EVALUATION OF AIR-CONDITIONING AND MECHANICAL VENTILATION (ACMV) PERFORMANCE IN AMBULATORY CARE CENTRE (ACC) HOSPITAL PULAU PINANG

By

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LIST OF ABBREVIATIONS

2D/ 3D	Two Dimensional/ Three Dimensional
ABCAT	Automated Building Commissioning Analysis Tool
ACC	Ambulatory Care Centre
ACH	Air Change per Hour
ACMV	Air-Conditioning and Mechanical Ventilation
AFDD	Automatic Fault Detection and Diagnostic
AHU	Air Handling Unit
APAR	AHU Performance Assessment Rules
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
BACNet	Building Automation and Control Network
BAS	Building Automation System
BEI	Building Energy Intensity
BEM	Building Energy Modelling
BEMS	Building Energy Management Systems
BEPS	Building Energy Performance Simulation
BESTEST	Building Energy Simulation Test
BIM	Building Information Modelling
BLAST	Building Loads Analysis and System Thermodynamics
BSEEP	Building Sector Energy Efficiency Project
CAD	Computer Aided Design
CANMET	Canada Mineral and Energy Technology
CAV	Constant Air Volume
CIBSE	Chartered Institute of Building Services Engineers
CO_2	Carbon Dioxide
ConFD	Conduction Finite Difference Method

COP	Coefficient of Performance
COP-15	Conference of Parties
CTF	Conduction Transfer Function Method
CV(RMSE)	Coefficient of Variations (Root Mean Squared Error)
DAS	Data Acquisition System
DABO	Diagnostic Agent for Building Operation
DDC	Direct Digital Controller
DOE	US Department of Energy
EE	Energy Efficiency
EIA	US Energy Information Administration
EIR	Energy Input Ratio
EIS	Energy Information System
EMCS	Energy Management and Control System
EMS	Energy Management System
eQUEST	Quick Energy Simulation Tool
FCU	Fan Coil Unit
FDD	Fault Detection and Diagnostic
FDM	Finite Difference Method
H_2O	Water
HB	Heat Balance Method
HVAC	Heating, Ventilating and Air-Conditioning
IEA	International Energy Agency
IES<VE>	Integrated Environmental Solution-Virtual Environment
IMDS	Information Monitoring and Diagnostic System
JACE	Java Application Control Engine
JKR	Jabatan Kerja Raya, Malaysia
K	Kelvin

kWh	kilo-watt hour
LAN	Local Area Network
LEED	Leadership in Energy and Environmental Design
Lon	Local Operating Network
MBE	Mean Bias Error
MS1525	Malaysian Standard 1525:2007
NBSLD	National Bureau of Standards for Load Determination
OT	Operation Theatre
OWS	Operating Work Station
PACRAT	Performance and Continuous Re-commissioning Analysis Tool
PDE	Partial Differential Equation
PID	Proportional Integral Derivative
RAT	Return Air Temperature
RE	Renewable Energy
SHGC	Solar Heat Gain Coefficient
STEM	Short-Term Energy Monitoring
TAMU	Texas A&M University
TFM	Transfer Function Method
TNB	Tenaga Nasional Berhad
TRY	Test Reference Year
UBBL	Uniform Building By-Law
VAV	Variable Air Volume
VLT	Visible Light Transmission
WBD	Whole Building Diagnostic
WkEND	Week End
WF	Weighting Factor
ΔT	Temperature Difference

