towards establishing a comprehensive guideline of sustainable buildings in Malaysia is the introduction of MS1525 Code of Practice on Energy Efficiency for Non-Residential Buildings [2]. The cover page of the standard is shown in Figure 2.2.

Fig. 2.2: Cover page of MS1525

The standard is applicable to the building that has at least 4,000 m^2 of indoor air-conditioned space. The standard was initially published in 2001 by a group that consists of academician and industry players who involved in building services and management. The purposes of establishing MS1525 are to:

i. Encourage the design, construction, operation and maintenance of new and existing buildings in a manner that reduces the use of energy without constraining building function and the comfort or productivity of the occupants.

ii. Provide the criteria and minimum standards for energy efficiency in the design of new buildings, retrofit of existing buildings and methods for determining the compliance.

iii. Provide guidance for energy efficiency design to comply with minimum standards.

iv. Encourage the application of renewable energy in new and existing buildings to minimize reliance on non-renewable energy sources, pollution and energy consumption whilst maintaining comfort, health and safety of the occupants.

There are 7 main areas covered by the MS1525 code of practice as shown in Figure 2.3. It has to be noted that the standards set out only the minimum requirements and designers are encouraged to practice beyond the stipulated standards. The first topic in MS1525 is the architectural and passive design strategy which focuses on the design and construction of a building taking optimal advantage of its environment. The important factors that should be considered are building orientation, configuration, geometry, room depth, floor to ceiling height, location of pillars, building façade, internal layout, fenestrations, building materials, roof design, roof colour, shading, day lighting and natural ventilation.

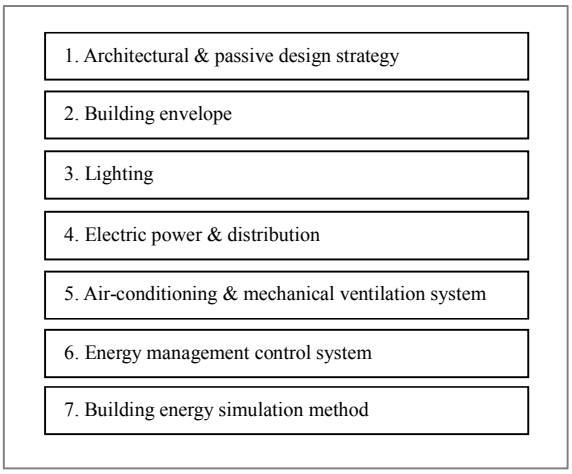

Fig. 2.3: Code of practice covered in MS1525

Building envelope is another area covered in the standard. The envelope is referred to wall, window, door and roof and is used to reduce heat gain from coming into the buildings via conduction and solar radiation. The heat gain constitutes a substantial share of cooling load in air-conditioned building.

In order to quantify the design criterion for building envelope, overall thermal transfer value (OTTV) concept has been adopted. The calculation of OTTV includes the parameter of window-to-wall ratio, solar absorptivity, thermal transmittance (U-value) and shading coefficient. In addition, there is also a calculation mentioned as roof thermal transfer value (RTTV) for roof with skylights. Lastly, the MS1525 requires the submission of the u-value for roof assembly and the OTTV and RTTV calculation for the building.

The code of practice for lighting is mainly focused on the usage of efficient lamps and luminaires. The recommended level of illuminance in unit lux is listed for several building space applications. Maximum allowable lighting power for different building types is also provided as well as lighting control in terms of automation and accessibility. The electric power and distribution clause applies to the energy efficiency requirements of electric motors, transformers and distribution systems of buildings except for those required for emergency purposes. All electrical power distribution equipment should be selected for their energy efficiency, capital cost and the cost of energy over the equipment life time.

The classification of high efficiency electric motors is provided for designer's reference. The guidelines for cable, wire, transformer and inverter are clearly explained. Lastly, the MS1525 requires the installation of electrical energy meters at strategic load centers to facilitate the monitoring of energy consumption and management.

The Malaysian Standard recommends that load calculation method should be determined in accordance with the procedures described by ASHRAE (American Society of Heating, Refrigeration and Air-conditioning Engineers) or other equivalent publication. MS1525 also suggests the design conditions of an air-conditioned space for comfort cooling in Malaysia as follows:

i. Indoor design dry bulb temperature of 23 - 26°C.
ii. Indoor design relative humidity of 55 - 70%.
iii. Indoor air movement of 0.15 - 0.50 m/s.
iv. Outdoor dry bulb temperature of 33.3°C.
v. Outdoor wet bulb temperature of 27.2°C.

According to the standard, oversizing is not recommended and the air-conditioning system and equipment shall be sized to provide no more than the space and system load being calculated. In addition, the usage of efficiency devices such as multi compressors, variable speed drive and high efficiency motor is encouraged. Also included in MS1525 are the guidelines for automation control, fan power rating and piping/ ducting insulation and leakage checking.

For factory-assembled package and unitary air-conditioning system, the minimum coefficient of performance (COP) is listed according to system capacity. There is also standard rating and specification for water chiller and heat-operated absorption system. The standard requires the submission of schematic drawing and operation manual as well as the scheduling of periodic maintenance.

Energy management control system is another important aspect described in the Malaysian Standard. The control and monitoring of equipment are for the purpose of improving the efficiency by providing:

i. Real-time information of running equipment.
ii. Historical data of equipment.
iii. Abnormal equipment condition.
iv. Analysis tool and diagram for a study purpose.

The application of energy management control system should be used for time scheduling to match occupancy pattern and chiller optimization program. The system could be further utilized for controlling the cooling coil valve, fan speed and the on-off mechanism for other equipment such as the lighting system. In order to enable energy monitoring, data logging facilities shall be provided for the air-conditioning system, lift, escalator, water pump, power supply and lighting.

The last code of practice is for building energy simulation method. It is a performance-based approach to compute the predicted energy use of buildings. MS1525 specifies that the computer-based simulation program should have a minimum of 8,760 hours of time step per year. Subsequently, a report of the simulation shall be produced according to ASHRAE or British CIBSE (Chartered Institution of Building Services Engineers) format for submission.

2.3.2 Green Building Index

An added effort to promote sustainable building in Malaysia is the establishment of the Green Building Index (GBI) which was launch on 21 May 2009. GBI is an assessment tool to certify energy efficient building and is comparable to Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan. However, GBI is designed specifically for the tropical climate of hot and humid environment and Malaysia's current social, infrastructure and economic development.

GBI certification started from the year 2010 with the Green Energy Office (GEO) building, shown in Figure 2.4, as the first building to be certified. Building energy intensity (BEI) of GEO is measured at 65 kWh/m^2/year based on the secondary power supply, which is the most energy efficient building in Southeast Asia. It has to be noted that the average BEI for Malaysian building is currently at 250 kWh/m^2/year.

Fig. 2.4: Green Energy Office building [3]

The success of GEO building in pioneering the concept of green building has opened the door for more subsequent GBI certification. As shown in Figure 2.5, the accumulation of buildings being certified has increased rapidly from 5 units in 2010 to 30 units in 2011, 55 units in 2012 and 100 units in 2013 [3]. Altogether there are currently 190 premises that have been registered as green buildings in the country. The certification would last for 3 years before a re-assessment is required to ensure that the buildings are well maintained and environmentally friendly. The positive development on the number of certification shows that more premise owners in Malaysia are aware of the needs towards building energy conservation.

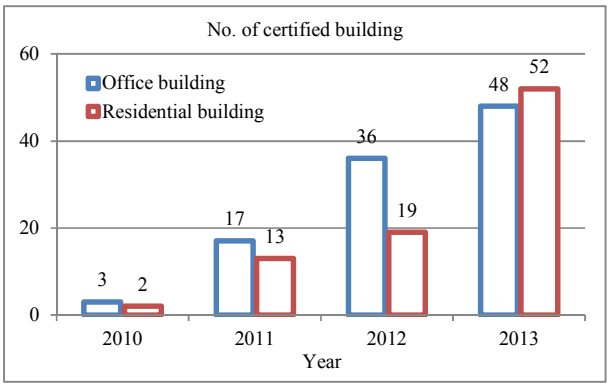

Fig. 2.5: Number of certified buildings

The main idea of green building is basically based on the concept of consuming less energy and resources but at the same time generate less waste to the surroundings. Therefore, GBI is based on six main assessment criteria as shown in Figure 2.6. Energy efficiency is the most significant factor with 35% score of the overall evaluation followed by indoor environmental quality (21%), site planning & management (16%), material resources (11%), water efficiency (10%) and innovation (7%).

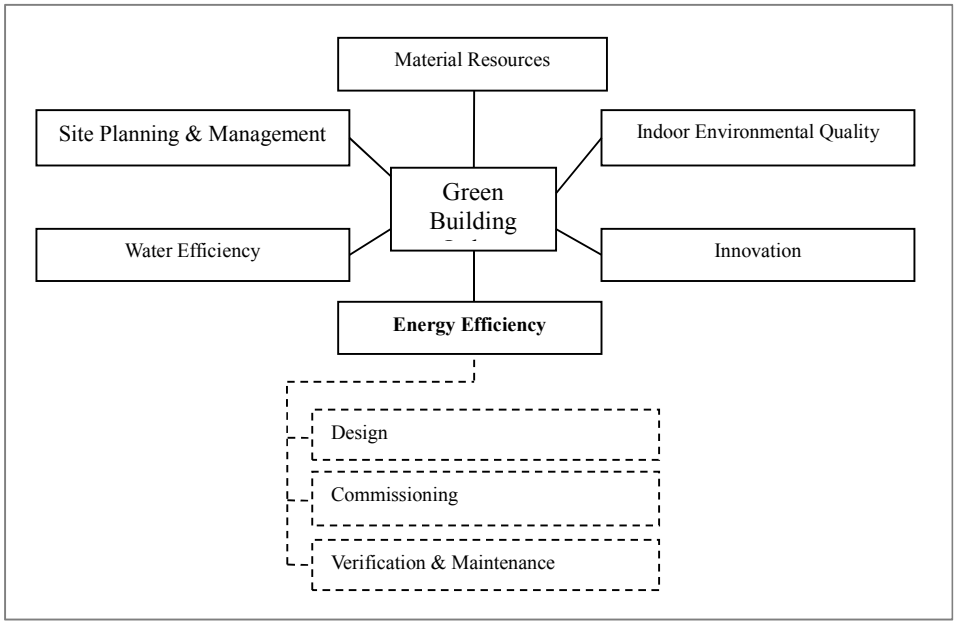

Fig. 2.6: Green Building Index assessment criteria

With the highest provision of score percentage, energy efficiency proves to be the most important factor towards green buildings and within the criteria, there are three sub-assessments available namely design, commissioning and verification & maintenance. The requirements stipulated under the design sub-assessment are the building envelope index, building energy management system, usage of renewable energy and building energy index achievement. GBI assessment demands that a proper commissioning being carried out for the building energy system during the design stage, installation and 12 months after initial operation. Lastly, under the verification & maintenance sub-assessment, energy consumption should be continuously monitored as well as the scheduled preventive maintenance exercise.

With the comprehensive environmental rating system offered by GBI, Malaysia is totally committed in the development of sustainable buildings in the country. In order to maintain the relevancy of the index, GBI criteria are reviewed annually by architects and engineers for continuous improvement.

2.4 Fiscal incentives by the government

The government of Malaysia sets the goal to ensure sustainable economic development for the future. The Ministry of Energy, Green Technology and Water which is responsible for the establishment of national policies relating to energy efficiency and renewable energy, offers attractive incentives to encourage the implementation of energy efficient buildings. Currently, there are two types of incentives:

2.4.1 Tax exemption

The beneficiaries are building owners who incur qualifying expenditure to obtain Green Building Index (GBI) certification. The tax exemption is equivalent to 100% of the amount of expenditure for each year of statutory income assessment. The qualifying expenditure includes building construction, alteration, renovation, extension or retrofit of existing building. Any unutilized expenditure can be carried forward to subsequent years of assessment until the amount is fully exempted.

2.4.2 Stamp duty exemption

The beneficiaries are the buyers of buildings and residential properties that have been awarded GBI certification. In Malaysia, any sales and purchase agreement of properties requires the inclusion of a stamp duty. The cost of stamp duty varies according to the value of premises involved. For properties up to RM100,000 the rate is 1% and for subsequent premise unit of RM100,001 – RM500,000 the fee is 2%. Stamp duty for properties over RM500,000 is charged at 3% of the sales value. The incentive for green buildings applies to first property owner only who acquired the fresh new unit from the developer.

These two incentives offered by the government shows the commitment of Malaysia in ensuring green technology to play an important role in the nation's development. Hopefully, in the future there are more incentives created to persuade the contribution of efficient resources for sustainable development.

2.5 Thermal comfort guidelines

The thermal comfort guideline was presented in the first issue of Malaysia Standard MS1525 in 2001 which defined the indoor comfort temperature and humidity as 23 - 26°C and 60 - 70% respectively. In the revised copy of the standard issued in 2007, the temperature range remains while the comfort humidity has been amended to 55 - 70%. These conditions are suggested in provision to the air movement of 0.15-0.50 m/s [4]. Therefore, as the standard suggests, the air-conditioning system should be designed and operated according to these recommendations, which in return not only provide thermal comfort to the occupants but would reduce its energy usage during the operation.

A widely renowned thermal comfort design basis for air-conditioning is ASHRAE Standard 55 [5]. Its purpose and definitions clearly show that the standard is established based on 80% acceptability. In other words, even if each criterion in the standard are met, all of the occupants may not be mutually satisfied with the indoor condition. The discrepancy is inevitable due to the individual preferences and thermal sensitivity. The upper limit of humidity comfort boundaries of ASHRAE Standard 55 is capped at 0.012 kg/kg dry air while there is none for lower humidity limit. The comfort zone for summer is set for occupants with clothing insulation of 0.5 clo and 0.1 m/s air speed. It is derived from the predicted mean vote (PMV) and predicted percent dissatisfied (PPD) indices, consistent with the method used in ISO Standard 7730.

One of the popular tools to evaluate thermal comfort condition in Malaysia is using the Predicted Mean Vote (PMV) calculation. PMV is a parameter for assessing comfort based on the conditions of temperature, humidity, metabolic rate, clothing and air velocity. PMV was developed by Fanger [6] and its value can be classified according to the thermal sensation scale as follows:

3 = hot
2 = warm
1 = slightly warm
0 = neutral
-1 = slightly cool
-2 = cool
-3 = cold

The perception of comfort varies from someone to another since there many factors affecting the thermal sense of a human. The difference in cooling requirement will affect the preferred air temperature of the particular occupant.

2.6 Practice related to air-conditioning design

The construction of energy efficient buildings requires a systematic management especially during the design and installation stage of the air-conditioning system. The architects and engineers have to sit together and discuss the details on planning and execution work from the blueprint period until the completion of the project. In other words, such complicated works requires co-ordination between related parties that involved in the project. Therefore, it is necessary to review the practice in Malaysia related to air-conditioning design to ensure conformance to the guidelines and standards available in the country.

2.6.1 Management system in building construction

In Malaysian practice, an architect firm is appointed by the building owner to act as the leader in a building construction project. The architect will also design the shape and aesthetic features of the building. As shown in the organization chart in Figure 2.7, the architect will assign three other parties namely civil & structural engineer, mechanical & electrical engineer and quantity surveyor to complete the management team.

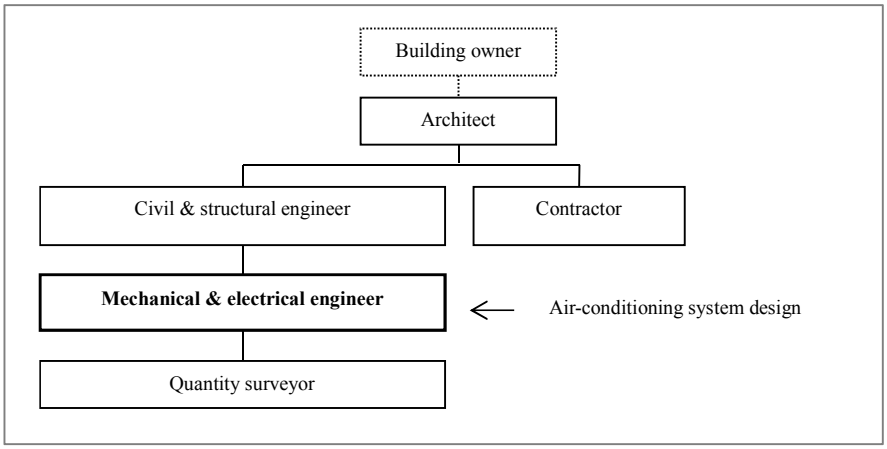

Fig. 2.7 Organization of building construction

The mechanical & electrical engineer is the party which provides consultation in terms of air-conditioning design to be used in the building. The design includes the determination of cooling load, the sizing of equipment and schematic drawings of the air-conditioning system. During the construction stage, mechanical & electrical engineer works closely with the appointed contractor to ensure that the air-conditioning equipment is installed correctly and ready to be used after building completion. The engineer is also responsible

in ensuring the initial commissioning exercise being carried out smoothly before the air-conditioning system being handed over to the building owner.

2.6.2 Cooling load calculation and equipment sizing

The initial stage of designing the air-conditioning system is the determination of building cooling load. The load calculation requires the input of building heat gain from external and internal sources. The skill and technique of determining the right cooling load and subsequently the accurate air-conditioning equipment sizing requires extensive training and years of experience in order to come out with a satisfactory design. The design and choice of air-conditioning system is one of the key factors in building energy performance.

Cooling load determination may be carried out using manual calculation with the aid of a spread sheet form. Usually, the spread sheet is provided by the equipment manufacturer but the guidance of calculation is minimal and depends a lot to the designer's own knowledge and technical know-how in air-conditioning. With the introduction of software in computer application, cooling load calculation can be more easily and accurately being determined. In using software as a tool, the experience level of the user is less important than that of using manual calculation.

In order to seek further clarification on the current air-conditioning design practice in Malaysia, an interview session was held with a credible air-conditioning designer from a mechanical & electrical engineering consultant firm as shown in Figure 2.8.

The approached designer had a work experience of over 17 years related to air-conditioning. Throughout that period, numerous air-conditioning systems had been designed by him mainly for office building, retail premises, shopping mall and academic institution in the country. In addition, the air-conditioning designer was a certified Professional Engineer. Under the Malaysian law, only a certified engineer is legally authorised to endorse construction drawings for building projects.

Name:	Ir. Kushairi Badiuzaman
Education:	Bachelor of Engineering (Mechanical) Master of Science (Construction management)
Designation:	Building air-conditioning designer
Experience:	17 years in professional consultancy

Fig. 2.8 Session with air-conditioning designer

During the interview, the designer revealed the process of sizing the air-conditioning equipment was assisted by utilizing the Carrier E-20 software. According to him, the software was not only used in his consulting firm, but also popular among other designers in Malaysia due to its reliable accuracy and easy-to-use. Furthermore, the software was acquired for free by the equipment manufacturer. Therefore, most of the air-conditioning designers in Malaysia have ditched out the traditional method of manual calculation as the thing in the past.

A sample of calculation for actual air-conditioning system sizing was provided by the designer. The calculation revealed that the outdoor design condition was determined to be 32°C and 80% humidity while the indoor design temperature was chosen as 23.0°C. Supplied air was determined to be 12.5°C and the resulting humidity of the conditioned space was 56%. In addition, 10% of oversizing was given the whole system. According to him, the reason for oversizing is for any future room expansion or modification inside the building that requires larger air-conditioning system. The air-conditioning designer also confirmed that there was no assessment of building energy consumption being carried out at the moment.

It was observed that the calculation was made so that the air-conditioning system operates in relatively low temperature. It is difficult to obtain good energy consumption with such a low temperature set point of air-conditioning system. A reduced sensible heat ratio exaggerates the dehumidification process at the cooling coil of air handling unit. As more moisture being taken out of the conditioned space, the indoor humidity will also become too low. In such design set-up, thermal comfort of the occupants is affected and resulting in unnecessary overcool condition.

Further review revealed the air-conditioning system design is intentionally oversized, forcing the chiller to run at partial load more often than normal. The oversizing is not necessary as the Malaysian Standard MS1525 recommends that the equipment size should be determined according to the calculation. In another words, oversizing is prohibited in order to avoid the air-conditioning system running at partial load more often than full load. In running at partial load, the efficiency of the air-conditioning is reduced and will affect the building energy consumption.

The clause for the requirement to perform building energy simulation is newly included in the first revision of MS1525 as it was not available in the initial issue. The simulation is necessary to predict the energy consumption in the buildings where the air-conditioning designer could opt for a more efficient system based on the simulation results. However, the exercise to predict building energy consumption through software-assisted tool is relatively new in Malaysia, and this may be the reason of the practice was not being carried out. It is hoped that the new clause in MS1525 regarding building energy assessment will be adhered in the future.

2.6.3 Air-conditioning system selection criteria

As the technology gets better, air-conditioning manufacturers around the world race among themselves to produce the most efficient equipment for the benefit of the consumer. In a typical Malaysian commercial building, there are several types of air-conditioning system being the most popular; the conventional chiller system, variable refrigerant volume (VRV) system, package system and unitary system. Each system has its own characteristics due to the variance in design. The function of a chiller is to produce chilled water and distribute it to the whole building. The chilled water will reach the air handling unit or fan coil unit where the cooled air is produced for the conditioned space. In VRV system, the cooled refrigerant is distributed to the building spaces instead of chilled water. On the other hand, the package system is a factory-assembled unit of air- conditioner and unitary system is the smallest type using direct expansion coil to produce cooled air.