PENILAIAN PRESTASI PENYAMAN-UDARA DAN PENGUDARAAN MEKANIKAL (ACMV) DI PUSAT RAWATAN HARIAN (ACC) HOSPITAL PULAU PINANG

ABSTRAK

Prestasi ACMV untuk kemudahan giat tenaga seperti ACC sangat bergantung kepada operasi EMCS. Pada umumnya, penurunan prestasi ACMV yang sepatutnya dikesan oleh EMCS tidak dapat dimanfaatkan. Matlamat kajian ialah untuk menyediakan kaedah mengecam status EMCS yang informatif, pembolehubah daripada data EMCS untuk anggaran penggunaan tenaga dan sasaran penggunaan tenaga ACC dari fungsi EMCS yang dioptimumkan. Data EMCS digunakan untuk mendiagnosis prestasi ACMV menggunakan visualisasi data. Data carta kontur telah membantu penyelenggara mengesan kerosakan, memantau keselesaan termal dan menilai penggunaan tenaga dengan andaian operasi sistem ACMV adalah baik. Carta kontur ditafsir berpandukan diagnostik EMCS yang dibangun menggunakan kaedah berasaskan model-kualitatif. Untuk menambah nilai kepada teknik kualitatif, data EMCS telah digunakan untuk menganggarkan penjimatan tenaga jika semua kerosakan yang dikesan dapat dibaiki. Anggaran penjimatan tenaga memerlukan suhu purata dan operasi kipas lebih masa sebagai pembolehubah. Dengan kedua-dua pemboleh ubah bagi setiap AHU, BEPS eQuest mensimulasikan keseluruhan penggunaan tenaga bangunan pada 5,757,600 kWh / tahun dengan MBE = 2.83% dan CV (RMSE) = 1.82%. Simulasi berkombinasikan suhu dan operasi kipas dibandingkan dengan model yang ditentukur. Keputusan simulasi menyokong tekaan penjimatan tenaga daripada status EMCS didiagnosis dan mensasarkan penjimatan tenaga sebanyak 6.95% berdasarkan operasi EMCS yang dioptimumkan. Kajian ini menunjukkan bahawa visualisasi data EMCS menggunakan carta kontur adalah alat FDD yang praktikal untuk menilai prestasi ACMV secara berkala.

EVALUATION OF AIR-CONDITIONING AND MECHANICAL VENTILATION (ACMV) PERFORMANCE IN AMBULATORY CARE CENTRE (ACC) HOSPITAL PULAU PINANG

ABSTRACT

ACMV performance for energy demanding facilities such as ACC is heavily dependent on EMCS operation. In general, ACMV performance degraded as faults which could be diagnosed through EMCS data went unnoticed. This research looked for an informative tool to diagnose EMCS status, variables from EMCS data for energy consumption estimation and the energy consumption target for the whole building from optimisation of EMCS. Readily available EMCS data was used to diagnose ACMV performance using data visualisation. Data presented in contour charts helps facility maintenance to detect fault, monitor thermal comfort and assess energy consumption, assuming that the ACMV system has been well maintained. Interpretation of contour charts was guided by EMCS diagnostic guide developed based on a qualitative model-based method. To add value to the qualitative technique, EMCS data was used to estimate energy saving if all faults detected were to be rectified. Energy saving estimation required temperature average and estimated fan extended hour as variables. Calibrated eQuest BEPS had incorporated the two variables for each AHU to simulate whole building energy consumption of 5,757,600 kWh/year with MBE = 2.83% and CV(RMSE) = 1.82%. Multiple simulations with combination of operating temperature and fan operation were compared to the calibrated model. Simulation results supported the guesstimated energy saving from the diagnosed EMCS status as well as established target energy saving of 6.95 % based on optimised EMCS operation. This research demonstrated that EMCS data contour chart is a practical off-line simplified FDD tool to periodically evaluate the ACMV performance.

CHAPTER 1 INTRODUCTION

1.1 Background of Study

Energy consumption is fast growing around the world that has led to the depletion of fossil fuel reserves along with the degradation of world's climatic conditions. Based on current rates of consumptions for crude oil and natural gas, their reserves were estimated to last for 41.8 and 60.3 years, respectively (Ong et al., 2010). Burnt fossil fuels were the main sources of CO_2 emissions that had contributed to global warming (Lau et al., 2009). Since 88.1% of world's energy was from burnt fossil fuels, an increase of 25 % in CO_2 emission (equivalent to 40 billion tons of CO_2) is projected by year 2030 compared to 2008 (Ong et al., 2010). However, if the emission level exceeded 55 billion tons of CO_2 by 2030 due to higher than anticipated consumption rates, low carbon challenge will surge by 4-folds within the period 2030-2050 (Blanco et al., 2014). Scientists cautioned that the world is crossing the point of no return (The Star, 2014) if no drastic measures were taken to reduce its reliance on non-renewable resources. Energy efficiency efforts in all sectors are crucial in mitigating the rapid growth in energy consumption throughout the world.

An important sector for energy efficiency efforts is building sector, which has grown in complexities over the years. According to Altweis and Nemet (2013), building energy efficiency has a pivotal role in climate stabilisation because the existing building energy efficiency technologies have matured but not been deployed to their full potentials. Within the building sector, healthcare facilities ranked second behind food service sector as the most energy intensive with $8.8 billion/year on energy consumption in the US (Hendron et al., 2013). Furthermore, based on an energy efficiency indicator survey done by ASHRAE in 2010, it was found that 58% of healthcare building decision makers placed energy management as being extremely important to their organizations (Checket-Hanks, 2010). Naturally, the focus of building energy management was on HVAC which contributed 50% of building energy consumption (Xiao and Wang, 2009). Healthcare facilities posed great demands on HVAC system to deliver a delicate balance between infection control, in-door air quality, optimal control and energy efficiency (Moghimi et al., 2011). Achieving building energy efficiency of complex facilities while juggling with the other priorities can only be achieved through automation.

Building Automation System (BAS) offered automated solutions in managing modern building systems but performed poorly especially in energy management and control system (EMCS). Major building functions supported by BAS had included risk, facility, maintenance and energy managements (Wang, 2006). Attracted by the solutions in managing modern buildings, owners' responses to BAS and EMCS resulted in 33% BAS market share of commercial building floor spaces in the US (Brambley et al., 2005). However, since its implementations in 1980s, many building owners were left with abandoned or under-utilized systems that could not be improved (Boed and Goldschmidt, 2000). Despite EMCS main objective to save energy especially for HVAC system, studies done on 60 buildings discovered that EMCS contributed 50% to energy wastages in those buildings (Iowa Energy Center, 2002). EIA reports indicated that 30% of 127 billion USD wasted in commercial buildings' HVAC system was due mostly to un-calibrated sensors, improper operation practices and improper implemented controls that went undetected (Katipamula et al., 2006).

As a solution to the predicament, advanced fault detection and diagnosis (FDD) system was developed to keep HVAC system operating at optimum conditions.

Advanced FDD main purpose was to assist building operators in analysing modern buildings enormous data (Lee et al., 1996). Real building demonstrations of advanced FDD showed a saving as high as 44 % (Friedman et al., 2010), but it came at the expense of new challenges to building owners in relation to knowledge gap (Heschong, 2006), resource allocation (Friedman et al., 2010) and cost (Piette et al., 2001). Advanced FDD may have a long way to convince building owners. To start plugging energy wastages from HVAC system, the final analysis focused on maximising the use of present EMCS technology for owners' consumption (House and Kelly, 2000) by focusing on qualitative methods and visualisation technique.

Malaysia's commitment and focus towards energy has always been in-line with the rest of the international communities. Malaysia stated its pledge for a 40% voluntary reduction in terms of carbon emission from 2005 level by the year 2020 during 2009 United Nation Climate Change Conference of Parties (COP-15) in Copenhagen (Singh, 2012). Reducing carbon emission can be achieved through efficient use of energy in buildings (Ahmed, 2009). Building sector in Malaysia accounted for a 48% of the total electricity consumption (Aun, 2004). One of the strategies for energy auditing of existing buildings after exhausting all passive solar design elements is on active systems mainly ACMV (Rahman and Ismail, 2008). ACMV system consumed a substantial 57% of building energy consumption in Malaysia (Saidur, 2009). To ensure ACMV system energy consumption remained efficient, Department of Standards (2011) recommended continuous checking of operating parameters involving measurement, detection and audit. ACMV and comprehensive building energy management (Public Works Department Malaysia, 2011) were attractive because they can be done within operational expenditure. Greentech

Malaysia estimated that a 3-10% energy saving potential by proper temperature control and load schedule can be achieved at no cost (Ibrahim, 2011). This percentage can lead to substantial amount if compared to the sum of RM 1.5 billion in electrical energy spent by the Malaysian government in 2007 (Ibrahim, 2011). Malaysia needs further technical improvement in the existing energy management system such as focusing on energy information and database (Al-Mofleh et al., 2009). Therefore, Malaysia can take advantage of an invaluable lesson on the implementation of EMCS and FDD developments abroad as reported by Annex-47 team under the auspices of International Energy Agency (Friedman et al., 2010, Neumann et al., 2010), so that it can complement Malaysia’s effort to stay on track for the 40% reduction in terms of carbon emission.