The air-conditioning designer explained that choosing the type of system to be installed in the building was purely due to the equipment initial cost, as far as the practice in Malaysia is concern. An energy efficient air-conditioning system would obviously cost more than the conventional type of equipment. Hence, convincing the building owners to acquire air-conditioning system which provide energy conservation but cost more capital investment is a difficult task. Such scenario occurred may be due to the fact that the building energy consumption was not being estimated in the first place. Without a proper prediction of long term energy saving, building owners hesitated in investing monies for an unknown return in the future. As a result, the type of air-conditioning system was chosen based on merely equipment cost but not energy-saving reason.

Using the monetary currency of Ringgit Malaysia (RM) as the basis, the rule of thumb for the costing of air-conditioning system was explained by the designer. The VRV system was valued at RM5,000/ton refrigerant and for the chiller system was rated at RM6,000/ton refrigerant. Therefore, the VRV system seems to be the preferred choice for the time being. However, unlike the chiller system which is suitable for high rise building, VRV system was limited to a 20-storey building or smaller. The air-conditioning designer pointed out that most of the other players in the industry are practicing an almost similar approach in terms of air-conditioning design and selection.

2.7 Conclusion

This chapter presents the review of current situation in Malaysia relating to energy efficient procedures, indoor thermal comfort and air-conditioning system design. It is observed that the guidelines towards low energy building and the platform for green buildings are already in place with the establishment of Malaysian Standard MS1525 and Green Building Index. The yearly increase in GBI certified buildings reflects the growing awareness among Malaysian architects, engineers and building owners on the importance of sustainable buildings. Government support is visible through the incentives offered to those who invest on GBI buildings throughout the country.

However, there are issues in the practices in air-conditioning design. It is observed that the design was made so that the system operates in relatively low temperature. Apart from affecting the indoor thermal comfort through overcooling, the low temperature also will increase the building energy consumption. Further investigation is required on the actual room condition in Malaysian buildings due to the low indoor temperature design.

In addition, the air-conditioning equipment was designed to be purposely oversized and this would prevent the system from running in full load and obtaining the best efficiency. Simulation of building energy consumption was not practiced accordingly as an energy saving tool. As a consequence, the selection to choose the air-conditioning system was merely based on the equipment cost. The energy cost was never in consideration. These weaknesses have to be addressed first before the benefits of a new air-conditioning system with energy-efficient features, as proposed by this research, could make the necessary impact on Malaysian building energy conservation.

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CHAPTER 3

Actual Observation of Thermal Indoor Condition

3.1 Introduction

Providing thermal comfort to the occupants is essential inside a building. The point of concern when dealing with air-conditioning system in tropical environment is the unsatisfactory indoor thermal comfort caused by high humidity. Getting rid of the sensible heat using conventional air-conditioning can be done successfully, but due to design limitations, the same could not be said for latent heat removal. It is the humidity that actually brings the challenge to the air-conditioning system in Malaysia. The damp feeling due to the excessive moisture is actually the root cause of thermal discomfort, as also happening in other tropical countries. The incapability of the existing system using air handling unit (AHU) to reduce the humidity to the presumed level hinders the attainment of indoor thermal comfort to the occupants.

In the previous chapter, it was found that generally the air-conditioning system in Malaysia is designed so that the system operates in relatively low temperature. Apparently, the move is to overcome the excess humidity level inside the room. Therefore, it is necessary to find out the effect of such design to the actual air-conditioning operation in Malaysia.

3.2 Objective

In this chapter, the actual indoor condition of the room in Malaysian buildings is observed through measurement exercise. The on-site observation was carried out for a few days to understand the current indoor thermal comfort condition in terms of temperature and humidity. The outcome of the study will be helpful in designing the new air-conditioning system that would reduce the building energy consumption while improving the indoor thermal comfort.

3.3 Thermal measurement setup and eventual exercise

The measuring equipment used was data logger and humidity meter as shown in Figure 3.1. The unit is powered by a battery with two-channel type data logger. The measured parameters were temperature and relative humidity. An external sensor was connected to the unit. The accuracy of thermometer and hygrometer was ± 0.3°C and ± 5% RH respectively.

Fig. 3.1: Thermal measurement tool

The software associated with the unit is shown in Figure 3.2. As all the data logger is intended to start and end concurrently, the record starting date and end date in the software was set to be similar to each other. A total of 15 pieces of these units were used in the whole exercise. The units were placed at about 1 m height above the floor for the best reading outcome. The measurement was conducted in September 2012 for 3 days for the first two buildings and extended to 6 days for the last building. The locations of buildings are shown in Figure 3.3. The data interval for this exercise was set to 5 minutes.

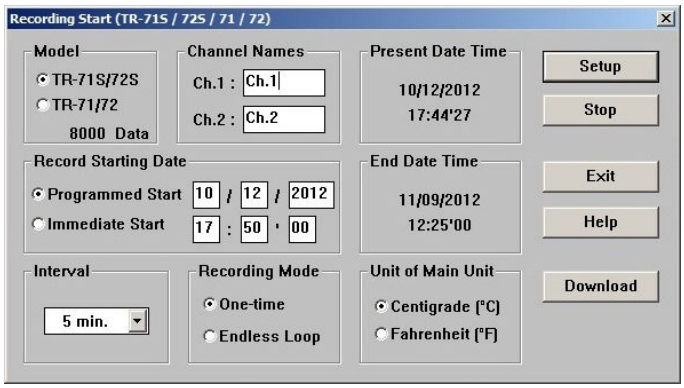

Fig. 3.2: Equipment software

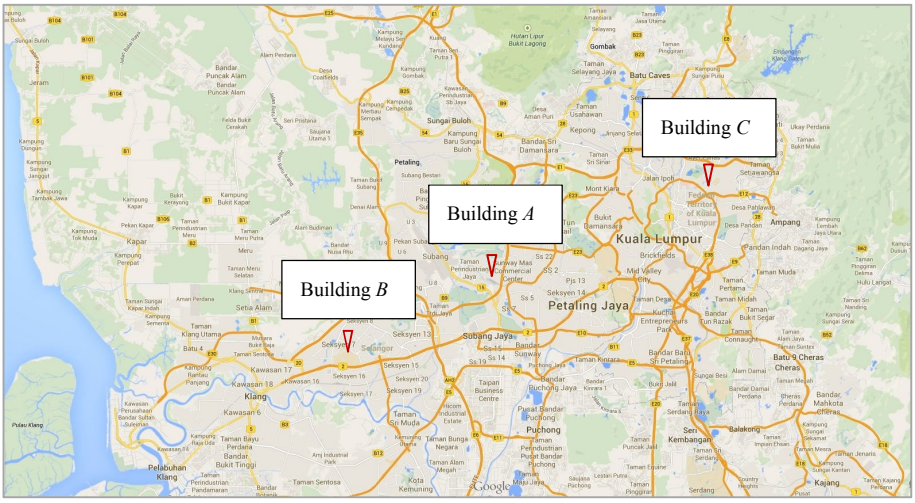

Fig. 3.3: Building locations

3.3.1 Observation and findings at Building *A*

The first target building, denominated as Building *A*, is shown in Figure 3.4 and was the head office of a company located in Subang, about 20 km to the east of Kuala Lumpur. The 4-storey building was first occupied in the year 1996 and consists of 12,000 m^2 of floor area. The premise was equipped with air-conditioning system consisting 2 units of chillers and 2 units of cooling towers.

Fig. 3.4: External view of Building *A*

The chillers of Building *A* are as shown in Figure 3.5 and Figure 3.6. Both chillers were of rotary screw type with a capacity of 985 kW. In Malaysia, the air-conditioning system operates all-year round, therefore a second chiller was required to alternate its operation. If on day one the first chiller was used, on day two the second chiller was in operation. On day three, the first chiller was back in running again, and so on. Therefore on any time of office hours, only one chiller and one cooling tower was in operation. The second chiller was also functioned as the backup system should there be any breakdown occurs. In Building *A*, chiller on/off period was from 7.00am - 6.00pm.

Fig. 3.5: Chiller no.1 of Building *A*

Fig. 3.6: Chiller no.2 of Building *A*

There were 2 cooling towers connected to the chillers as shown in Figure 3.7. Both units were of cross-flow induced type with the capability of supplying condenser water at the capacity of 238 m^3/hr.

Fig. 3.7: Cooling tower of Building *A*

The reading from the measuring equipment located on the rooftop is shown in Figure 3.8. The peak temperature was recorded at 33.1°C in the afternoon and the lowest at 25.6°C during nighttime. Rainfall was observed during the evening of September 20, resulting to the increase in relative humidity at 99 %. The lowest RH was spotted at 45% during a hot afternoon.

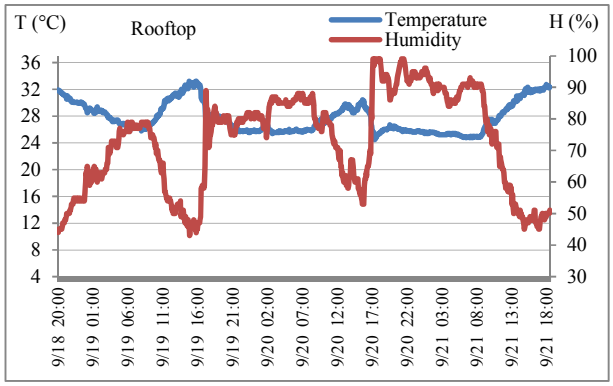

Fig. 3.8: Thermal measurement at Building *A* rooftop

There were a total of 13 air handling units (AHU) available to serve the office halls as shown in Figure 3.9. For smaller rooms, fan coil units were used to supply the cooled air. AHU on/off period was from 6.30am - 6.30pm during weekdays for Building *A*.

Fig. 3.9: Air handling unit of Building *A*

In order to observed the pattern of supply air parameters, thermal measurement equipment was placed inside the AHU as shown in Figure 3.10.

Fig. 3.10: Measuring point inside the AHU of Building *A*

The measurement results are shown in Figure 3.11. The average temperature supply was 20°C which is normal for constant-air-volume system and the humidity fluctuated between 85-90%.

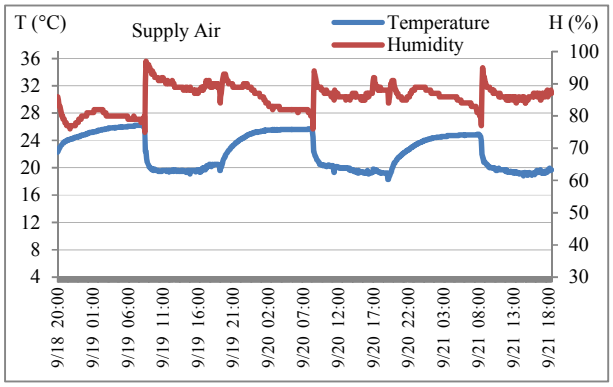

Fig. 3.11: Thermal measurement inside the AHU of Building *A*

Return air from the conditioned space is channeled through the ducting panel as shown in Figure 3.12. The return air mixes with fresh air inside the AHU room. Thermal measurement equipment was placed on top of the AHU to record the return air mixture data.

Fig. 3.12: Return air ducting outlet of Building *A*

Figure 3.13 shows the observation results on the return air-fresh air mixture of Building *A*. The temperature was around 25°C during office hours and 50% relative humidity.

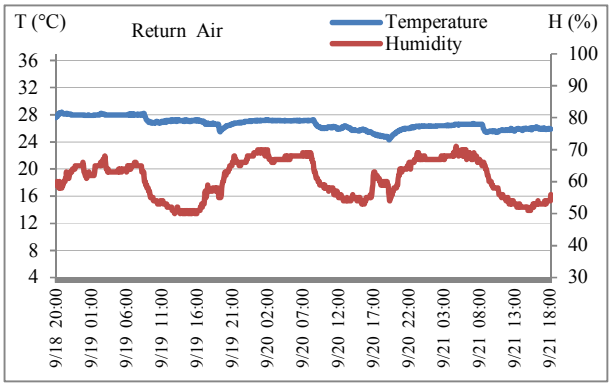

Fig. 3.13: Thermal measurement of return air mixture of Building *A*

Building A employed the so-called building automation system which integrated the building services operation into a centralized monitoring system. The display for chiller operation is shown in Figure 3.14. Among other monitored parameters were chiller water supply and return temperature, chiller water supply and return pressure as well as condenser water supply and return temperature.

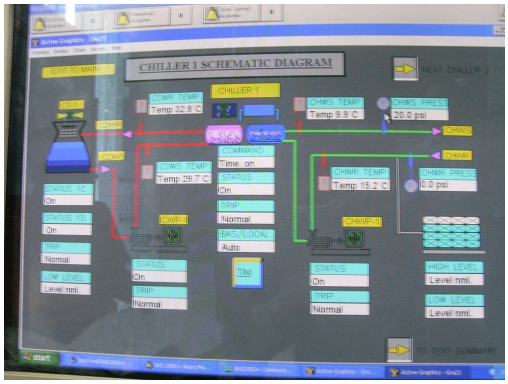

Fig. 3.14: Chiller operation monitoring of Building *A*

On the other hand, the display for AHU operation is shown in Figure 3.15. The system provided the monitoring data for outdoor air temperature, supply air temperature, return air temperature, room temperature set-point, chilled water supply and chilled water return pressure.

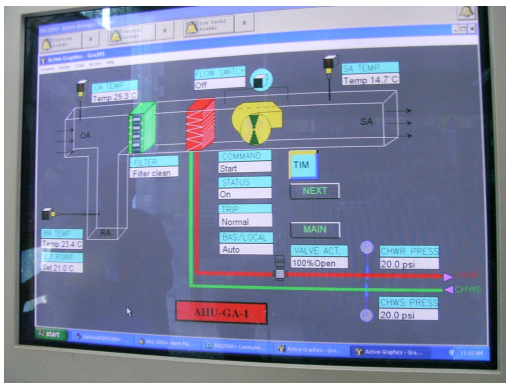

Fig. 3.15: AHU operation monitoring of Building *A*

The monitoring system is meant for live observation only, meaning that the data was not recorded and therefore the history figures could not be retrieved. Furthermore, the system was already 16 years old and there were signs of malfunction on a few readings.

The office hall in each floor of the building is shown in Figure 3.16 and Figure 3.17. It was 3,000 m^2 in area and could hold a total of 100 personnel in full attendance. However, during the observation period, the hall was only about 50% in occupancy.

Fig. 3.16: Office hall of Building *A* – east view

Fig. 3.17: Office hall of Building *A* – central view

Two measuring equipment were placed at the office hall as shown in Figure 3.18 and Figure 3.19. The measuring equipment was placed on top of a table which was approximately 1.0 m above the floor. Its sensor was left hanging in the air so that the temperature and humidity reading was from the ambient, not the table. The equipment was carefully placed so that it will avoid the direct air flow from the ducting outlet which is slightly colder than the ambient temperature.

Fig. 3.18: Measurement point no.1 inside Building *A*

Fig. 3.19: Measurement point no.2 inside Building *A*

The position of measurement equipment relative to the floor plan is shown in Figure 3.20. The choice of position was based on highly crowded area according to the sitting layout of the office.

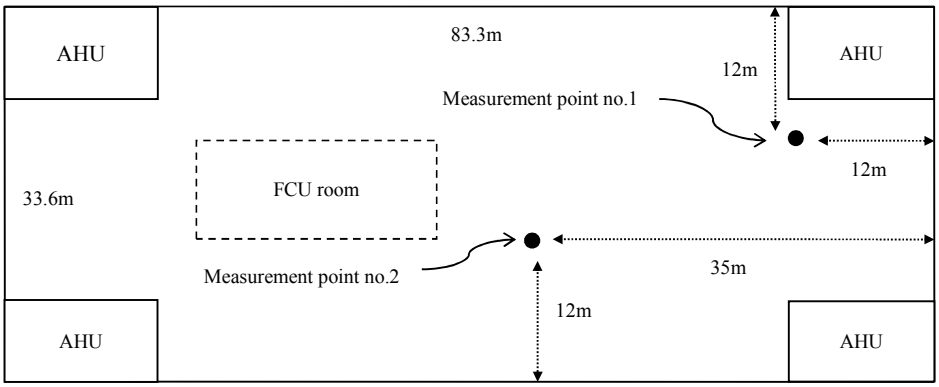

Fig. 3.20: Location of measurement equipment inside Building *A*

The measurement of temperature and humidity is shown in Figure 3.21 and Figure 3.22 for observation point no. 1 and 2 respectively. When the air-conditioning system was turned on in the morning, the temperature descended rapidly to nearly 24°C and gradually settled at around 23°C. It was also found that the relative humidity inside the room was slightly high at 65%. The aging condition of the 16-year-old chiller may be one of the reasons of slow descendant to the set point requirement and rather high humidity readings.

On the second day of measurement, one of the humidity sensors was found to be malfunction and had to be replaced. Therefore, the earlier portion of humidity profile is erased from Figure 3.22. From the beginning until the last period of observation, the relative humidity inside the office halls was found to be fluctuating between 60 - 70%.

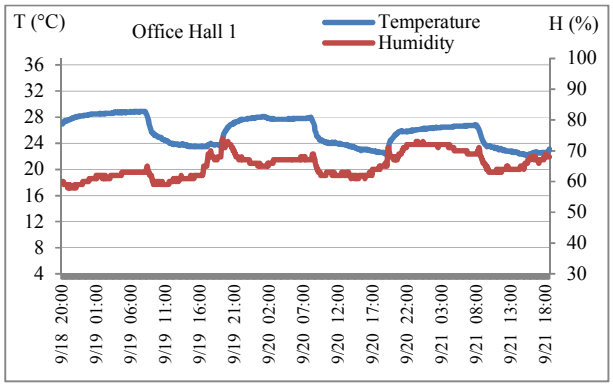

Fig. 3.21: Thermal measurement at Office Hall 1 of Building *A*

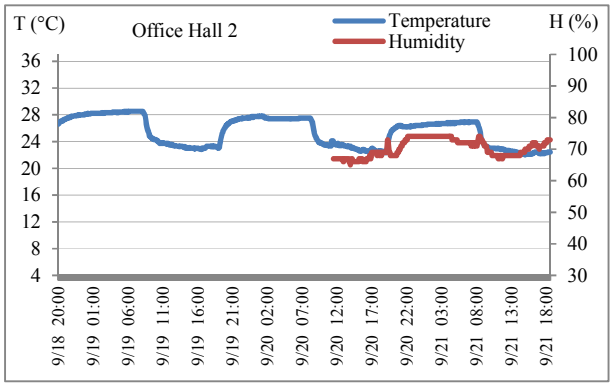

Fig. 3.22: Thermal measurement at Office Hall 2 of Building *A*

3.3.2 Observation and findings at Building *B*

The second building to be observed, denominated as Building *B*, is shown in Figure 3.23 and was used as a library. The building consists of 6 stories with a total of 11,000 m^2 of floor area. It was located in the vicinity of Shah Alam, about 32 km to the east of Kuala Lumpur. The premise was equipped with air-conditioning system consists of a chiller and cooling tower installed at a nearby facility house.

Fig. 3.23: View of Building *B*

There were 2 chillers installed to serve the building as shown in Figure 3.24. However, the exact capacity of the chiller could not be confirmed as the specification documents had been missing. Only one chiller was in use at a time and each chiller run in an alternate day. Chiller operation was for 24 hours.

Fig. 3.24: Chiller of Building *B*

There were 12 AHUs available to serve the building as shown in Figure 3.25. Two AHUs were placed in each floor and each unit served a different task, one was meant for normal air-conditioning and the other unit was for humidity reduction as to keep low moisture in the library. The normal AHU was in operation for 24 hours while the humidity reduction AHU runs from 8.30am to 9.30pm. Open hours of the library were from 9.00am until 12.00am midnight.

Fig. 3.25: Air handling unit of Building *B*

Measurement equipment was placed inside one of the AHUs to monitor its operation as shown in Figure 3.26. The data collected from the particular equipment is presented in Figure 3.27. It was observed that the supply air was set to a very low temperature of 5°C during its 13-hour operation to reduce the humidity in the room. It was believed that such setup would increase the building energy consumption.

Fig. 3.26: Measuring point inside the AHU of Building B

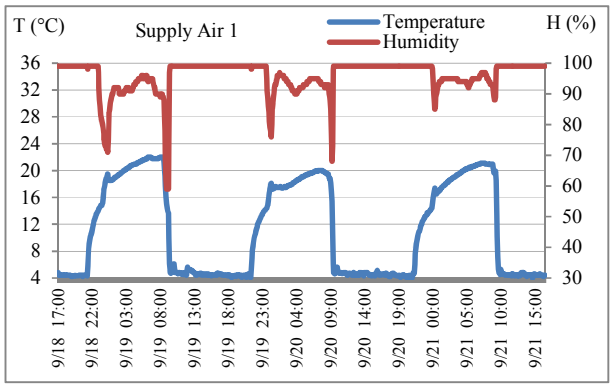

Fig. 3.27: Thermal measurement inside the AHU of Building *B*

Return air from the conditioned room was channeled back into the AHU room through the ducting outlet as shown in the red circle in Figure 3.28. In order to measure the condition of return air mixture with fresh air, measurement equipment was placed inside the AHU room.

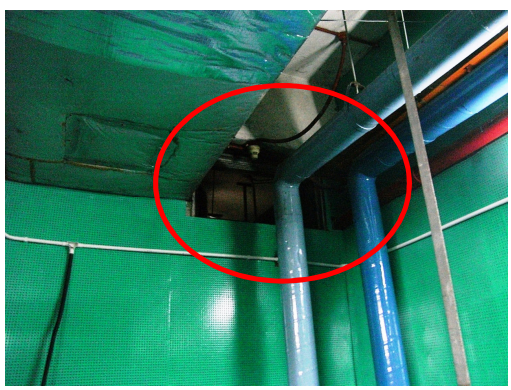

Fig. 3.28: Return air ducting outlet of Building *B*

The condition of return air-fresh air mixture inside the AHU room is shown in Figure 3.29. It was observed that the humidity of return air was relatively lower during the period of 8.30am to 9.30pm, most probably due to the moisture reduction AHU in operation.