1.2 Problem Statement

Despite EMCS strength in energy management and control of ACMV performance, degradation and poor maintenance can render EMCS data unreliable. Painter et al. (2012) questioned the reliability of EMCS data and conducted a sensor overlay project to verify them. ACMV set-points using electronic control do not drift. However, other factors such as damaged sensors, faulty actuators, improper EMCS configuration or poor maintenance plaque the EMCS functions (Brambley et al., 2005). Therefore, researchers hesitated to use EMCS data directly, instead parallel system of additional sensors were installed to execute advanced control function.

Many researchers and end-users found that EMCS reports were not informative or intuitive. According to Colmenar-Santos et al. (2012), EMCS basic data presentation still lacked of practical diagnostic feature. Without time intensive or powerful software analysis of EMCS data, control errors or degradation might be missed or were almost impossible to detect. Colmenar-Santos et al. (2012) recent attempt was to use carpet plots to quickly detect control errors. Present EMCS has poor graphical performance visualisation simply because of there are so many ways to display the data. Choices are limited only by the number of sensors installed in EMCS networks. Without the said features, facilities maintenance is simply overwhelmed by analyses of measured data which lacked of actionable information.

As a result, EMCS have continued to generate and archive thousands of data yet faults remained undetected and ACMV energy consumption might increase. Potential energy saving from EMCS can be undone by ineffectiveness of maintenance or faulty field devices. Study in Netherlands had found that there was a 25% ACMV energy increase due to operational factors such as maintenance and faulty sensors (Elkhuizen and Rooijakkers, 2006). Increase in energy consumption in between 5 % – 30% had been attributed to inefficient or poorly configured EMCS (Colmenar-Santos et al., 2012).

Even though EMCS was considered deficient in terms of integrating and processing EMCS data towards actionable items (Marinakis et al., 2012), EMCS data had generated substantial energy saving with FDD advanced technology. Energy savings up to 44% for electricity and 78% for natural gas were reported when EMCS data were analysed and controlled by an advanced commercial FDD system (Neumann et al., 2010). Even with such success stories, industry acceptance was very slow. Owners' reluctance in FDD advanced technology was due to requirement for dedicated control engineers, highly trained technicians and many time consuming programming, training and tuning to avoid detection such as false alarm. Low FDD market penetration was a great setback due to missed opportunities for energy saving. International experts of Annex-47 team concurred into further research for cost effective, integrated and user friendly tool to detect faults in ACMV system (Neumann et al., 2010). Therefore, the lacked of practical and owner-centred FDD tools to optimise EMCS operation had prevented persistent energy saving that could be achieved with optimum performance of ACMV system.

1.3 Research Questions

From the above problem statement, there is a need to analyse EMCS data in order to evaluate ACMV performance through the following research questions:

(i) How to efficiently utilise validated EMCS data towards persistent ACMV energy performance?

(ii) What are the variables within EMCS data that can be used to estimate energy saving of a fault-free EMCS operation?

(iii) What is the energy consumption level of EMCS-optimised ACMV performance at ACC?

1.4 Research Objectives

This research aspires to analyse EMCS data in order to evaluate ACMV performance through the following research objectives:

(i) To develop informative and practical visual trend-reports of EMCS data for persistent ACMV energy performance

(ii) To determine and extract useful variables within EMCS data for energy saving estimation of a fault-free EMCS operation

(iii) To estimate energy consumption level from EMCS-optimised ACMV performance at ACC using BEPS

1.5 Scope of the Study

Due to the complexity of building energy analysis where factors such as varied systems, occupancy, weather and plug loads, this research focuses on the following scope to achieve its objectives:

(i) Investigate only the parameters that can be monitored and controlled by EMCS and simulated by energy modelling software. Based on this condition, the focus of this research was on AHU of the ACMV system. ACMV term will be used when referring to the Malaysian context. In the literature review, HVAC term will be retained to reflect its applicability according to other climate regions.

(ii) Evaluation of whole building ACMV energy performance using calibrated BEPS in order to be able to manipulate selected parameters while maintaining others constant.

(iii) Validation of the critical control points for data collection with minimal interruption to building operation and owner resources.

(iv) Validation of EMCS data will be done through desktop processing rather than physical adjustment in the systems.

(v) This research was conducted based on a case study at Ambulatory Care Centre (ACC) building, Hospital Pulau Pinang. It is a 5 storey block day-care facilities. This building was selected due to its representative of multi-disciplinary day care health centres with administrative offices out of 15 ACCs throughout Malaysia (Bernama, 2009). Furthermore, most of ACC processes or protocols for ambulatory services were adopted from Hospital Pulau Pinang (Sivasakthi, 2012).

1.6 Research Flowchart

Literature review was guided into body of knowledge in the areas of healthcare building energy management, ACMV system, building automation system and EMCS, FDD and building energy modelling. Based on the literature review and theoretical framework, an outline of study was conceptualised. Once the experiment parameters were determined, diagnostic guide, experimental procedure and data collection method were finalised. The outline of this research is described in the following flowchart as in Figure 1.1.

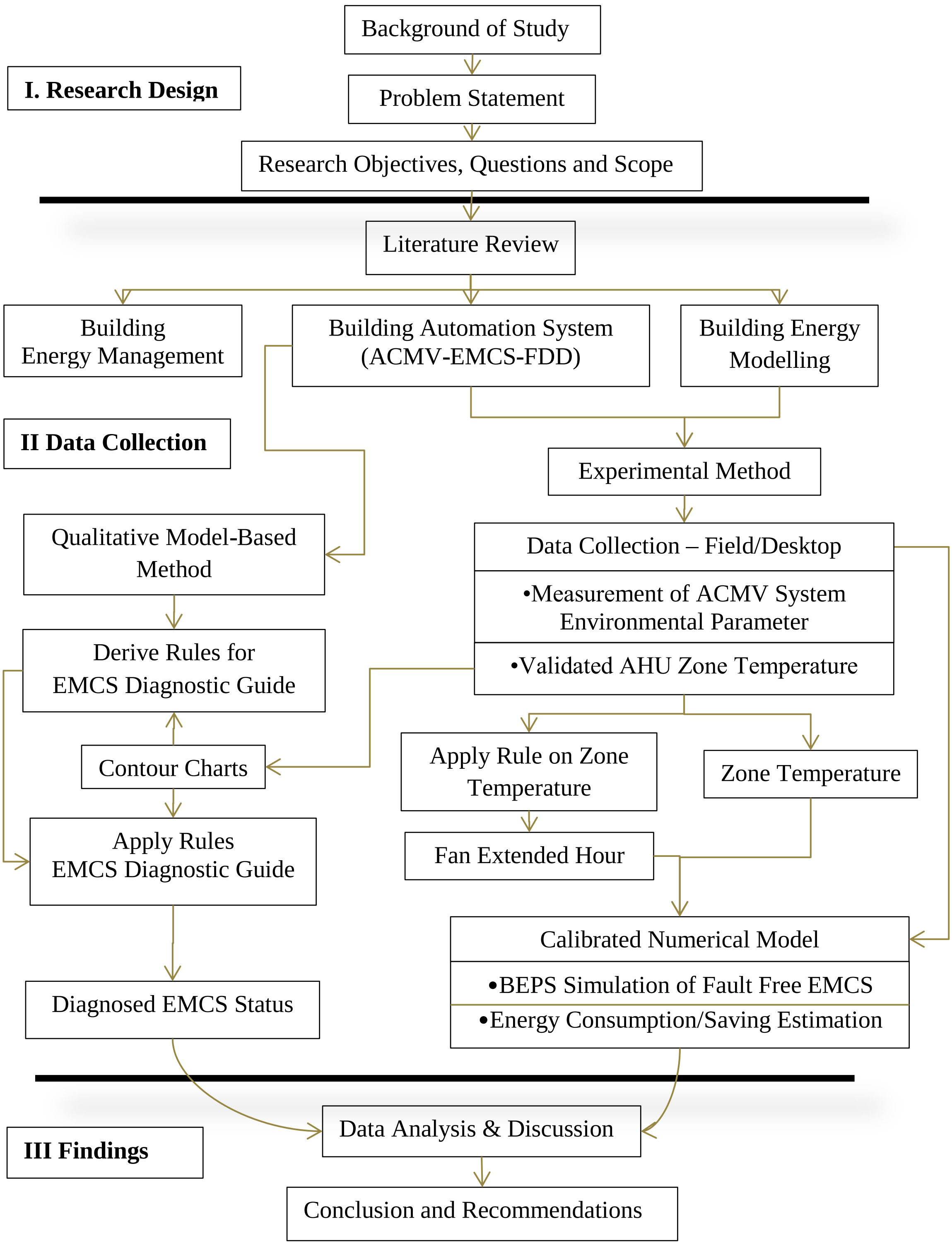

Figure 1.1 Research Flowchart

1.7 Organisation of the Thesis

In order to fulfil the research objectives, this thesis was divided into 5 chapters. Chapter 1 covered background, problem statement, research questions and objectives as well as scope and research flowchart. Chapter 2 examined on past literature and researches on building automation (BAS) and EMCS, fault detection and diagnosis, building energy model and effect of EMCS on ACMV performance. Chapter 3 explained the research methodology with respect to data collection, validation, instrumentation and measurement. Chapter 4 analysed the data and presented result of the research findings. Lastly, chapter 5 concluded the study and identified recommendations for future research.