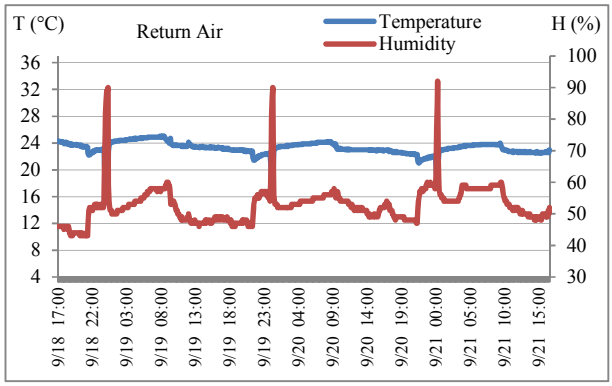

Fig. 3.29: Thermal measurement of return air mixture of Building *A*

Measurement equipment was placed at the rooftop of the building as shown in Figure 3.30. From the data in Figure 3.31, the first and third day of observation was extremely hot as the soaring temperature peaked at 36°C. During nighttime, it was more comfortable at low temperature of 26°C. When the day was cloudy as in the second day, the temperature peaked at 32°C. Humidity increased at night at 80 % maximum, and lowest in the afternoon at 45%.

Fig. 3.30: Equipment placement at rooftop of Building *B*

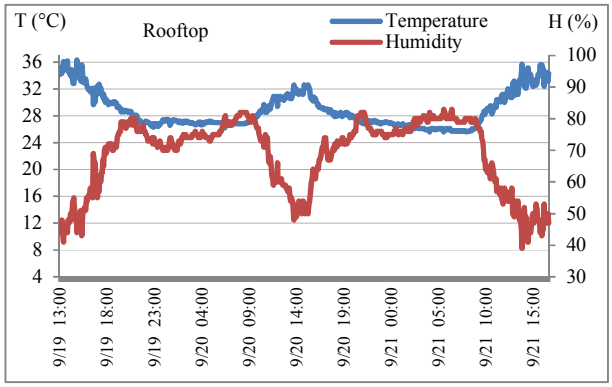

Fig. 3.31: Thermal measurement at rooftop of Building *B*

The library hall as shown in Figure 3.32 was the next location to be observed. Thermal measurement equipment was intended to be placed on the first, second and third floor. The equipment was carefully placed so that it will avoid the direct air flow from the ducting outlet which is slightly colder than the ambient temperature.

Fig. 3.32: Library hall of Building *B*

For the first floor, the exact position of the sensors relative to the floor plan of the building is shown in Figure 3.33. The first floor was having the most occupants at the time of observation due to the fact that a computer room was available there for the students to utilize.

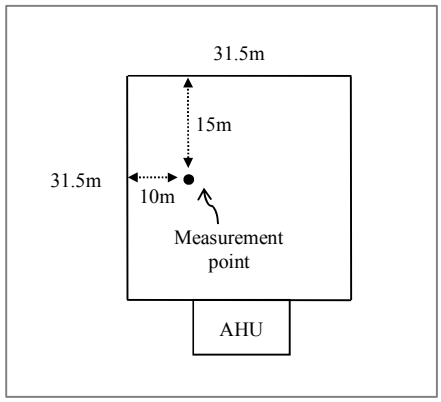

Fig. 3.33: Location of measurement at 1st floor of Building *B*

Figure 3.34 shows the measurement results for hall 1F. Remember that the air-conditioning was running for 24 hours in the library. The hall temperature was nearly to 24°C during library open hours and rose slightly to 26°C during library close hours. The humidity was well kept at 45% during library operation and escalated to 55% when the library was free of occupants.

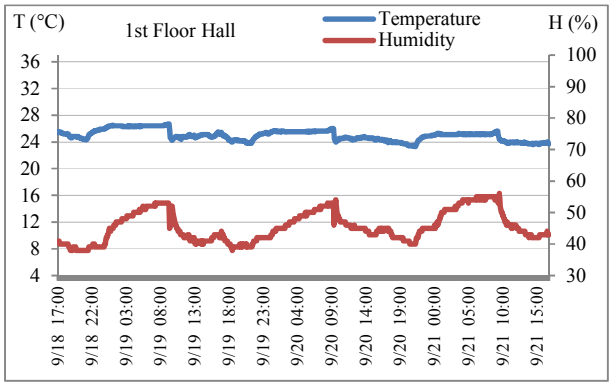

Fig. 3.34: Thermal measurement at 1st floor of Building *B*

For the second floor of the library, measurement equipment was placed in the hall at the location as shown in Figure 3.35. The results of the particular measurement unit are shown in Figure 3.36. Apparently, the hall in the second floor was colder with a temperature of 20°C during working hours. After midnight, the temperature slowly climbed to 24°C. The relative humidity was observed to be around 50% in daytime and gradually peaking to 65% in the dusk.

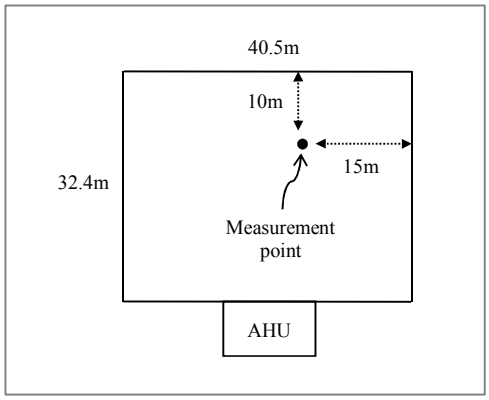

Fig. 3.35: Location of measurement at 2nd floor of Building *B*

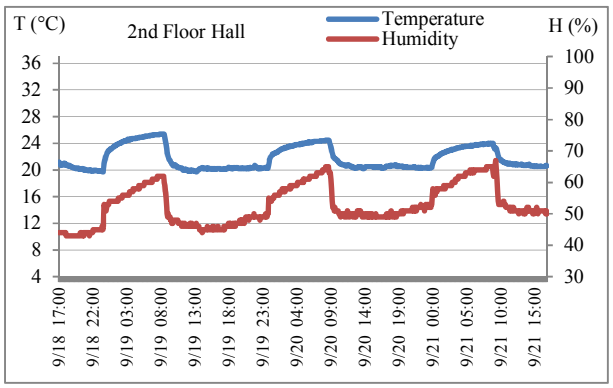

Fig. 3.36: Thermal measurement at 2nd floor of Building *B*

Lastly, measurement equipment was placed at the 3rd floor of Building B as shown in Figure 3.37. The thermal condition of the hall in the 3rd floor is recorded in Figure 3.38. It was observed that the temperature was around 22°C when the library was opened to visitors and increased to 25°C when the library was closed. Humidity level stayed at 50% during operation hours and rose steadily to 65% after the occupants left the building.

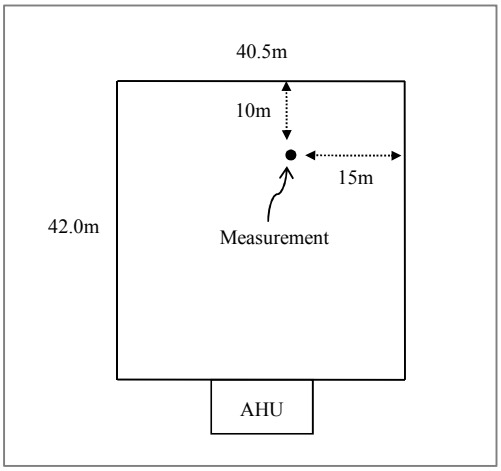

Fig. 3.37: Location of measurement equipment at 3rd floor of Building *B*

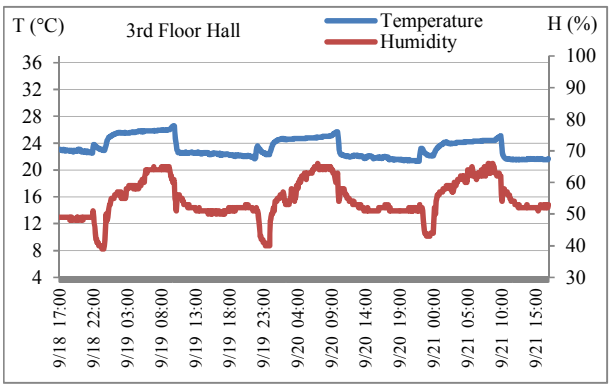

Fig. 3.38: Thermal measurement at 3rd floor of Building *B*

The head of library management revealed that the control of temperature and relative humidity is critical in the preservation of their archival collections. The increase in temperature contributes significantly to the deterioration of manuscripts. High relative humidity will provide more moisture to promote harmful chemical reactions in materials and, in combination with high temperature, encourages mold growth and insect activity. Fluctuations in temperature and relative humidity are also damaging the books. As the paper is capable of absorbing and releasing moisture, they will expand and contract continuously if the indoor climate is not consistent. Dimensional changes will lead to visible damage of the manuscripts. For these reasons, air-conditioning operation was necessary to be maintained 24 hours all year round.

3.3.3 Observation and findings at Building *C*

The last building, denominated as Building *C*, is shown in Figure 3.39 and was a public tertiary learning institution located in Kuala Lumpur. It was a huge 9-storey building and the premise was newly opened in 2012 and can be categorized as multi-purpose consisting office halls, lecture rooms, meeting rooms as well as individual rooms.

Fig. 3.39: View of Building *C*

It was equipped with variable-refrigeration-volume (VRV) system as shown in Figure 3.40. The system utilizes refrigerant as the heat medium to be distributed in the building instead of chilled water. There were many VRV units being installed at the building as it was available in the market in small capacities only.

Fig. 3.40: Variable-refrigeration-volume system at Building *C*

The first measuring sensor was placed at building rooftop as shown in Figure 3.41. From the measurement profile shown in Figure 3.42, it was observed that the peak temperature was 36°C for most of the days. On the third day which was cloudy, the temperature peaked at 32°C. On average, nighttime temperature was 28°C with an exclusion of the fourth night which was raining and the temperature dropped to 24°C. Relative humidity reached the maximum of 99 % during the rainy night, while exceeding at least 75% on the other nights. The RH descended to below 50% on normal days whilst hanging on to 65% on a cloudy day.

Fig. 3.41: Equipment placement at rooftop of Building *C*

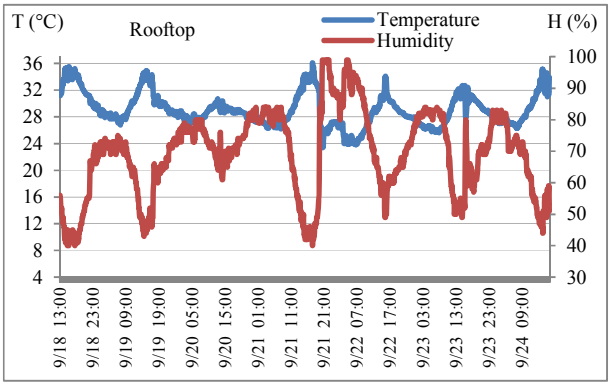

Fig. 3.42: Thermal measurement at rooftop of Building *C*

The office hall of the building was situated at the second floor of the building as shown in Figure 3.43. There were two units of measuring equipment being placed at the office hall. Figure 3.44 shows the first location of measurement equipment.

Fig. 3.43: Office hall of Building *C*

Fig. 3.44: First measurement at 2nd floor office of Building *C*

The thermal data recorded for the particular unit is shown in Figure 3.45. It was observed that the air-conditioning system was switched-on at 8.00 am and switched-off at 6.00 pm. The hall temperature was at 23°C during office hours. The humidity was noted to be around 50%.

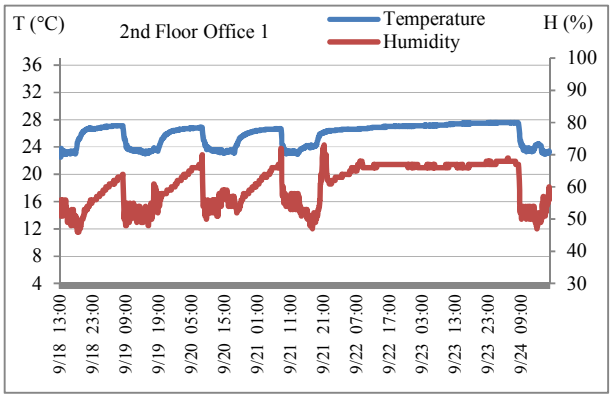

Fig. 3.45: Measurement at location 1 of 2F office of Building *C*

For the second location at second floor, thermal measurement location is shown in Figure 3.46. The results are shown in Figure 3.47. It was observed that space temperature was near to 23°C with a corresponding 55% of relative humidity. The air-conditioning system was not in used during the weekend.

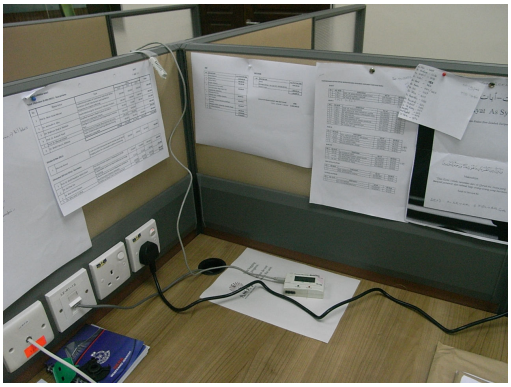

Fig. 3.46: Second measurement point at 2nd floor office of Building *C*

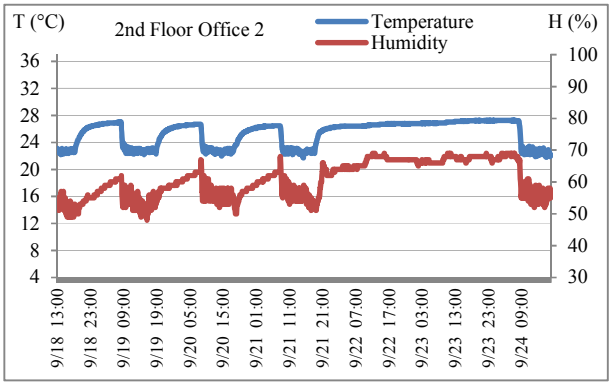

Fig. 3.47: Measurement at location 2 of 2F office of Building *C*

Afterwards, thermal measurement equipment was placed in a smaller office hall at the third floor of Building *C*. The location of the placement is shown in Figure 3.48.

Fig. 3.48: Measurement point at 3rd floor office of Building *C*

The result of thermal data collection for the third floor office is shown in Figure 3.49. In this case, the temperature was observed to be around 24°C with 50% humidity.

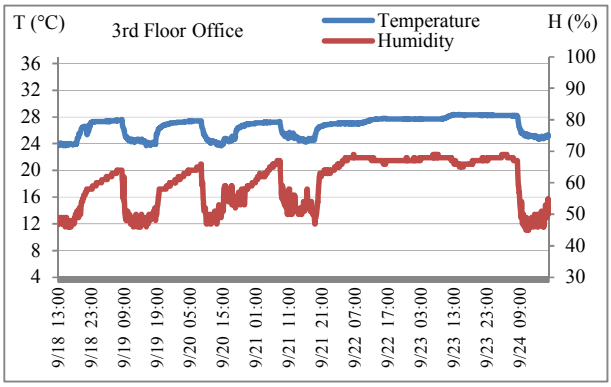

Fig. 3.49: Thermal measurement at 3rd floor hall of Building *C*

Next, the measurement equipment was placed on the lecture room as shown in Figure 3.50. The room can cater to a maximum of 40 occupants in full attendance and the air-conditioning system was in operation only if there was a class activity being held. Figure 3.51 shows the view of measurement point.

Fig. 3.50: Lecture room of Building *C*

Fig. 3.51: Measurement point at lecture room of Building *C*

The outcome of thermal measurement in lecture room is shown in Figure 3.52. The temperature was around 27°C when the class was having a lecture except on one occasion when the temperature was at 24°C. Relative humidity dropped to 45% when the air-conditioning unit was switched on.

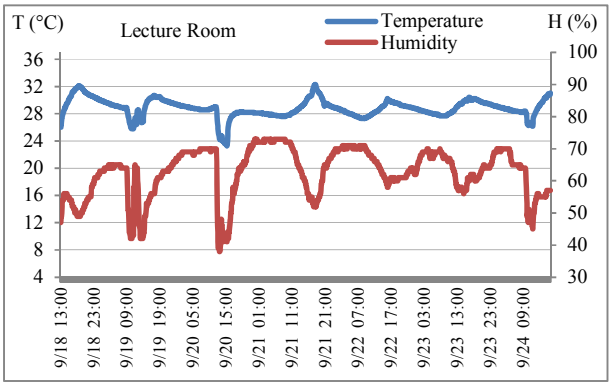

Fig. 3.52: Thermal measurement at lecture room of Building *C*

A small student room that occupies 3 people was next in the measurement. The view of the room is shown in Figure 3.53. As it was located in the middle section of the building, there was no window in the room. Measurement equipment was placed in the room as shown in Figure 3.54.

Fig. 3.53: Small student room of Building *C*

Fig. 3.54: Measurement point at small student room of Building *C*

According to the corresponding data shown in Figure 3.55, the temperature was maintained at 25°C throughout the day. During the occupational period, the humidity was about 60%.

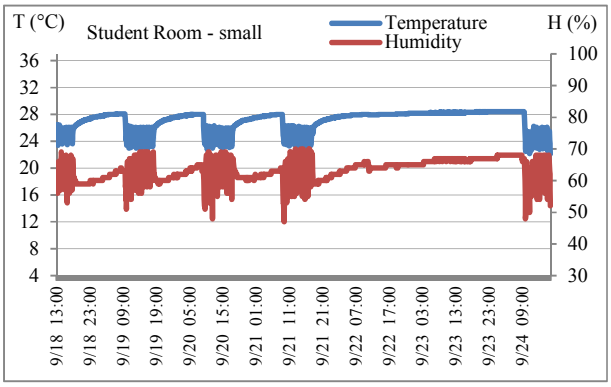

Fig. 3.55: Thermal measurement at small student room of Building *C*

The size and dimension of a post-graduate student room, shown in Figure 3.56, was similar to the lecture room and the seating layout was made for a maximum of 20 occupants.

Fig. 3.56: Student room of Building *C*

Readings from thermal measurement equipment for the post-grad room is shown in Figure 3.57. It was observed that the temperature in the room was around 24°C during office hours with 45% relative humidity.

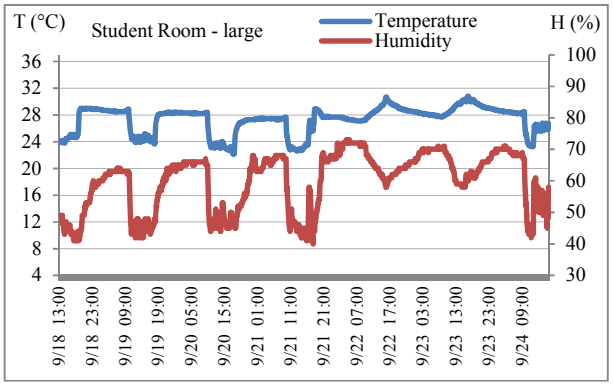

Fig. 3.57: Thermal measurement at large student room of Building *C*

Lastly, the measurement equipment was placed in an individual room as shown in Figure 3.58. The measured thermal profile is shown in Figure 3.59. It is observed that the temperature in the room seems to fluctuate as the person switched-off the air-conditioning unit whenever he leaves the room. The room set point was about 28°C with 55% relative humidity.

Fig. 3.58: Measurement point at individual room of Building *C*

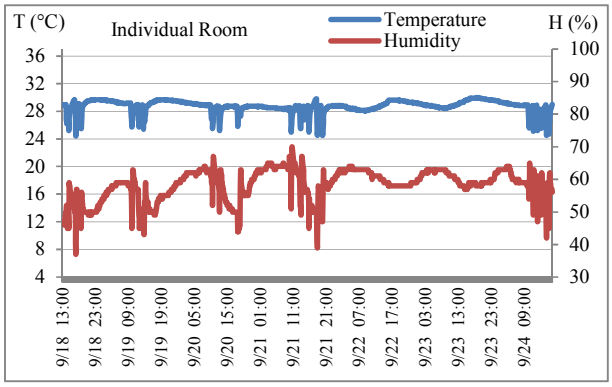

Fig. 3.59: Thermal measurement at individual room of Building *C*

3.4 Summary of results

There are altogether 12 locations of observations from all 3 buildings in which the thermal measurement exercise took part. The summary of indoor average temperature and humidity during occupational hours at the measured locations is gathered in Table 3.1. The lowest of average temperature recorded was 20.6°C in the library 2nd floor of Building *B*, while the highest of average temperature was 27.9°C in the individual room of Building *C*. On the other hand, the lowest of average humidity recorded was 45.2% in the 1st floor of Building *B*, while the highest of average humidity was 68.8% in the office hall of Building *A*.

Table 3.1: Summary of measured temperature and humidity

No.	Location	No. of people	No. of PC	Light (lux)	Occupancy time	Set point temp. (°C)	Mea-sured temp. (°C)	Mea-sured hum. (%)	Out-door temp. (°C)	Out-door hum. (%)
1	Bdg.*A*: Office *2F-1*	30	50	330	8.00-19.00	23.0	23.3	63.6	29.1	65.2
2	Bdg.*A*: Office *2F-2*	30	50	270	8.00-19.00	23.0	23.4	68.8		
3	Bdg.*B*: Library *1F*	80	100	400	8.30-23.30	-	24.6	45.2	30.1	63.9
4	Bdg.*B*: Library *2F*	20	10	270	8.30-23.30	-	20.6	48.9		
5	Bdg.*B*: Library *3F*	10	5	220	8.30-23.30	-	22.5	51.9		
6	Bdg.*C*: Office *2F-1*	20	20	515	8.00-18.00	-	23.7	53.7	30.4	61.3
7	Bdg.*C*: Office *2F-2*	20	20	515	8.00-18.00	-	22.9	55.2		
8	Bdg.*C*: Office 3*F*	20	20	550	8.00-18.00	24.0	24.8	50.8		
9	Bdg.*C*: Lecture room	30	1	460	inconsistent	-	24.9	49.6		
10	Bdg.*C*: Study room-s	3	3	350	9.30-18.00	25.0	24.9	63.8		
11	Bdg.*C*: Study room-b	15	15	660	9.30-18.00	-	24.4	48.0		
12	Bdg.*C*: Individual	1	1	350	inconsistent	28.0	27.9	54.9		

The measured outdoor humidity is high, obviously due to the typical weather condition in Malaysia. Most of the rooms are observed to be practicing low temperature set point. As a result, most of the indoor humidity is also being reduced as well. The high humidity observed in Building *A* is suspected due to the aging air-conditioning system.

The prospect of energy saving strategy and improvement in thermal comfort is to shift the indoor temperature slightly higher but in the same time to hold down the humidity in the middle region.

In order to confirm that the data from the measurement represents the normal situation in Malaysian buildings, the data from previous researches done in 2008 and 2011 are excerpted as shown in Table 3.2. From the table, it is observed that the temperature and humidity is generally low and the trend is consistent to the present measurement.

Table 3.2: Previous research on measured temperature and humidity

	Researchers	Year	Location	Temperature (°C)	Humidity (%)
1	Y.H Yau [1]	2008	Library	23.8	48.7
2	R. Sulaiman, S.N. Kamaruzzaman, S.P Rao, M. Pitt [2]	2011	Office	24.5	53.5
3	Y.H. Yau, B.T. Chew, A.Saifullah [3]	2011	Lecture hall 1	20.8	47.7
4		2011	Lecture hall 2	22.3	48.2
5		2011	Lecture hall 3	21.4	49.0

3.5 Actual room conditions versus thermal comfort standards

Altogether there are 17 room conditions from Table 3.1 and 3.2 and these data are then projected on the same psychrometric chart as shown in Figure 3.60. Thermal comfort zones defined by Malaysian Standard MS1525 and are also included in the chart [4]. It is observed that only 3 room conditions or 17.6% are located within the MS1525 comfort zone and all data are from present measurement exercise. On the other hand, only 5 room conditions or 29.4% are situated inside the ASHRAE Standard 55 comfort zone [5]. The evidence is clear that the majority of occupants inside Malaysian buildings are thermally uncomfortable due to the low set-point room temperature.

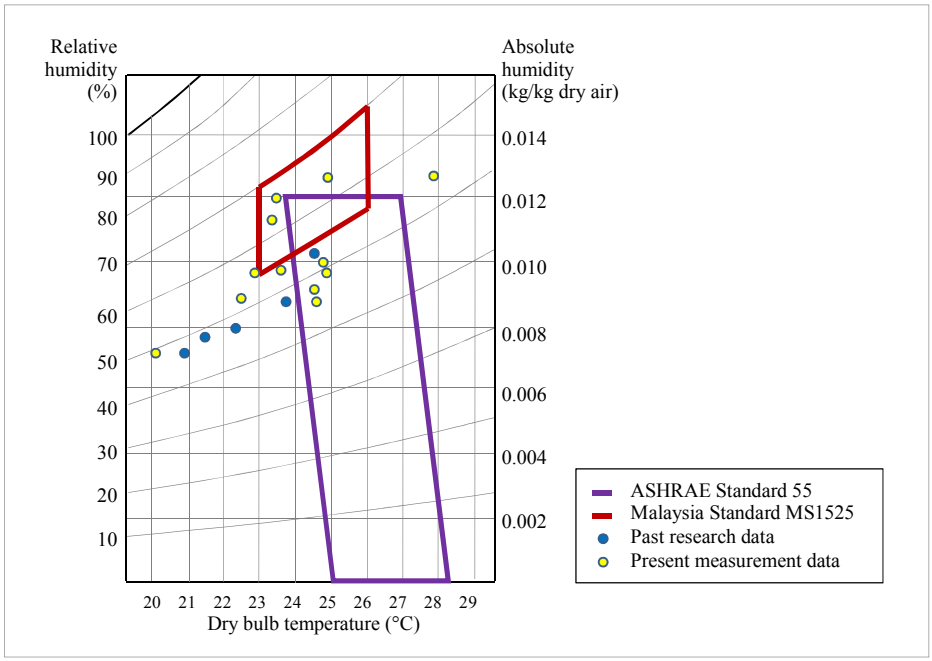

Fig. 3.60: Actual room conditions versus comfort zone standards

In terms of thermal comfort, the current room condition is slightly cold and uncomfortable. However, it is customary for tropical buildings to have a low temperature setup. In addition, this will affect the energy consumption of the building. Therefore, for the proposed air-conditioning system, a slightly higher temperature set-point is preferable. The humidity should be in the middle range to maintain comfort.

3.6 Conclusion

In this chapter, a field study was carried out to measure the temperature and humidity in a total of 12 air-conditioned rooms located in 3 different buildings in Malaysia. The results showed that only 17.6% and 29.4% of the rooms were within the comfort zone defined by Malaysian Standard MS1525 and ASHRAE Standard 55 respectively. Most of the indoor temperature set-point was found to be low in readings. As a result, the indoor humidity was reduced as well. The observation results confirm that the existing air-conditioning system in Malaysia is not suitable to be used and brings an undesirable effect to indoor thermal comfort.

The prospect of energy saving strategy and improvement in thermal comfort is to shift the indoor temperature slightly higher and in the same time to peg the relative humidity in the middle zone. Further analysis of the enhanced comfort zone is required together with the study of a new concept of energy-efficient air-conditioning system.

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CHAPTER 4

Solution Analysis

4.1 Introduction

From the discussions in previous chapters, the solution to overcome the excessive humidity that occurs in tropical country such as Malaysia leads to the requirement of an innovative design of latent cooling air-conditioning system. Latent cooling basically works as a dehumidifier that reduces the moisture in the air, in contrast to sensible cooling that removes heat to maintain the air temperature. Cooling coil is needed to transform the moisture into water droplets at a relatively low temperature. The accumulated water, known as the condensate is then collected and drained out. In the process, the dehumidifier reduces the absolute humidity of the processed air. In addition, a control system is required to monitor the dehumidification process so that the room humidity is maintained at the desired level.

4.2 Objective

The objective of this chapter is to find the suitable solution for the problems faced by Malaysian buildings and subsequently define the design criteria required in the proposed air-conditioning system. The solution should overcome the hindrance faced by the existing air-conditioning and dehumidification system. The design concept of a new air-conditioning system is then explained, having the features that fit into the solution requirements.

4.3 Strategy to overcome the problems

Much has been said of the problems faced by Malaysian buildings as per discussion in Chapter 1-3. The answer to the problems requires a holistic approach as the problems links to each other. Therefore, the best solution is as proposed in Table 4.1.

Table 4.1: Summary of the problems and solutions

	Problem	Solution
1	High building energy consumption	Shift to higher temperature set-point
2	Unsatisfactory indoor thermal comfort	Identification of a new room condition
3	Inability to remove sensible and latent load in correct proportion	Independent temperature and humidity control
4	High initial cost of dehumidification system	Simple design and control system by using 2 AHUs

The situation of high energy consumption and unsatisfactory indoor thermal comfort faced by tropical buildings is caused by the unsuitable design of existing air-conditioning system. Therefore, a few enhancements have to be done in the new system to improve its performance. The modifications should fit the following 3 major criteria of the new design of air-conditioning system:

i. Effective in reducing building energy consumption.
ii. Able to provide a better human comfort zone.
iii. Capable of keeping the desired indoor temperature and humidity.
iv. Possessing a low initial cost of equipment and installation.

The necessity of humidity control is vital in the proposed air-conditioning system. In the existing system, the cooling coil in the air handling unit (AHU) failed to offset the sensible and latent loads of the room in the correct proportion. The situation occurs since the AHU is designed only to control the temperature of the room. Hence, in a high humidity environment of tropical climate, the AHU can only removes the moisture from the air at a reduced rate.

As an enhancement in the new system, it is necessary to add the humidity control in order to monitor the dehumidification process. As the existing AHU is already handed the task of temperature control, the duty to control the humidity has to be assigned to other equipment. In order to keep low initial cost of the proposed system, the use of additional AHU for humidity control is deemed the best solution.

4.4 Implication of the equipment cost

For a developing country like Malaysia, the initial cost of a system during the procurement stage is indeed crucial. This situation has been confirmed by the air-conditioning designer as reported in Chapter 2. The constraint in equipment cost is the main factor causing the existing system of outdoor air latent cooling using desiccant materials is unpopular in the country.

Typical dehumidification system utilizes desiccant material to attract moisture from the treated air. The moisture is then retained within the desiccant material and can be released when heated. As the desiccant can only hold a certain volume of water, the process requires works in a cycle of repetition. Therefore, the desiccant material is manufactured in a wheel shape and be able to move in rotation. There are various types of desiccant available in the market but the typical choice is silica gel [1].

The desiccant-type latent cooling system is proven to work effectively in high and low temperature background. It can be used for industrial purposes as well as for human-occupied room. Nevertheless, due to its design configuration, the system is rather expensive to purchase and to install. In the new system, it is important to consider a simple yet effective air-conditioning configuration. A feasible solution is by using an additional air handling unit to handle the humidity. The AHU is a relatively cost equipment and familiar to install. Likewise, a simple control setup is required to make it affordable in the market.

4.5 Enhancement to thermal comfort zone

The existing thermal comfort zone defined by Malaysian Standard MS1525 is found to be unpractical based on the actual observation findings. Therefore, an enhanced comfort zone that is energy-friendly has to be defined. The first step is to shift up the temperature a few degrees. The caveat in the practice is that the humidity level must be kept to a low level to avoid the damp situation that leads to the uncomfortable condition. Therefore, the proposed comfort temperature is suggested to be in the region of 25-26.5°C but in lower humidity zone of 40-55% RH.

Based on past research of thermal comfort in Malaysia, the interesting highlights are the neutral value of indoor temperature and its comfort range. The results are summarized in Table 4.2 for space with air-conditioning. The average comfort range is found to be in the region of 24.9 - 27.2°C with an average neutral temperature of 26.1°C.

Table 4.2: Past studies of thermal comfort

	Researcher	Year	Neutral value	Comfort range
1.	R. Daghigh et.al [2]	2009	26.1 °C	25.8 - 26.3 °C
2.	Y.H Yau et.al [3]	2011	26.4 °C	25.3 - 28.2 °C
3.	Y.H Yau et.al [4]	2011	25.3 °C	23.8 - 26.6 °C
4.	F. Azizpour et.al [5]	2011	26.6 °C	24.6 - 27.6 °C

The option of employing higher temperature set-point of 26°C in a room of tropical building and its effect to thermal comfort has been studied by Sekhar [2]. The research will adopt the same temperature of 26°C for case study purposes later for the set-point of the new system. As the proposed system is equipped with humidity control, relative humidity level of 50% and below is deemed suitable for the occupants. As shown in Figure 4.1, the recommended room conditions of 26°C and 50% is well inside the ASHRAE standard zone and should be thermally acceptable [3-4].

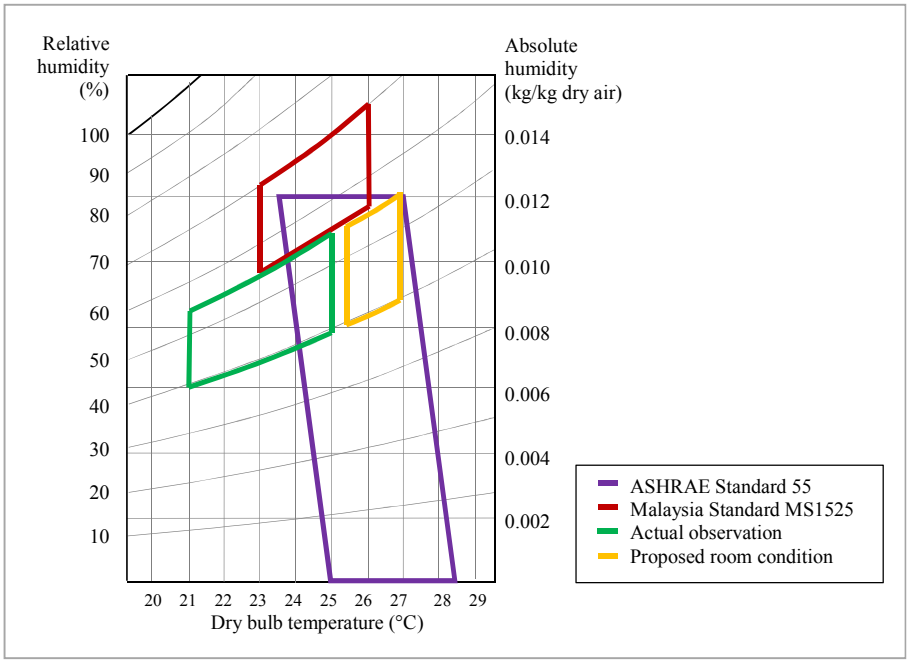

Fig. 4.2: Thermal comfort zones and room conditions

A more thorough inspection between the actual and proposed room condition through predicted mean vote (PMV) calculation is shown in Table 4.3. As the existing air-conditioning system does not offer any humidity control, the resultant humidity of 63% in the actual room condition is not objective and may differ according to cooling coil performance and room heat gain. The calculated PMV of the actual room condition shows that the occupants is rather suffering due to excessive coolness compared to the neutral situation achieved in the proposed room condition.

Table 4.3: PMV comparison between actual and proposed condition

	Actual condition	Proposed condition
Air temperature	23°C	26°C
Mean radiant temperature	23°C	26°C
Relative humidity	63%	50%
Metabolic rate	1.1 met	1.1 met
Thermal resistance of clothing	0.5 clo	0.5 clo
Air velocity	0.1 m/s	0.1 m/s
PMV	-0.696	0.202
PMV scale	slightly cool	neutral

4.6 Design concept of the proposed air-conditioning system

The new system to be proposed is introduced as Dual AHU system. As the name suggests, the system requires 2 AHUs in parallel configuration to serve a common room. It has some unique features in order to serve the requirement of human comfort in tropical buildings. However, it possesses low initial cost by the usage of off-the-shelf equipment in order to make it affordable. Both AHU1 and AHU2 construction is of normal design and specification that could be found in most commercial AHU catalogue. In order to avoid confusion, the first AHU is identified as AHU1 and the second AHU is termed as AHU2.

In the new system, AHU1 is given the task to control the temperature inside the room while AHU2 is assigned to control the indoor humidity. For that matter, AHU1 may also be referred as the Sensible AHU and AHU2 might also be mentioned as the Latent AHU. Bear in mind that notwithstanding the name, Latent AHU will not only remove latent heat while doing its job, but handling the sensible heat as well. Hence, the function of AHU1 is to complement AHU2 by getting rid of the remaining sensible heat in order to reach the temperature set-point. If necessary, AHU1 can be utilized to assist AHU2 in reducing the humidity through a low supply air temperature.

AHU2 will handle the humidity set-point with the purpose of dehumidifying the huge amount of moisture in the conditioned room. The Latent AHU evaporator coil must be cold enough in order to fulfil its task. Therefore, its supply air temperature needs to be sufficiently low, indeed below the dew point in order to carry its duty. As the humidity is being kept to a low level by the Latent AHU, it creates an opportunity for energy savings by allowing the shift of temperature set-point higher than that of normal air conditioning practice in tropical buildings.

The sensors are one of the important components of the system for monitoring and giving feedback signals to the valves and dampers. In the new system, humidity sensor is required for the Latent AHU configuration in addition to the temperature sensor for the Sensible AHU. Although the humidity sensor may not be a regular apparatus in conventional air-conditioning, its procurement cost is more or less similar to that of regular temperature sensor. In terms of air distribution, normal over-head ducting system would serve the system operation well enough. In short, the usage of familiar equipment and mechanisms is essential from the erection point of view, as it ensures low expenses for the installation service works.

4.7 Design configuration in CAV and VAV system

The schematic diagram of the constant-air-volume (CAV) system is shown in Figure 4.2. Temperature sensor gives the feedback to AHU1, whose valve will regulates accordingly. On the other hand, humidity sensor sends the signal to AHU2 and the corresponding valve adjusts itself according to the humidity set-point. As the outdoor air contains latent heat, the task of handling fresh air is given to the Latent AHU only.

The supply air produced by both AHUs will mix in the duct before being distributed to the conditioned room. Subsequently, the return air will flow straightaway to AHU1 but for AHU2, the return air will mix with the incoming fresh air.

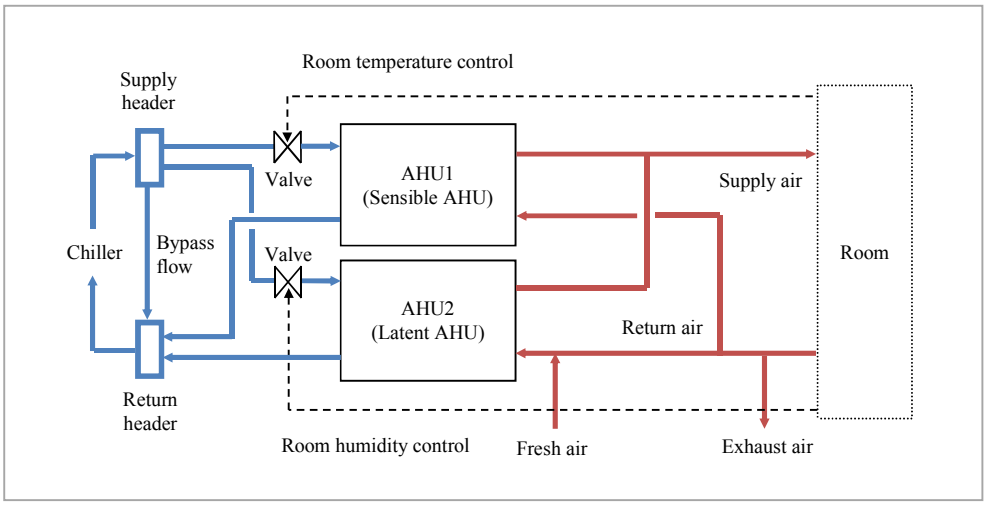

Fig. 4.2: Schematic diagram of Dual AHU in CAV system

Figure 4.4 shows the schematic diagram of the Dual AHU configuration in variable-air-volume VAV system. Similar to the setup in normal air-conditioning, temperature sensor of the supply air will give the feedback signal to the AHU1 valve which in turn adjusts itself corresponding to the set-point. Room temperature is monitored by the damper which will vary its opening accordingly. AHU2 is also equipped with supply air temperature sensor which is connected to its valve.

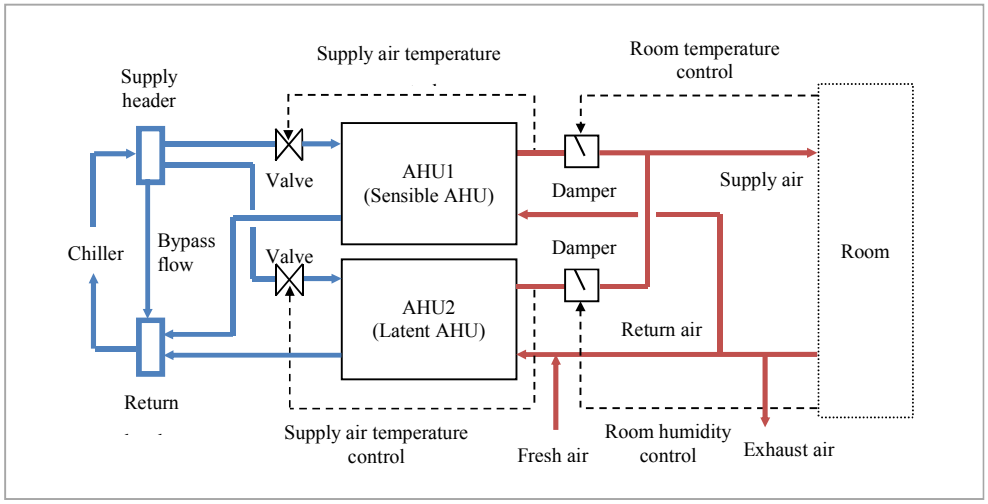

Fig. 4.3: Schematic diagram of Dual AHU in VAV system

Room humidity control is taken care by the damper with the help of a sensor. In order to ensure continuous flow of chilled water and supply air, the valves are set to a minimum opening of 5% and the dampers are fixed to operate at a minimum of 10%.

4.8 Conclusion

The solution to the problems through the proposal of a new air-conditioning design to be used in Malaysia has been presented. The weakness point of existing dehumidification system due to high equipment cost has been resolved by using an additional AHU that is relatively cheaper but capable in handling the task of humidity control. The unpractical thermal comfort zone of MS1525 and the high energy consumption of existing room condition have been replaced by a new comfort zone of 25-26.5°C in temperature and 40-55% in relative humidity which is more energy-friendly. The next step is to prove that these solutions are the best for Malaysian buildings.