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

The purpose of this chapter was to document technical discourses identified within the building technology community on theoretical basis, approaches, search for standards and best practices in the areas of building automation system (BAS), building energy performance simulation (BEPS) and effect of EMCS on ACMV performance and energy use.

2.2 Energy Sustainability

According to Ong et al. (2010), International Energy Agency has predicted a global energy consumption increase of 53% by 2030. If our reliance on non-renewable energy continues, that would simply lead to a vicious cycle. Increase in energy consumption will hasten fossil fuel depletion and build-up concentration of green-house gasses (GHG). Carbon dioxide (CO_2) being one of the GHG and ranked 1^{st} in terms of global warming potential will contribute towards an increase in global mean temperature (Lau et al., 2009). So far, the global mean temperature has increased by $0.8^{\circ}C$ for the last century and will continue to rise to the detriment of our climate system if production of green-house gases were not capped (Chiari and Zecca, 2011). Ensuing this shall be climate change, severe weather patterns, insecure food productions and other environmental issues that scientists foresee.

Governments of developed countries were also necessitated to voluntarily fund projects and technology transfer to developing countries in order to collectively meet CO_2 emission targets. Kyoto Protocol had targeted emission of green-house gases (particularly carbon dioxide, CO_2) to 5.2% below 1990 levels (Lau et al., 2009). It was estimated that a third of energy related CO_2 emissions worldwide were produced by commercial buildings (Pande, 2010). Moreover, lighting and HVAC consumptions were responsible for an estimated 85% of the buildings' carbon emissions. Based on Figure 2.1, CO_2 emissions in Malaysia had reached nearly 2 ton-carbon per capita in 2009 (Kimura, 2011).

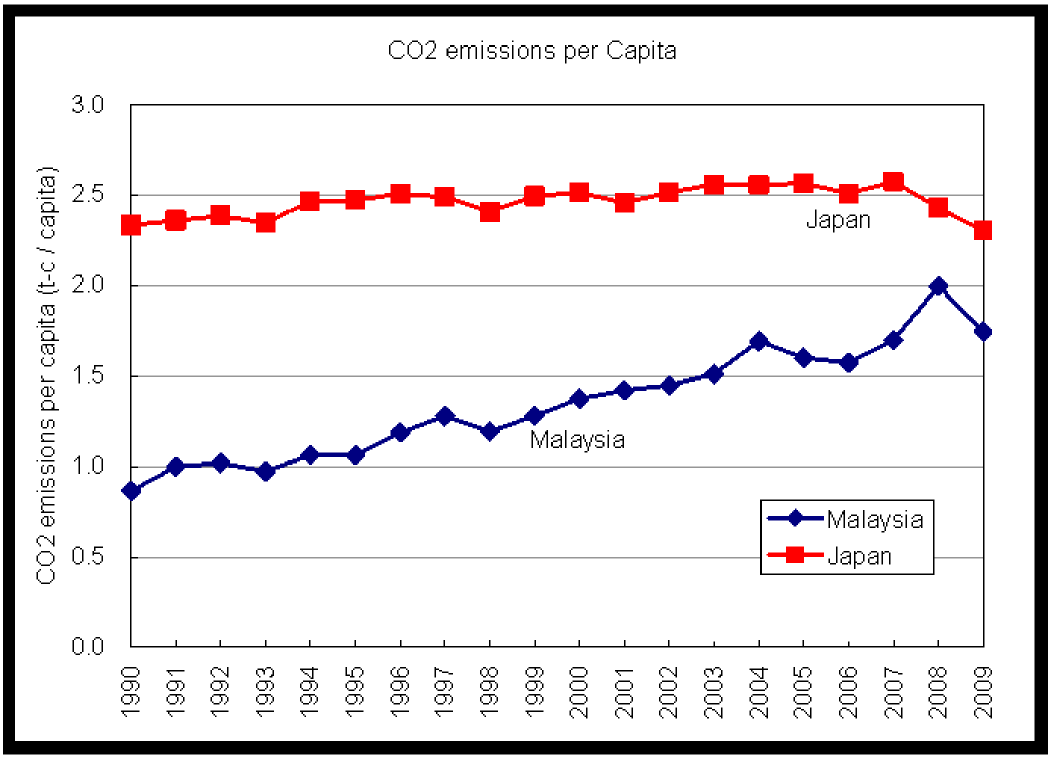

Figure 2.1 CO_2 Emission Per Capita (Kimura, 2011)

Our increasing trend of CO_2 emission per capita compared to a fairly stable emission in Japan was a cause for Malaysia to intensify effort to reduce energy consumption and learn from Japan's experience.

With continued high consumption rate of non-renewable energy, the world's fossil fuel productions will reach their peaks in terms of oil, gas and coal by 2015, 2035 and 2052 respectively (Maggio and Cacciola, 2012) as illustrated in Figure 2.2. It was worrying to note that oil production curve was approaching a downward trend in just a couple of years from now.

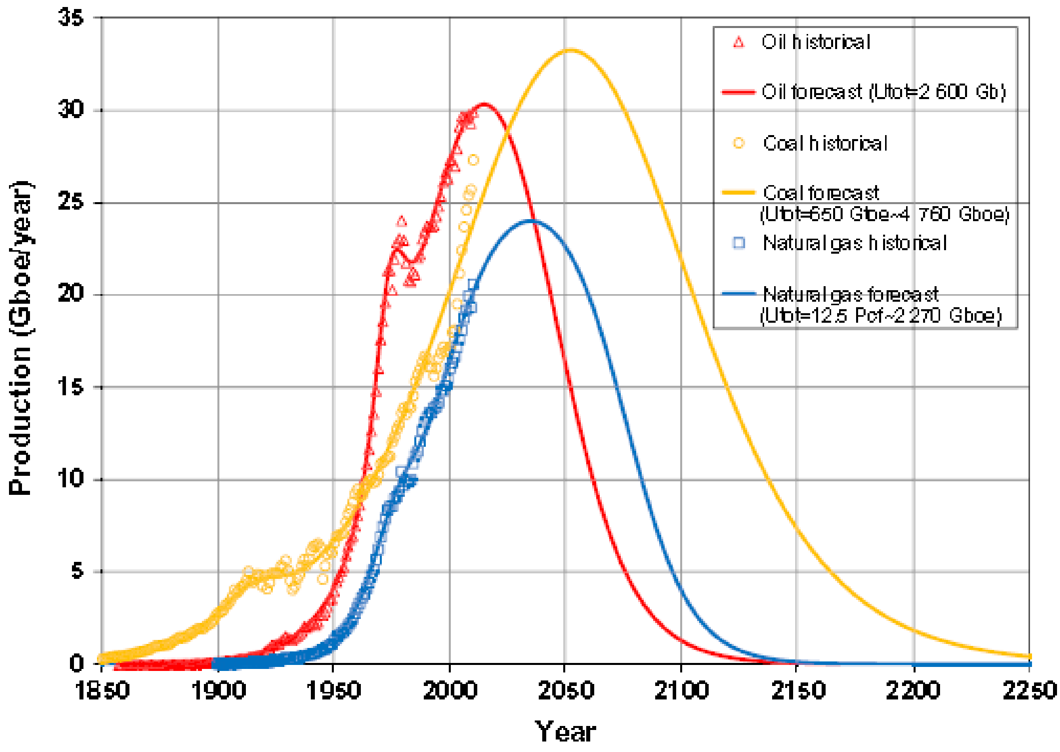

Figure 2.2 Comparison of Fossil Fuel Forecast (Maggio and Cacciola, 2012)

Knowing the status on the supply side was helping us to control on the demand side through energy efficient operation and sourcing for renewable energy. Significant demand side was coming none other than building sector which constitute 40% of US energy use (Jarnagin, 2009).

By middle of the 21st century, buildings in the tropics should brace for an increase in energy use by 20% as a result of global warming. Those in the cold climates can expect a 10% reduction in building energy use. While those in temperate climates should expect more cooling energy instead of heating (De Wilde and Coley, 2012). To manage or minimise the impact of this phenomena, government agencies and research institutions worldwide and in particular developed countries were intensifying research & development in renewable and energy efficient technologies.