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CHAPTER 5

Performance of the Proposed Air-conditioning System

5.1 Introduction

The solution requirement and the design concept of Dual AHU system has been presented in the previous chapter. The final step of the research is to demonstrate the behavior of the proposed air-conditioning system in solving the problems faced by Malaysian buildings. In order to do so, a reliable simulation program is employed to execute the task. Since the proposed system currently does not exist, it is necessary to setup the new system according to the design concept in the simulation program. In addition, calculations for air mixtures and room conditions have to be carefully added where necessary.

5.2 Objective

The purpose of this chapter is to evaluate the performance of the proposed air-conditioning system. The analysis will utilize a simulation program to compare the new system against the normal air-conditioning system. The important aspect in the comparison is the temperature and humidity of the room as well as the energy consumption. The outcome form this chapter will determine whether or not the proposed Dual AHU system is really the right solution.

5.3 Simulation model and system description

The characteristic of Dual AHU system is analyzed through a simulation using dynamic thermal load calculation program. Fortran-based HASP/ACLD/8501 program is used for the simulation for the building model [1]. The proposed Dual AHU system is modelled to run continuously throughout the year in a fictitious square-shaped office building. Simulation setup for the building model is shown in Table 5.1.

Table 5.1: Building setup in HASP/ACLD/8501 program

Latitude & longitude	3.148° & 101.693°
Building height	5.6 m
Room dimension	(40 x 20) m
No. of rooms	3
Reference temperature	26 °C
Reference relative humidity	50 %
Solar reflectance	10 %
Solar radiation limit	250 kcal/m^{2}h
Outer solar absorption rate	80 %
Outer solar emissivity	90 %
Lighting capacity	20 W/m^2
Illuminance	700 lux
Occupant activity	Office work, light walking
Indoor heater cooling method	Natural heat dissipation
Indoor heater latent heat	0 kcal/h
Indoor sensible heat capacity	10 kcal/m^2.°C
Indoor latent heat capacity	20 kcal/ m^2.(g/kg)
Wall - plasterboard, concrete, mortar, tile	(12 x 150 x 20 x 8) mm
Floor - plastic tiles, concrete, plaster board	(3 x 150 x 9) mm
Window - endothermic glass	8 mm

In order to simulate the proposed air-conditioning system, a new program has been developed with the combination of equipment sub-models from HASP/ACSS/8502 [2]. The original control models are altered accordingly to suit the new design.

The schematic diagram of the air-conditioning system is shown in Figure 5.1. The blue line represents chilled water flow, the red line denotes air flow and the purple line is for condenser water flow. Figure 5.2 shows the structure of the simulation program. The code of program is based on Fortran 77 language. The flow of simulation process is shown in Figure 5.3.

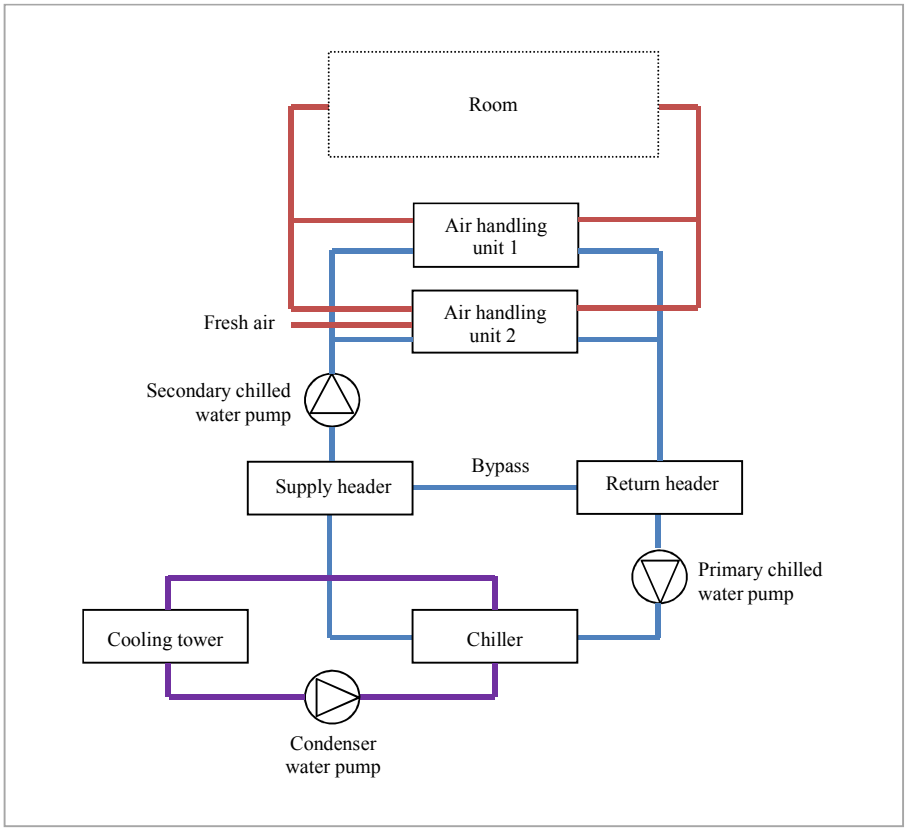


Fig. 5.1: Schematic diagram of the air-conditioning system

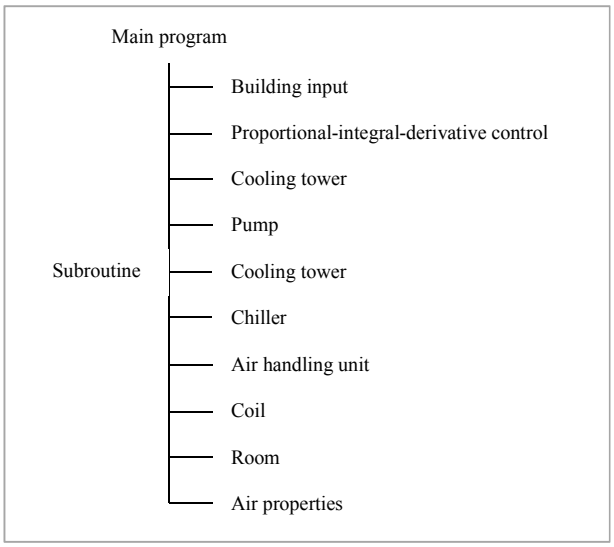


Fig. 5.2: Structure of simulation program

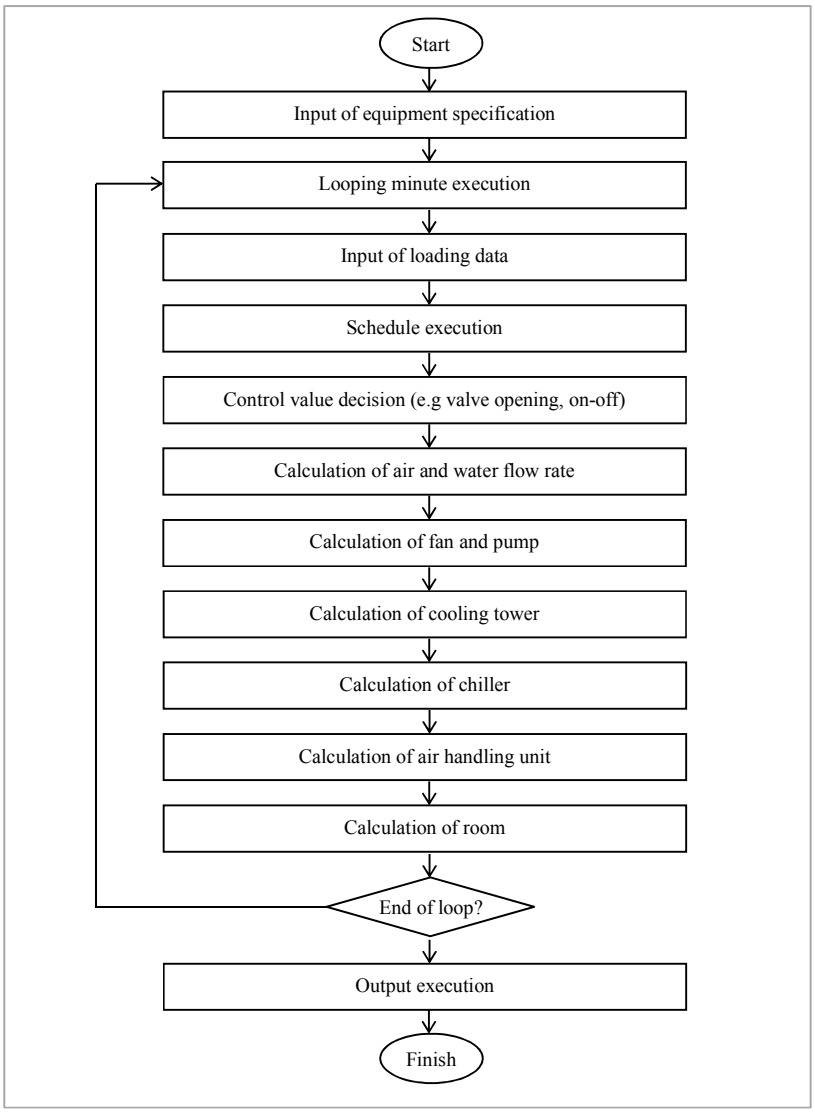


Fig. 5.3: Flow of simulation process

Simulation setup for the air-conditioning system is shown in Table 5.2. For the climate input, actual meteorological weather data of Kuala Lumpur is used in the simulation [3]. Although the local building regulations currently specify the minimum outside air of 2.3 liter/s per person, fresh air quantity of 10.0 liter/s per person is used in the simulation. This is in accord with the ventilation requirements specified by ASHRAE Standard 62.1 [4]. The simulation time interval is set for 1 minute.

Table 5.2: Air-conditioning simulation setup

Chiller capacity	984.6 kW
Chiller water flow	302.4 m^3/h
Chiller power	186.0 kW
Chilled water pump flow rate	302.4 m^3/h
Chilled water pump head	20 m
Chilled water pump power	20 kW
Cooling tower capacity	1,582.3 kW
Cooling tower air volume	945,000 m^3/h
Cooling tower water volume	381.6 m^3/h
Cooling tower power	11.0 kW
Condenser water pump flow rate	381.6 m^3/h
Condenser water pump head	20 m
Condenser water pump power	15 kW

5.4 Case study

Simulation case study is divided into two air-conditioning system configuration which are constant air volume (CAV) and variable air volume (VAV). In each configuration, the research is further expanded in to 3 analysis as follows:

i. AHU size ratio analysis
ii. Latent heat analysis
iii. Energy analysis

The AHU size ratio analysis is necessary since there are 2 AHUs in the new system, thus it allows for the combination of size percentage between them, namely 10:90, 20:80, 30:70, 40:60, 50:50, 60:40, 70:30, 80:20 and 90:10. In short, size ratio 20:80 means that the size of AHU1 and AHU2 is 20% and 80% respectively of the total cooling capacity.

Latent heat analysis is required in order to evaluate the performance of the proposed air-conditioning system in the variation of indoor latent heat through changes in occupancy. By varying room occupancy, the average sensible heat factor (SHF) is adjusted. As the fresh air flow is a fixed value but the AHU2 size varies in each size ratio, the percentage of outdoor air in AHU2 varies accordingly. The occupancy variation is shown in Table 5.3.

Table 5.3: Occupancy variation

Occupancy (person/m^2)	SHF
0.1	0.742
0.2	0.698
0.3	0.668
0.4	0.644
0.5	0.628

Last but not least, the energy analysis is the most important study in the research in order to justify the feasibility of the proposed air-conditioning system. Remember that the two AHUs are tasked for different functions therefore the varying blend of AHU size will produce a unique results in terms of thermal parameters and energy consumption.

5.4.1 Dual AHU in CAV system

The flow of logic control is shown in Figure 5.4. The specification of water-cooled chiller, cooling tower, pumps and air handling unit are all part of the input of the simulation program. There is no outdoor air for Sensible AHU. The valve is programmed to utilize PID (proportional-integral-derivative) control to regulate chilled water flow. Therefore, the valve will react to the difference between measured variable of current room temperature and the set-point of 26°C.

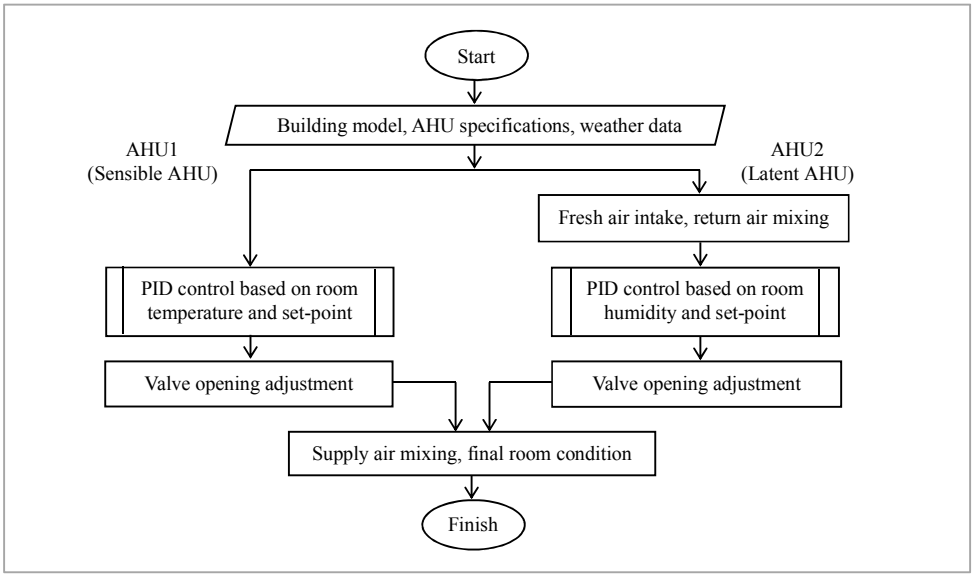


Fig. 5.4: Logic control algorithm of CAV system

The same goes to the AHU2, only that the measured variable is the room relative humidity and the set-point is 50%. As a result, the corresponding valve will adjust itself after receiving the output from the PID controller. As to ensure continuous flow of chilled water inside the AHUs, a minimum flow of 5% is fixed in the valve setup.

The simple arrangement of the proposed air-conditioning system is made possible due to the fact that the outdoor thermal condition of Malaysia is rather consistent. The mild fluctuation of ambient temperature and humidity brings stability to the room condition hence helping the simple configuration system to function effectively as proven by the simulation results.

The psychrometric process for AHU size ratio 60:40 is shown in Figure 5.5. At point ② in the figure, the hot and humid outdoor air mixes with the return

air in Latent AHU. The point of mixing is unique for each AHU size ratio, due to the difference in the percentage of fresh air-return air flow rate. The mixture flows through the cooling coil in which it is cooled sensibly until the saturation point. The saturated air is being cooled at its dew point and the moisture turns into liquid form. The condensate is collected before being drained eventually.

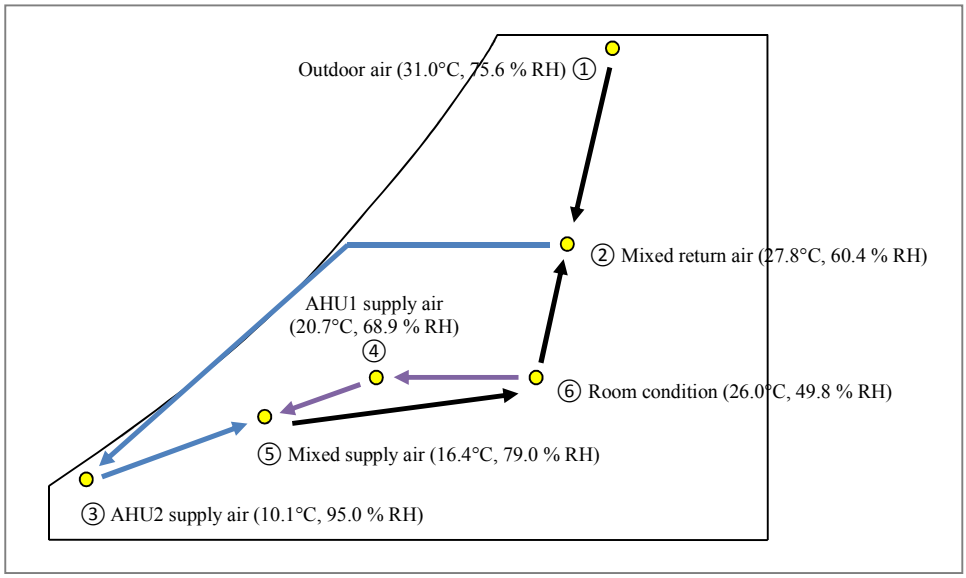


Fig. 5.5: Psychrometric process of AHU size ratio 60:40

On the other hand, the return air inside Sensible AHU is cooled in sensible manner until point ④. The supply air produced in both AHUs mixes together at point ⑤ in the figure before being distributed into the room.

Cooling load profile comparison amongst the AHU size ratios inside the conditioned room is shown in Figure 5.6 from size ratio 20:80 until 50:50. Figure 5.3(a) shows that for size ratio 20:80, AHU1 size is too small that it can only removes a minor fraction of the total sensible heat. As explained before, AHU1 does not handle any latent heat in all cases of size ratio. That explains its zero value of latent heat in all case studies.

On the other hand, AHU2 eliminates a large portion of sensible and latent heat due to its relatively bigger size in size ratio 20:80. As the volume of AHU1 becomes bigger in size ratio 30:70 and onwards, it removes the sensible heat more while the effect of AHU2 becomes less. Note that even though the size of both AHUs is identical in size ratio 50:50, the amount of heat being removed is not similar. It was due to the difference in valve response to either temperature or humidity in each AHU setup.

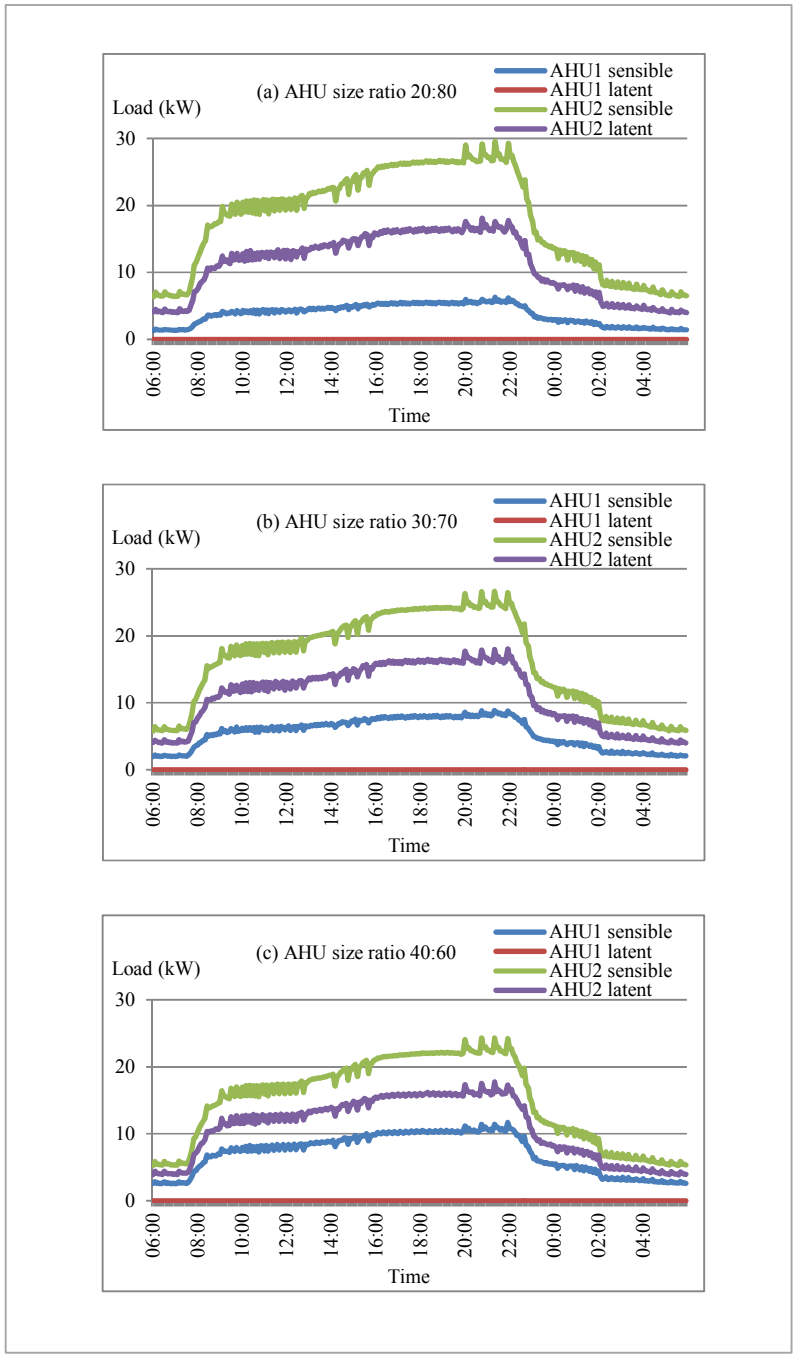


Fig. 5.6: Cooling load profile of CAV system

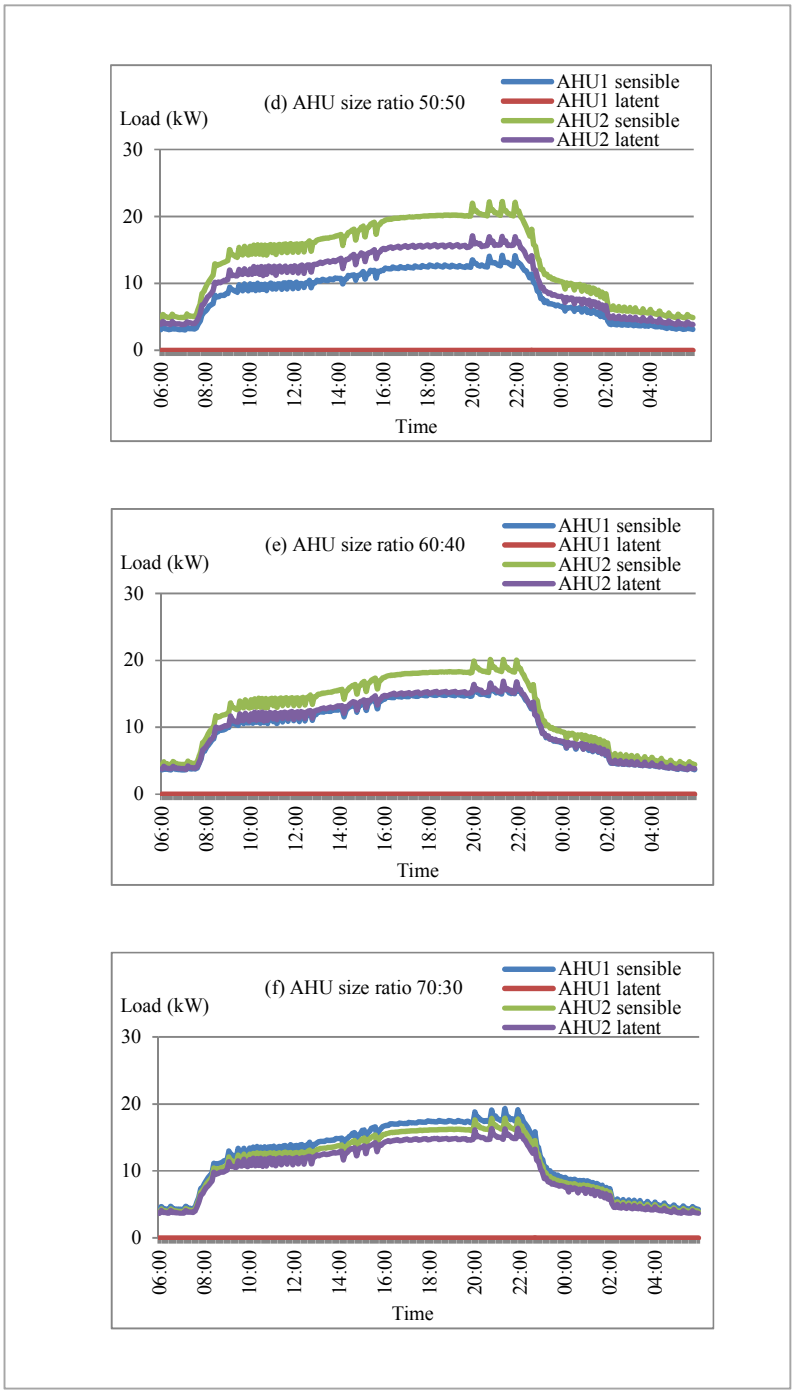


Fig. 5.6: Cooling load profile of CAV system (cont'd)

In the research, it is important to study the situation of room condition for each AHU size ratio with the comparison vis-a-vis normal air-conditioning system. The objective is to examine the room condition in terms of temperature and relative humidity for all options. However, changing the capacity of the AHUs resulted in some restrictions of its function as shown in Table 5.4.

Table 5.4: Restrictions of system function in case study

System	Description	Temperature set-point	Humidity set-point	Rated flow (m^3/h)	Fresh air supply	Remarks
1. Dual AHU	Size ratio 0:100	-	50%	22,400	Yes	AHU1 not functioning
2. Dual AHU	Size ratio from 10:90 to 90:10	26°C	50%	22,400	Yes	AHU2 too small at 80:20 & 90:10, inadequate fresh air
3. Dual AHU	Size ratio 100:0	26°C	-	22,400	-	AHU2 not functioning
4. Normal air-cond.	Base case 1	23°C	-	30,880	Yes	
5. Normal air-cond.	Base case 2	26°C	-	30,880	Yes	

The simulation results of the effect of AHU size ratio to the room condition is shown in Figure 5.7. The figures are shown for SHF values between 0.742 and 0.628. The fact that AHU1 responds to temperature set-point and AHU2 reacts to humidity set-point is critical in the assessment.

The analysis begins from the right side of the figure which is size ratio 100:0, given that it is almost similar to the situation in normal air-conditioning system. At 100:0, AHU2 is totally switched off leaving AHU1 functioning alone. Therefore, the room space is fixed at 26°C without any humidity control system. Furthermore, the non-operation of AHU2 deprives the room of any fresh air. The base case of normal air-conditioning temperature of 23°C and 26°C with the resulting humidity is shown side-by-side with size ratio 100:0 of Dual AHU system.

At size ratio 90:10, AHU2 is now in operation but too small in size thus a slight reduction in room humidity is observed. Fresh air intake is noted but inadequate for the occupants. Eventually at size ratio 60:40, the combination of both AHUs managed to lower the room relative humidity to the specified design condition of at least 50% RH. The room humidity value keeps on dropping as the Latent AHU becomes relatively bigger in size.

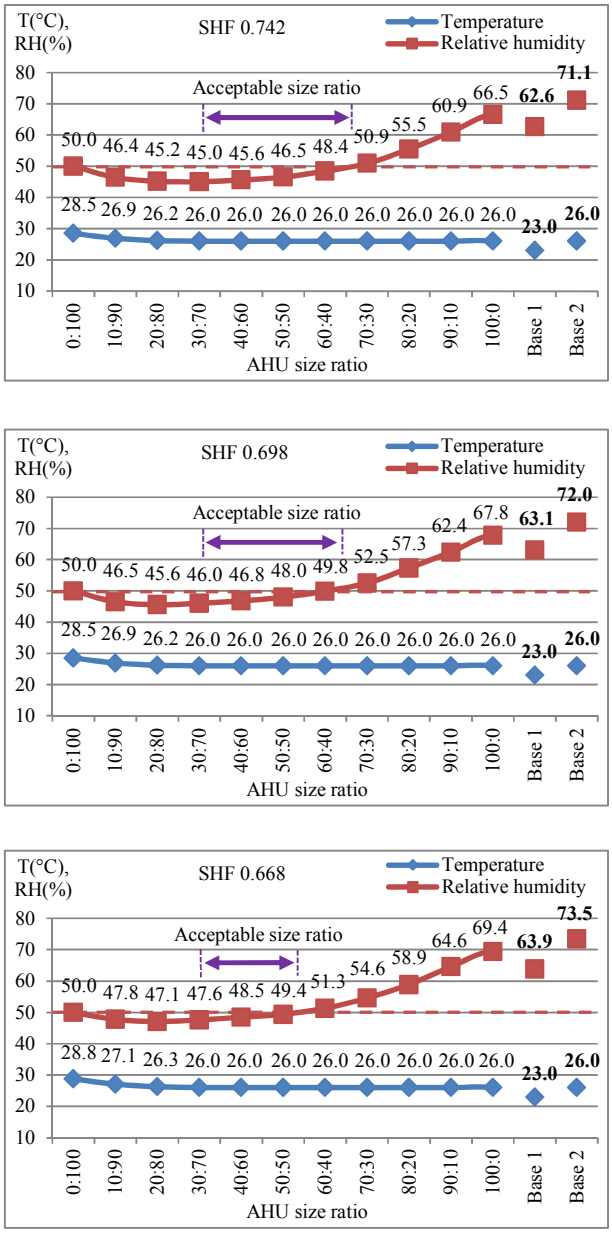
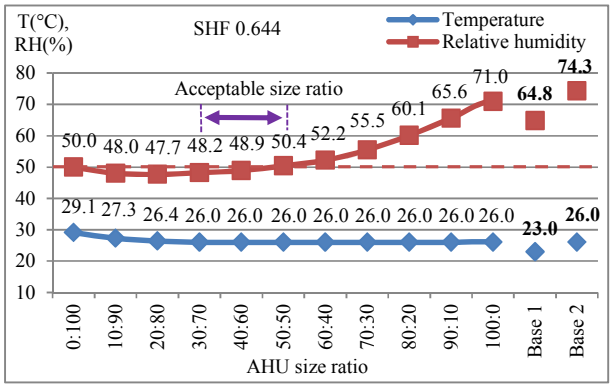


Fig. 5.7: Room condition of CAV system



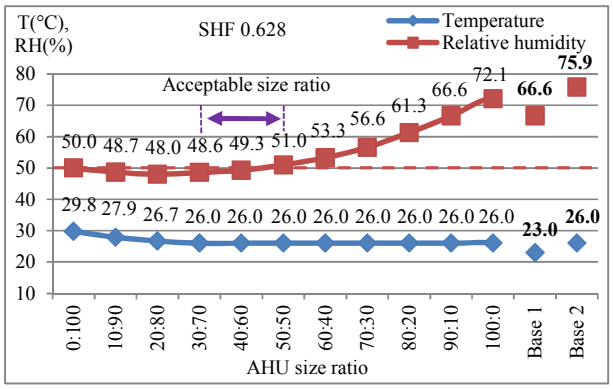


Fig. 5.7: Room condition of CAV system (cont'd)

In addition, larger capacity of AHU2 increases the fraction of outdoor air to fresh air percentage. At size ratio 20:80, the AHU1 is too small in size to hold the room temperature at set-point value and starts to concede its control. The temperature yielding shifts the room humidity upwards. Finally at size ratio 0:100, AHU1 is switched off altogether leaving the AHU2 solely functioning. As a result, the room space is pegged at 50% humidity but without any temperature control system.

Since the design of indoor room condition is decided to be 26°C of temperature and 50% of relative humidity, it is noticed that not all size ratios in case study of Figure 5.4 is able to fulfill the planned criteria. Only 4 size ratios from 30:70 to 60:40 are identified to be acceptable. It is observed that the range of acceptable AHU size ratios is a function of indoor latent heat. Therefore, it is necessary to study the effect of latent heat addition to the room.

The average SHF is changed to 0.668 by increasing the room occupancy to 0.3 person/m^2 and the fresh air intake is increased to 8,640 m^3/h. As a result, size ratio 60:40 is now out of favor as its relative humidity leaps above the 50% threshold. In addition, the acceptable AHU size ratios shrink to only 3 options.

Figure 5.8 is the projection of the available size ratio options for the room of case study. For a relatively high SHF at 0.742, the choices of AHU size ratio vary from 30:70 to 70:30. As the latent heat increases, the SHF drops and size ratio options shrinks gradually.

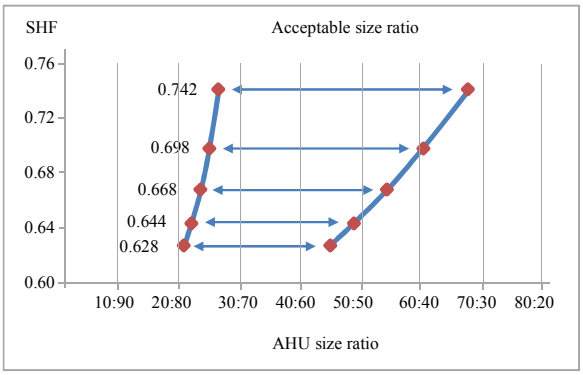


Fig. 5.8: Acceptable AHU size ratio of CAV system

The analysis of energy consumption is the utmost important in the research. Energy savings in Dual AHU system is fairly expected due to the reduced air-conditioning load. The new system with optional size ratios is compared against the base case of standalone AHU with temperature set-point of 23°C and 26°C.

The results of simulation are presented in Figure 5.9. The figures are shown for SHF values between 0.742 and 0.628. All size ratios in the proposed system offer a significant reduction in energy consumption compared to normal air-conditioning. Although normal air-conditioning system at 26°C is also using relatively less energy consumption, room condition from this setup is thermally uncomfortable to the occupants. The decline of chiller load of primary equipment is obviously due to the raise of temperature from 23°C to 26°C.

In the energy consumption figure, only the AHU size ratios in the acceptable range according to Figure 5.5 are put into consideration. That explains the absent of size ratio 60:40 and 50:50 in the lower SHF case studies in Figure 5.6.

The drop in cooling load due to the raised temperature resulted in smaller AHUs being used thus smaller fan is suffice enough to handle the reduced air flow. The combination of similar size AHUs in size ratio 50:50 exhibits the highest fan energy consumption and size ratio 30:70 displays the least. The overall savings for CAV ranged between 10.2% and 13.6% with the most savings offered in SHF 0.628.

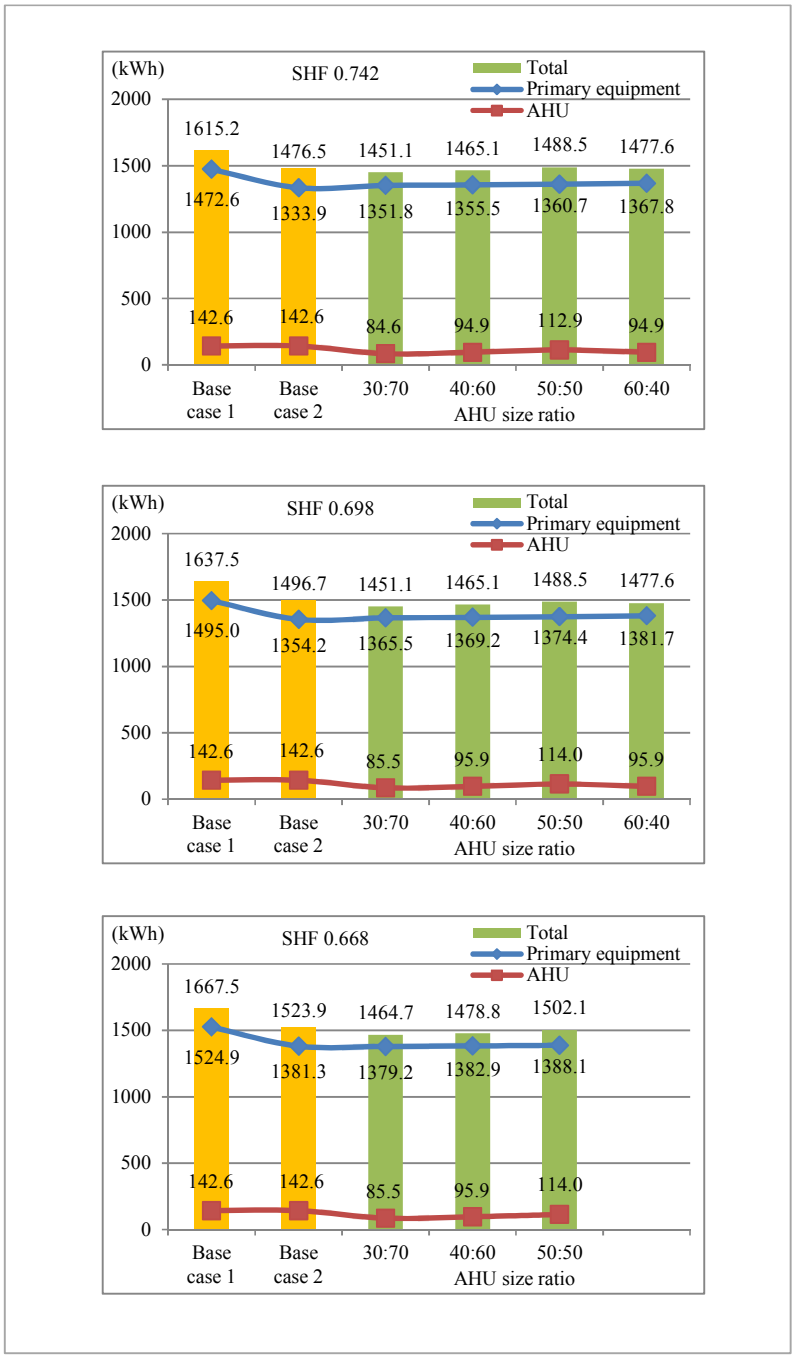


Fig. 5.9: Energy consumption of CAV system

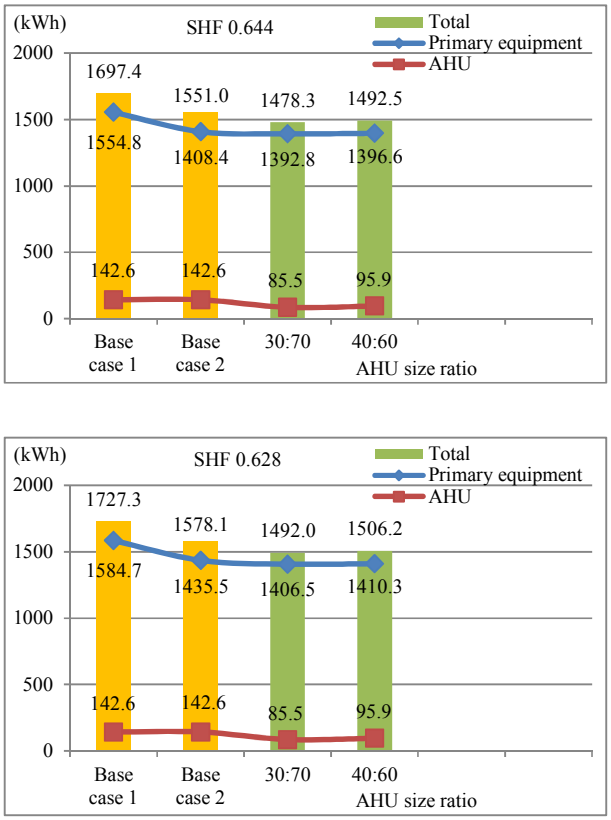


Fig. 5.9: Energy consumption of CAV system (cont'd)

5.3.2 Dual AHU in VAV system

The flow of logic control for VAV system is shown in Figure 5.10. It is similar to that of CAV system but with the additional function of damper control. The valves for both AHUs are assigned to maintain the supply air temperature at their set-points. AHU1 supply air set-point is fixed at 18°C so that the temperature difference between the room and the supply air is 8°C.

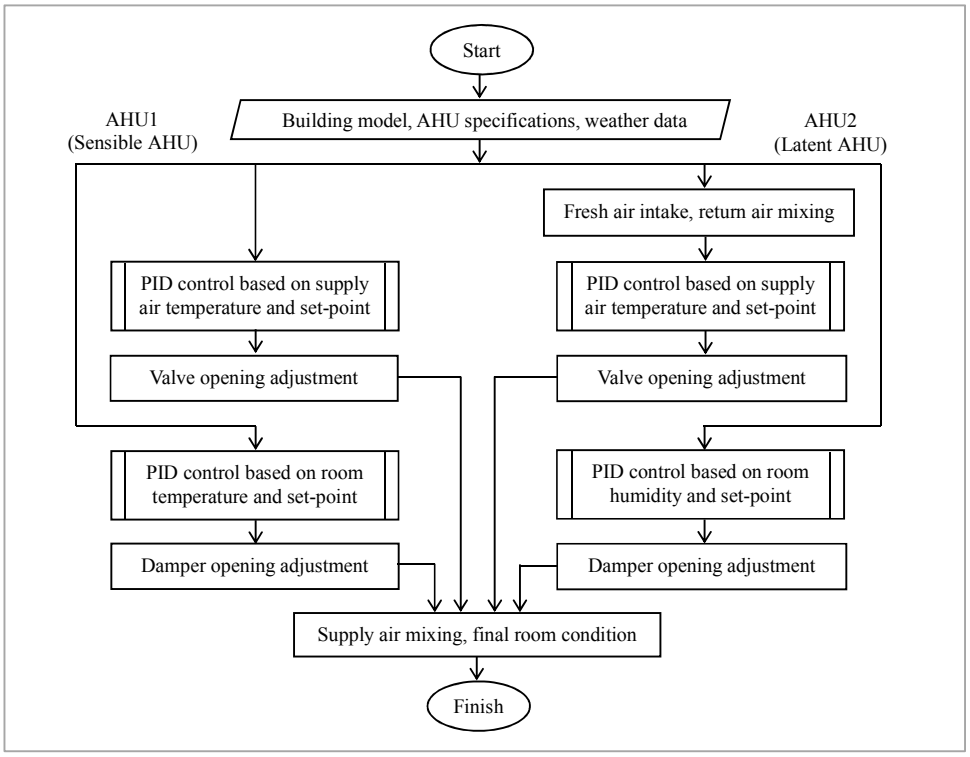


Fig. 5.10: Logic control algorithm of VAV system

On the other hand, AHU2 supply air set is set to be much lower at 10°C as to ensure effective dehumidification. PID control will assist the damper opening to reach the set-point of 26°C and 50% for AHU1 and AHU2 respectively.

The psychrometric process for AHU size ratio 20:80 is shown in Figure 5.11. Take note that the distance between point ⑥ and ② is relatively short due to the low percentage of outdoor air. It happens because bigger size of AHU2 resulted in higher flow of return air. The size advantage of AHU2 also shortens the distance between point ③ and point ⑤.

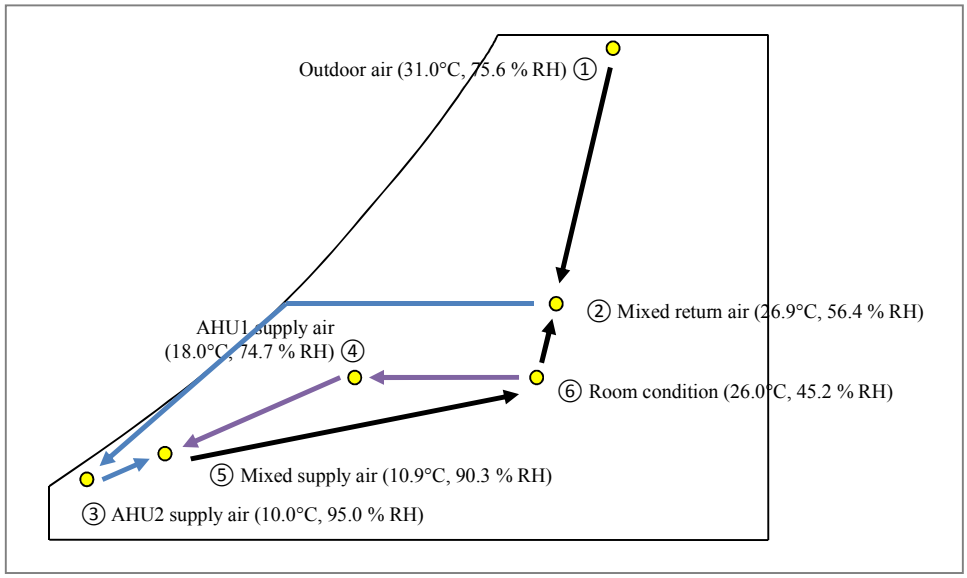


Fig. 5.11: Psychrometric process of AHU size ratio 20:80

The hourly room condition and supply air temperature is shown in Figure 5.12. It is observed that the new system is able to maintain the room temperature and humidity at respective set-points.

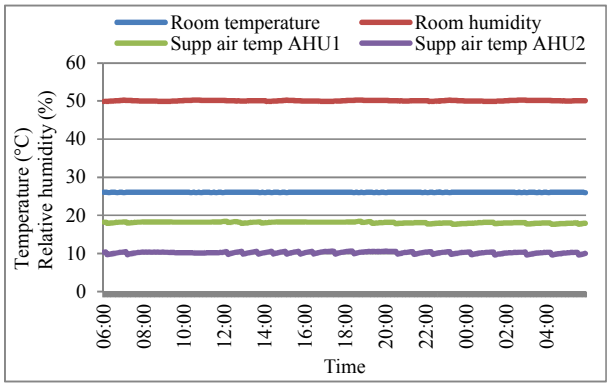


Fig. 5.12: Hourly room condition and supply air temperature

Meanwhile, the existence of dampers has changed the pattern of cooling load profile as shown in Figure 5.13, but the comparative behavior amongst other size ratios remains identical to that of CAV system.

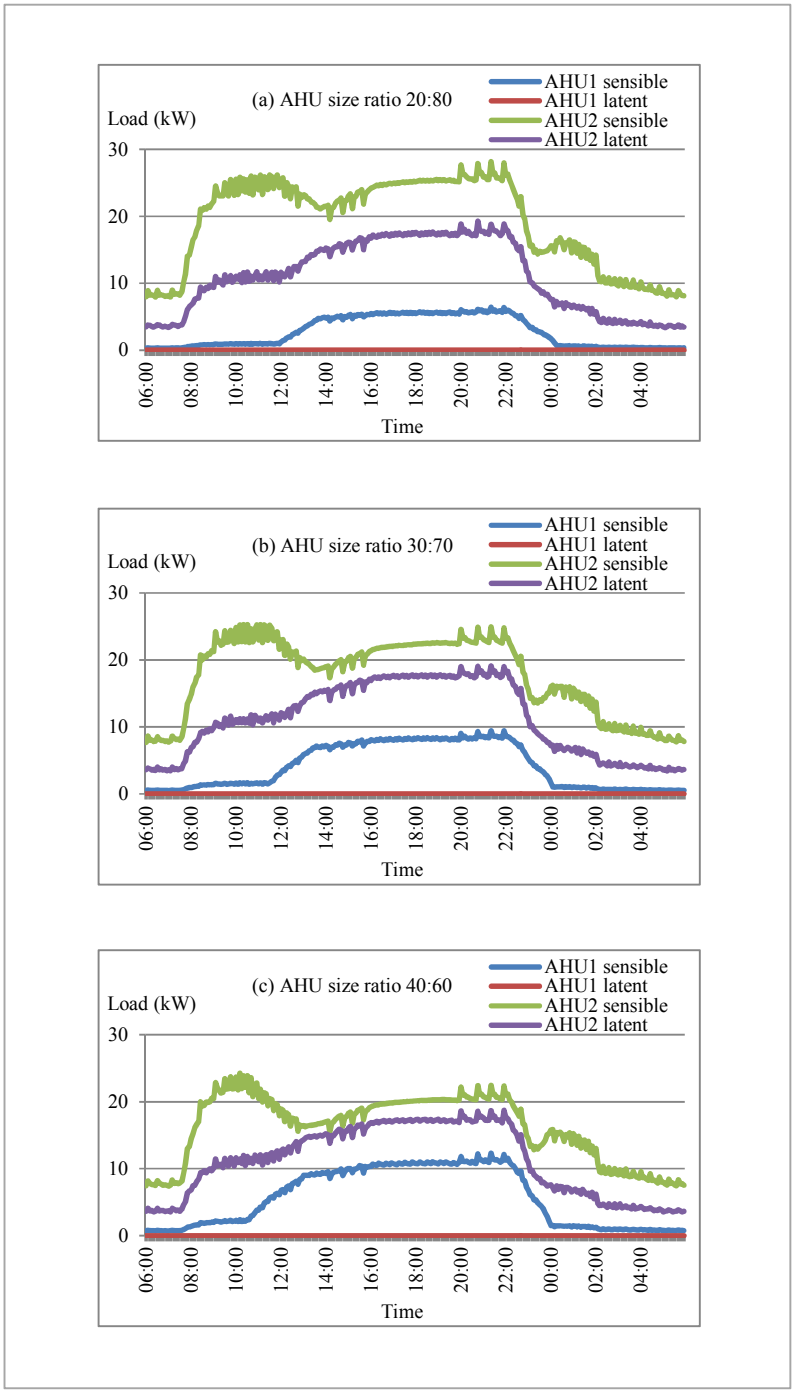


Fig. 5.13: Cooling load profile of VAV system

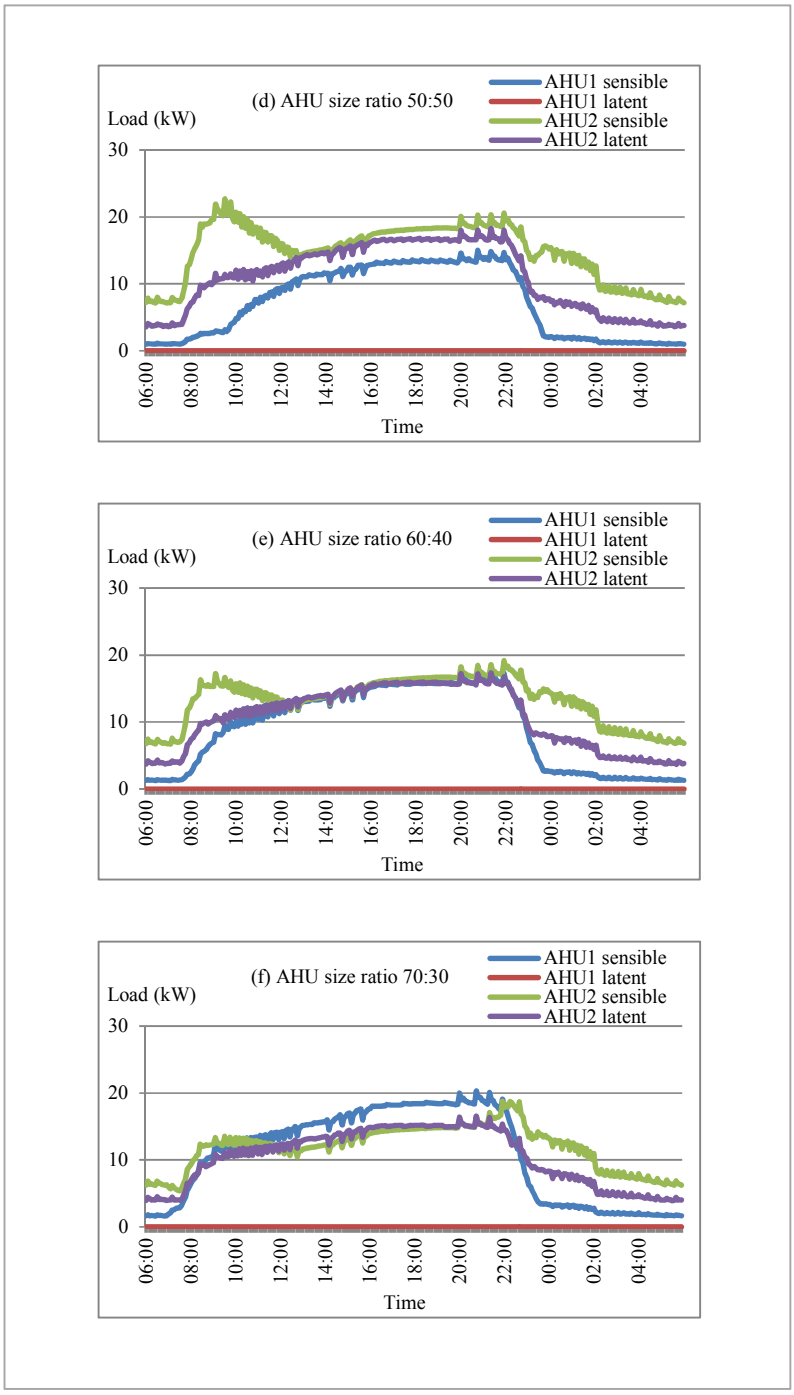


Fig. 5.13: Cooling load profile of VAV system (cont'd)

As expected, VAV system is able to lower the indoor humidity much better than CAV system according to the simulation results in Figure 5.14, together with the comparison of normal air-conditioning system having a temperature set-point of 23°C and 26°C. The figures are shown for SHF values between 0.742 and 0.628.

By reducing the SHF, the humidity line is offset upwards, similar to the behavior in CAV system. As a result, the range of acceptable size ratio shrinks accordingly.

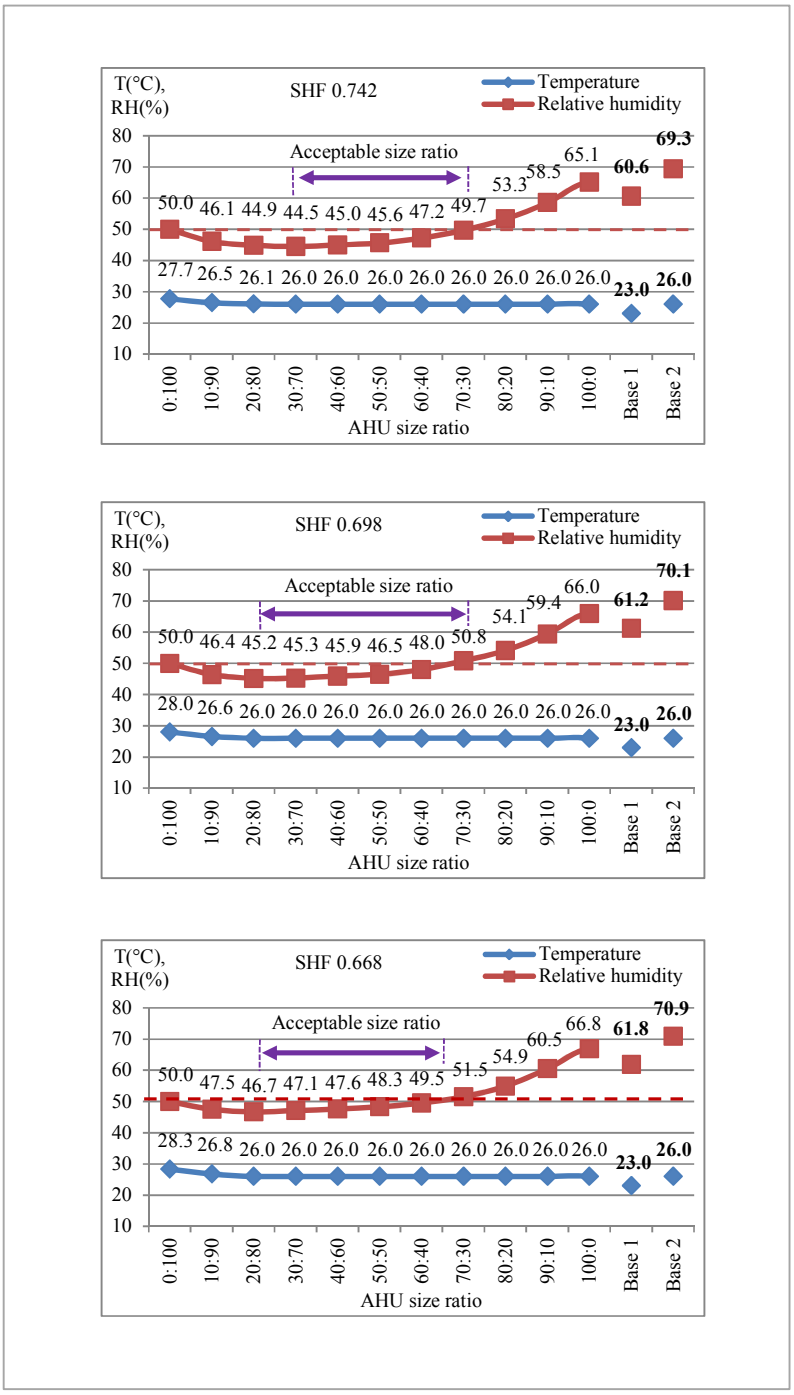
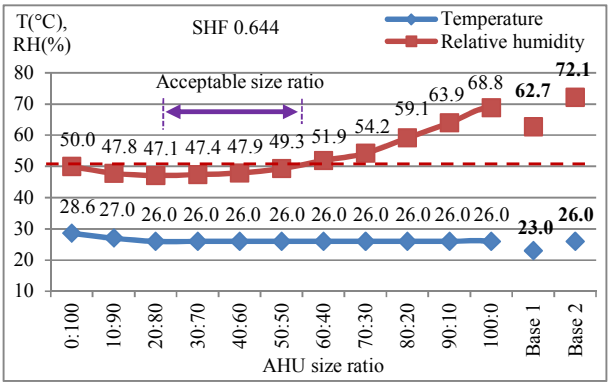


Fig. 5.14: Room condition of VAV system



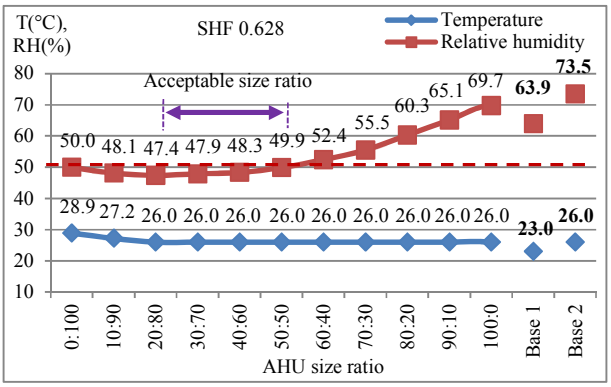


Fig. 5.14: Room condition of VAV system (cont'd)

The possible size ratio options of VAV system is shown in Figure 5.15. Clearly the VAV system offers many more choices of AHU combinations compared to that of CAV system.

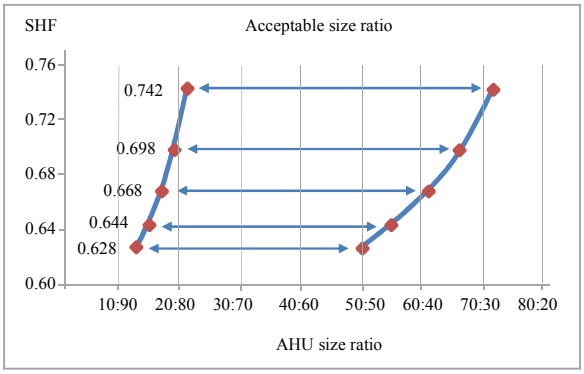


Fig. 5.15: Acceptable AHU size ratio of VAV system

Figure 5.16 presents the comparison of energy consumption of VAV system. The figures are shown for SHF values between 0.742 and 0.628. The proposed Dual AHU system is compared against the base case of similar room having normal air-conditioning. The temperature set-points of base case are 23°C and 26°C which it is controlled by a standalone AHU.

Generally, fewer savings trend is observed in VAV system than that of CAV system. For SHF 0.742, size ratio 20:80 is not included in the analysis since it is not within the acceptable size ratio range in Figure 5.15. The same goes to other size ratio which does not appear in the energy consumption figure. The overall savings for VAV ranged between 10.7% and 13.2% with the most savings offered in SHF 0.628.

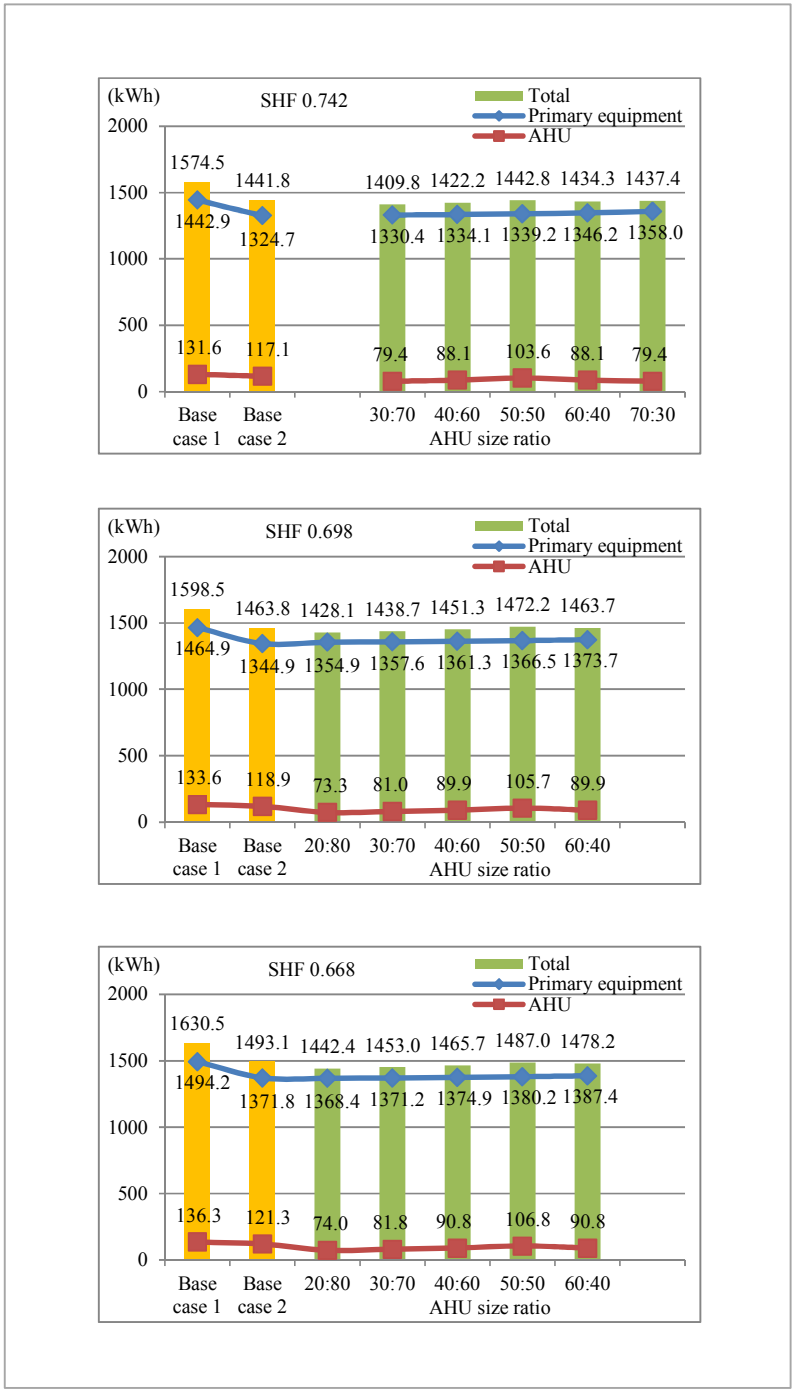


Fig. 5.16: Energy consumption of VAV system

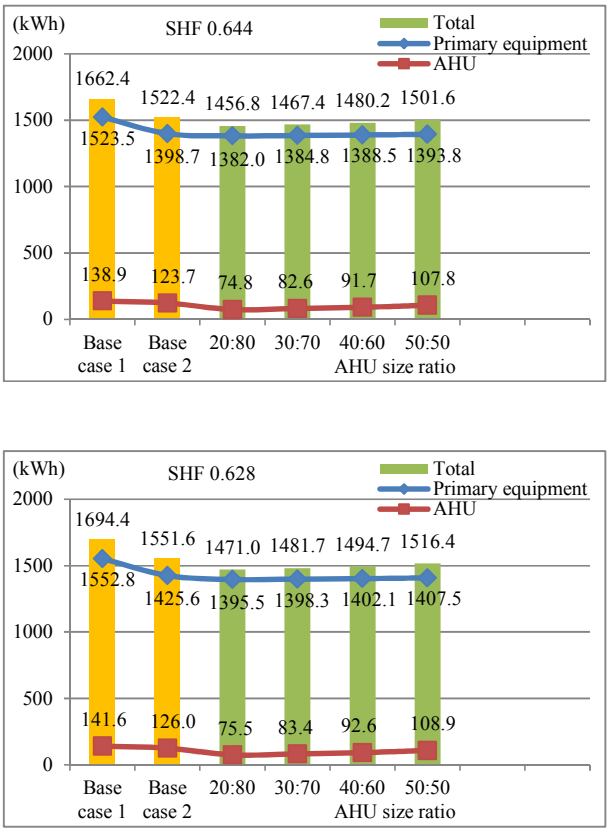


Fig. 5.16: Energy consumption of VAV system (cont'd)

5.4. Conclusion

The performance of the proposed air-conditioning system for buildings in tropical environment is presented in this chapter. Two units of AHU are required in the configuration, as each unit is tasked to monitor the set-point of room temperature and room humidity respectively. The independent control of both parameters gives the opportunity for the improvement in thermal comfort and energy savings. The set-point of 26°C and 50% RH is used in the simulation to evaluate the performance of the new system. Room condition in terms of temperature and humidity is evaluated through the variation of AHU size ratios to ensure preservation of thermal comfort of the occupants.

Simulation results showed that the range of acceptable AHU size ratios is a function of indoor latent heat. In addition, VAV system is capable in providing a wider range of acceptable AHU size ratio compared to CAV system. Further analysis of AHU size ratio is required in the future for the method of designing Dual AHU system using manual calculation with the help of a psychrometric chart. Comparative assessment with normal air-conditioning system of standalone AHU revealed that the new system is able to offer a significant energy savings of up to 11.4% annually. Furthermore, the simple design of the new system ensures that it possesses a relatively lower cost in terms of procurement and installation than the existing humidity removal system. The improvements observed in thermal comfort and energy consumption confirmed that the new system is efficient in removing sensible and latent heat simultaneously, yet affordable to building owners.

References

[1] Association of Mechanical and Electrical Building Engineers of Japan, Manual of HASP/ACLD/8501, 1986. (in Japanese)

[2] Association of Mechanical and Electrical Building Engineers of Japan, Manual of HASP/ACSS/8502, 1986. (in Japanese)

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

[4] ASHRAE Standard 62.1-2007 Ventilation for acceptable indoor air quality, American Society of Heating, Refrigeration and Air-conditioning Engineers, Atalanta, 2007.

CHAPTER 6

Design Method

6.1 Introduction

In the previous chapter, the performance of the proposed air-conditioning system has been evaluated through simulation approach. The control system is observed to respond well to maintain the room condition at desired set-points. Through the simulation, it is shown that the mixture of supply air between the 2 AHUs has resulted in a slight difference of room condition. It is also noted that there are limitation to the system capability causes by the blend of AHU size ratios. These kinds of information could not be gathered without the assist of a dynamic simulation program. However, in the real world, the design of such air-conditioning system is often performed without any modelling tool. It is easier and faster for an air-conditioning designer to utilize manual calculation method in order to come out with a decent sizing of equipment. In such situation, the simulation is use to complement the initial design of the system.

6.2 Objective

The purpose of this chapter is to clarify the guidelines pertaining to the design of Dual AHU system using manual calculation. The steps of design procedure are explained with the aid of appropriate formulas, tables and figures. The examples of calculation may be shown where necessary in order to enhance the design method comprehension.

6.3 Design procedure

There are several steps of design procedure which is necessary to be performed in the analysis of Dual AHU system. It is important to remember that the values of thermal parameters are not objective, meaning that an air-conditioning designer may use a different value to suit the particular building application. However, the sequential of steps listed in the following subsections is necessary to be adhered to during the design stages. The steps of design procedures are as follows:

i. Indoor design condition
ii. Fresh air flow
iii. Outdoor design condition
iv. Room cooling load
v. Capacity of both AHUs
vi. Supply air temperature of AHU2
vii. Supply air temperature of AHU1
viii. Enthalpy of both AHUs

6.3.1 Indoor design condition

The necessity to change the indoor condition of tropical buildings has been discussed thoroughly in Chapter 4 based on the findings in Chapter 3. The particular indoor condition is chosen based on two reasons; to improve the thermal comfort of the occupants and to reduce the energy consumption of existing buildings. Therefore, the room temperature is shifted higher and the room relative humidity is pegged at the middle region.

Room temperature, dry bulb	26°C
Room humidity	50%

From the psychrometric chart,

Coincident absolute humidity	0.0105 kg/kg dry air

6.3.2 Fresh air flow

In Malaysia, the minimum requirement of fresh air flow inside a non-residential building is governed by the Third Schedule (By Law 41) Article 12(1) of Uniform Building by Laws, 1984. For conditioned office space, the minimum outdoor air required is as follows:

Fresh air 16.8 m^3/h per person

Table 6.1 shows the requirement for other building applications. The values are observed to be almost similar to the requirement of ASHRAE Standard 62.1 Ventilation for Acceptable Indoor Air Quality.

Table 6.1: Minimum fresh air for Malaysian buildings [1]

	Type of space	Minimum fresh air (m^3/min)
1	Residential building	0.14
2	Commercial premises	0.14
3	Factory and workshop	0.21
4	School classroom	0.14
5	Projection room	0.14
6	Theatre and auditorium	0.14
7	Canteen	0.28
8	Building of public resort	0.28
9	Office	0.14
10	Conference room	0.28
11	Hospital ward	0.14
12	Computer room	0.14
13	Hotel room	0.14

6.3.3 Outdoor design condition

Due to the hot and humid condition of Malaysian environment, the choice of outdoor design condition is very important as it will influence the design parameters of the new air-conditioning system. The Malaysian Standard MS1525 [2] has outlined the outdoor design condition of 33.3°C dry bulb and 27.2°C wet bulb of temperature. It is observed that the given values are for the hottest outdoor condition in Malaysia. According to the psychrometric chart, for the given condition, the coincident relative humidity and absolute humidity are 63.2% and 0.0205 kg/kg dry air respectively. It is clear that the humidity value is not severe at the hottest condition. Therefore, the outdoor condition is not suitable to be used in the new Dual AHU system since the highest humidity occurs at part load condition.

The necessary information on the highest humidity condition is found in the ASHRAE Handbook that provides the particular data of major cities around the world. The data on six Malaysian cities are shown in Figure 6.1. The values are available for either hot of humid condition and are presented in British unit. Values in SI unit are also available but could be found during the research.

	Hot condition						Humid condition					
	Cooling DB/MCWB						Dehumidification DP/HR/MCDB					
	0.4%		1%		2%		0.4%			1%		
	DB / MCWB		DB / MCWB		DB / MCWB		DP / HR / MCDB			DP / HR / MCDB		
Malaysia												
KOTA KINABALU	91.9	81.8	91.4	81.5	90.4	80.9	82.1	167.1	89.7	80.8	160.1	88.7
KUALA LUMPUR SUBANG	93.6	78.1	93.0	78.2	91.8	78.1	79.2	152.1	84.7	79.0	150.8	84.5
KUANTAN	92.9	79.1	91.7	79.0	91.0	78.9	79.3	152.3	84.8	79.0	150.5	84.4
KUCHING	93.0	78.5	91.7	78.4	91.1	78.4	79.0	151.1	85.3	78.4	147.9	84.3
SANDAKAN	92.3	79.3	91.3	79.2	90.2	79.2	79.4	152.8	85.2	79.1	151.0	84.8
TAWAU	90.2	78.3	89.6	78.4	88.9	78.5	79.6	154.2	85.5	79.0	151.1	85.0

DP Dew point (°F)
HR Humidity ratio (gr/lb. dry air)
MCDB Mean coincident dry bulb (°F)

Fig. 6.1: Outdoor condition of Malaysian cities [3]

The percentage value in the figure represents annual cumulative occurrence of the outdoor condition. For instance, 0.4% means that in a yearly basis, the particular outdoor condition happens at a total of 0.4/100 x (365x24) = 35.0 hours of cumulative occurrence. An air-conditioning designer may choose 0.4%, 1% or 2% based on his/her particular requirement. For the sake of argument, this research will take 0.4% occurrence for the Kuala Lumpur Subang location.

By converting the values to SI unit, the outdoor design conditions are as follows.

Outdoor temperature, dry bulb	29.3°C
Dew point	26.2°C

From the psychrometric chart,

Coincident relative humidity	83.4%
Coincident absolute humidity	0.0216 kg/kg dry air

6.3.4 Room cooling load

In this procedure, the cooling load of the room is first calculated according to both hot and humid conditions. The calculation is similar to the one used in normal air-conditioning system. Normally, the sensible load for hot condition is higher than that of humid condition but the latent load for hot condition is lower than that of humid condition. Also, the total cooling load for hot condition is higher than that of humid condition. For the sake of argument, the cooling load of a fictional 800 m^2 floor area room is calculated using both hot outdoor condition and humid outdoor condition. The results are shown in Table 6.2. It is observed that by using humid outdoor condition, the sensible load is reduced 29.4% and the latent load is increased 17.8% compared to hot condition. Subsequently, the humid condition lessened the SHF by 14.9%.

Table 6.2: Sample results of cooling load for hot and humid condition

Cooling load	Hot condition	Humid condition
Sensible (kW)	49.23	34.74
Latent (kW)	17.33	20.41
Total (kW)	66.56	55.15
SHF	0.74	0.63

6.3.5 Capacity of both AHUs

The capacity of AHU2 is directly chosen by the air-conditioning designer without any calculation. However, it is important to remember that there are limitations in the size combination of AHU1 and AHU2 as per discussion in Chapter 5. As a result, the range of acceptable AHU size ratio is a function of indoor latent heat as shown in Figure 6.2 for constant-air-volume system. Therefore, the chosen capacity of AHU2 must be within the acceptable range or else the system will not be able to function effectively.

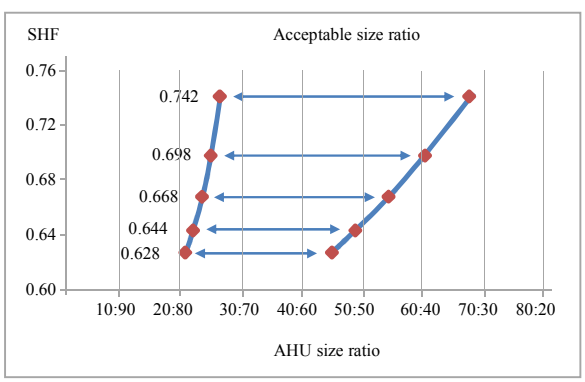


Fig. 6.2: Range of acceptable AHU size ratio

For instance, the SHF for humid condition from Table 6.2 is 0.63. According to Figure 6.2, the acceptable AHU size ratio of 0.63 lies between 21:79 and 45:55. If size ratio 30:70 is chosen, the AHU2 capacity can be directly calculated as follows:

$$\text{AHU2 capacity} = 0.7 \times 66.56 \text{ kW}$$
$$= 46.59 \text{ kW}$$

Note that the total cooling load of 66.56 kW of hot condition is used in the calculation instead of 55.15 kW of humid condition. This is to ensure that the AHUs have enough capacity during hot condition.

6.3.6 Supply air temperature of AHU2

The determination of supply air temperature of AHU2 does not involve any calculation. It is up to the air-conditioning designer to choose his/her preferred value. However, one has to remember that the function of AHU2 or Latent AHU is to provide dehumidification to the conditioned room. Thus, a low temperature is required for the moisture removing process. In a normal application, the chiller produces chilled water at 7°C. Therefore, AHU2 supply air temperature can be chosen from 8°C to 14°C.

6.3.7 Supply air temperature of AHU1

The method to determine the supply air temperature of AHU1 involves the use of a psychrometric chart. Based on the Figure 6.3, the technique is described as follows:

i. Draw the line between the outdoor air condition of 29.3°C DB/83% RH and room condition of 26°C DB/50% RH.

ii. Draw the SHF line of 0.56 from AHU2 supply air point of 10°C DB/95% RH until the horizontal line of 0.0105 kg/kg dry air. The intersection point of represents AHU1 supply air temperature and marked as point ① in the figure.

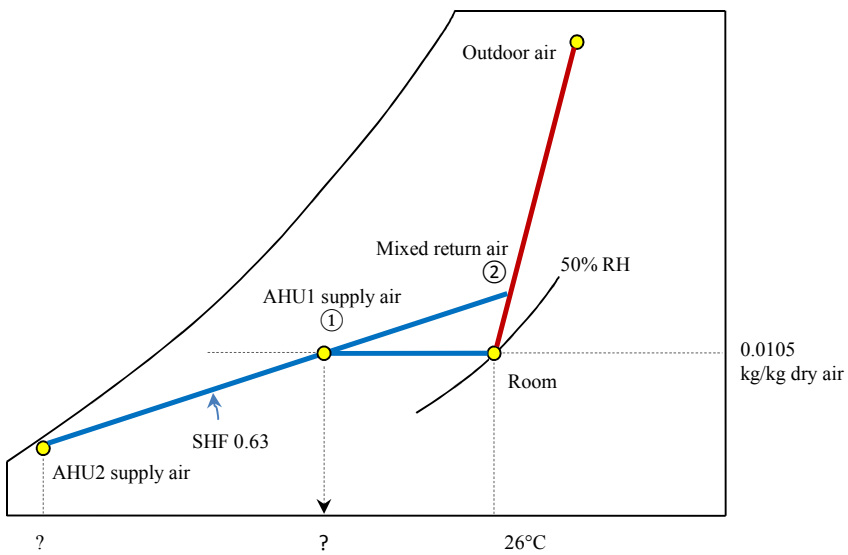


Fig. 6.3: Determination of AHU1 supply air temperature

The difference in choices of AHU2 supply air leads to the outcome variation of AHU1 supply air. Table 6.3 shows the options of the supply air temperature combination between both AHUs.

Table 6.3: Results of AHU supply air temperature

	AHU2 (°C)	AHU1 (°C)
Supply air temperature of SHF 0.63	8.0	24.0
	10.0	22.0
	12.0	19.5
	14.0	17.5

6.3.8 Enthalpy of both AHUs

In order to find the flow rate of the AHU, it is necessary to determine its enthalpy with the help of the psychrometric chart. As the capacity of AHU2 has been calculated as 46.59 kW in the example from previous procedure, its SHF can be clarified by matching the required latent heat load of the humid condition. The details are as follows:

AHU2 capacity	= 46.59 kW
AHU2 latent load	= 20.41 kW
SHF	= 0.56

As shown in Figure 6.3, the next step is to draw a line of SHF 0.56 from AHU2 supply air temperature and 95% RH until it intersects the fresh air line at point ②. The difference between these two points represents AHU2 enthalpy. On the other hand, AHU1 enthalpy is defined by the difference between point ① and the room condition in Figure 6.4.

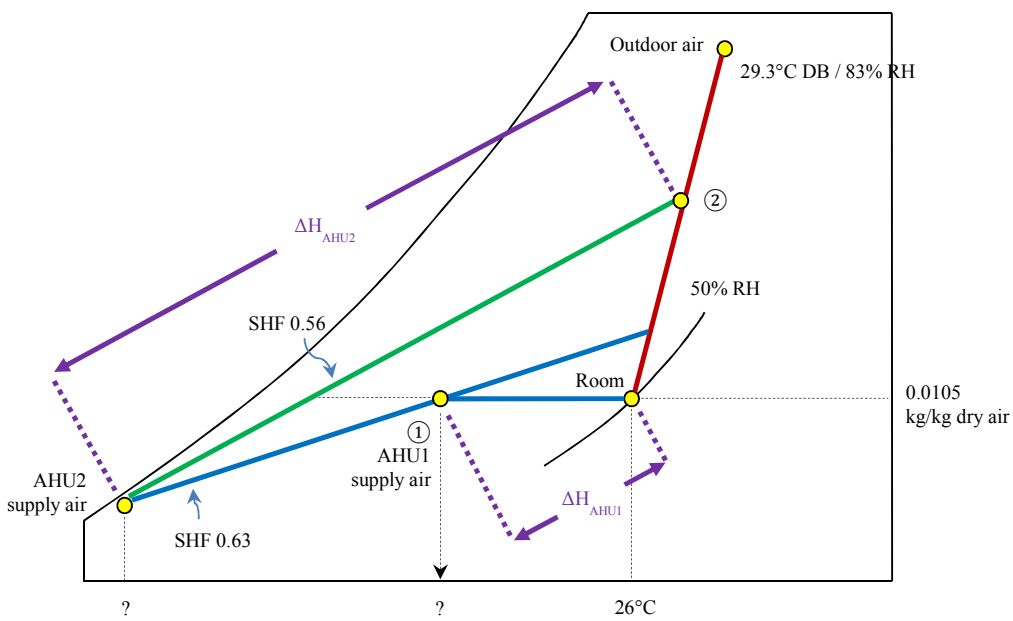


Fig. 6.4: Determination of enthalpy

6.4 Retrofit of existing air-conditioning

Another advantage of the proposed Dual AHU system is that it can be designed as an add-on configuration to the existing air-conditioning. However, a foreseen hindrance is the space availability to mount an additional AHU in a tight space as it is a normal practice in Malaysia to place the AHU inside a small room in the building. A practical solution is by using fan coil unit (FCU) as the sensible coil in the new system. Apart from the fact that the FCU can be mounted on the wall, the system setup is also made possible as the FCU only utilizes the return air, without any fresh air intake. Therefore, it can play the role of AHU1 in the new system. Subsequently, the existing AHU is converted into AHU2 due to its capability in handling the outdoor air.

6.5 Conclusion

The procedures of design method are presented in this chapter with the use of manual calculation and psychrometric chart. There is a major difference between normal air-conditioning and Dual AHU system in selecting the outdoor design condition. The normal air conditioning utilizes the hot outdoor condition while the new system adopted the humid outdoor condition in the cooling load calculation. A low temperature set-point is use for the Latent AHU to removes the moisture inside the conditioned room. For the existing building, the new system can be designed as an add-on configuration to the existing air-conditioning system.

References

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[2] Department of Standards Malaysia, MS1525:2007 Code of Practice on Energy Efficiency for Non-Residential Buildings, 2007.

[3] ASHRAE Handbook: Fundamentals, American Society of Heating, Refrigeration and Air-conditioning Engineers, Atalanta, 2005.

CHAPTER 7

Conclusion

7.1 Conclusion

The research aims to present an alternative system for architects and engineers to consider during the design stage of the building. It has been explained that the answer to the various problems arise from tropical buildings is by replacing the existing air-conditioning system with a more comfort cautious and energy friendly setup. The new system is equipped with humidity control capabilities to keep the indoor humidity at the desired level. As the existing air handling unit is meant for temperature set-point, another air handling unit is added to the system configuration in order to fulfill the task of humidity control. The simple design of the new system ensures that it possesses a relatively minimum cost in terms of procurement and installation.

The conclusion for each chapter is presented as follows;

Chapter 1 summaries the problems pertaining to the building in the tropical climate of Malaysia. The growth in economy and population in Malaysia has resulted in high energy consumption. Unsatisfactory in indoor thermal comfort happens due to tropical climate and unsuitable air-conditioning system. Existing dehumidification system is unpopular due to its high initial cost. Therefore the purpose of this research is to propose a new air-conditioning system for the use in tropical climate. The design criteria of the new system are humidity control, low energy consumption, better thermal comfort and low equipment cost

Chapter 2 concludes that the guidelines towards low energy building and the platform for green buildings are already in place with the establishment of Malaysian Standard MS1525 and Green Building Index. There is evidence of growing awareness in Malaysian on the importance of sustainable buildings. Government support is visible through the incentives offered to those who invest on GBI buildings throughout the country. However, the air-conditioning design was made so that the system operates in relatively low temperature. The effects are on indoor thermal comfort as well as building energy consumption.

Chapter 3 confirms that the existing air-conditioning system in Malaysia is not suitable to be used in a hot and humid climate since it brings an undesirable effect to indoor thermal comfort. The results from the measurement exercise showed that most occupants are thermally uncomfortable due to the room condition which was mainly colder in temperature. Therefore, the prospect of energy saving strategy and improvement in thermal comfort is to shift the indoor temperature slightly higher and in the same time to peg the relative humidity in the middle zone.

Chapter 4 concludes that there is a possible solution to resolve the problems faced by Malaysian buildings. A new room condition is defined with an improved comfort zone that utilized less energy consumption. 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. Design concept of the new air-conditioning setup is briefly described especially the role of task given to the two AHUs in operating the control method.

Chapter 5 verifies that the new system is indeed can be used in the tropical climate of Malaysia. The control system responded well to maintain the room condition at the temperature and humidity set-point. 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. The new system is also confirmed to use less energy than conventional system.

Chapter 6 confirms that the new system could be successfully designed for new building application using manual calculation with the help of psychrometric chart. The advantages of using the new air-conditioning system are visible through its flexibility to be designed as an add-on configuration to the existing air-conditioning system.

The research is successful in the proposal of a new air-conditioning system of tropical climate. In the design process of any system, the results from simulation must be complemented against a real experiment in order to validate its feasibility. However, it is safe to say that the research proves that there is a potential solution to the problems of Malaysian buildings

7.2 Recommendation for future works

This research focused on the design of the new air-conditioning system using computer simulation program. It is useful to utilize the simulation approach in the initial phase to understand the behavior of the new system. As far as the research is concerned, the simulation exercise proves that Dual AHU system is indeed viable to operate in a hot and humid condition. The control system seems to work according to the temperature and humidity set-point in order to maintain the room condition.

The next step of the research is to use real air-conditioning equipment to understand more about the new system. The control configuration is the most important features in the proposed Dual AHU system. It is also important to remember that the final room condition is a result of the mixture between both air handling units. Hence, the use of actual sensor connected to the real valve and damper may result in a slightly different room condition compared to simulation results due to the reaction time needed to the valve and damper to react after receiving the signal from the sensors.