As one of the biggest energy consumers, commercial buildings were the focus of most research initiatives. Energy efficiency studies for commercial buildings had received great attention with further emphasis on European Union (EU) directive 2002/91/EC through Energy Performance Building Directive (EPBD) (Escrivá-Escrivá, 2011). Various other researchers such as Olesen and De Carli (2011), and Yao et al. (2012) had also cited EPBD as the catalyst for much of interest and focus in this research area.

In order to sustain Malaysia economic growth, a rate of 6.3% annual increase in energy demand was projected in the Ninth Malaysia Plan (Manan et al., 2010). Based on Malaysia energy scenario, Ong et al. (2010) concluded that Malaysia must increase effort to seriously improve efficiency in energy conversion, transmission and utilisation because Malaysia was not prepared to displace fossil fuels with renewable energy in the near future.

In Malaysia, one of the efforts to promote EE in the industry was by introducing the efficient management of electrical energy regulation 2008. This regulation which came under the electricity supply act 1990 was instrumental in mitigating rising energy demand entails for better efficiency. This was quite similar to the effect of EPBD to European Union. However, a poll conducted by Malaysia Energy Centre and ASHRAE during a half-day workshop in Putrajaya revealed that there were energy efficiency (EE) barriers in Malaysia (Manan et al., 2010) such as:

i. Business community lukewarm response to implement EE projects
ii. Policy makers awareness on EE issues
iii. Expertise on EE project implementation
iv. Uncertainty in guaranteed savings from EE projects
v. High capital investment coupled with financing difficulties

Nevertheless, Energy Commission had a way forward for EE and RE in Malaysia is as per outlined by Hasan (2009)

i. Establish SMART EE and RE targets
ii. Establish effective and sustainable funding mechanism for EE and RE projects
iii. Minimize costs and price distortions in energy supply
iv. Strengthen capacity of industry players and policy makers in EE and RE
v. Foster EE and RE culture among Malaysians
vi. Strengthen and streamline policy as well as legal and institutional framework

Efficient energy management regulation will continuously demand industry to innovate and be efficient. Industry has an array of energy efficient technologies that can be capitalised to ensure sustainability.

2.3 Building Energy Management

Building energy management had taken the centre stage in the life of almost all responsible citizens. In pursuits for better and advanced built environment in cities around the world, building energy use had taken the lead among other energy consumers with sizeable amount attributed to HVAC and lighting systems. (Underwood and Yik, 2004). Mitigating the magnitude of building energy consumption started with small behavioural changes in terms of consciously switching off lighting and electrical appliances at individual level. Whereas at organisational level, investments were made to introduce technology to efficiently manage energy especially in commercial buildings.

2.3.1 Commercial Buildings

ASHRAE (2011) has outlined four basic energy management methods to effectively reduce energy costs that consist of controlling the energy system use, purchasing lower-cost energy, optimising energy system operation and purchasing an efficient replacement system.

(i) Control Energy System Use

This is the most effective method which can be carried out simply by switching off equipment when not in used or occupied. This method can be also be expanded to include central systems where building operation energy needs can be communicated to building manager so that energy can be reduced during low occupancy or turned off when not required. According to Escrivá-Escrivá (2011), interaction between building manager and users was one of the basic actions to improve energy efficiency in buildings.

(ii) Purchase Lower-Cost Energy

Second most effective action involved understanding energy purchasing terms and options. It was important to select suitable tariff structure and align energy utilisation strategies that best suits business strategies. Scheduling of processes can help manage the maximum demand period thus save on extra charges or penalties (Escrivá-Escrivá, 2011). Other approaches will include possibility for cogeneration or other incentive rebates.

(iii) Optimise Energy System Operation.

Third most effective measure was to tune energy system for optimal performance. This task optimisation includes preventive maintenance of assets and training all operational staff on energy use towards optimal energy performance.

(iv) Purchase Efficient Replacement System

Replacement system method is normally the most expensive and with high liability. Among available efficient replacement technologies were using energy star rated devices, high efficiency motors, using inverters or soft starters. Energy saving light bulbs or de-lamping facilities was also considered. An efficient replacement system was potential for high return on investment. An objective evaluation of cost benefit analysis was critical to avoid poor results with efficient replacement energy projects. Lack of keenness by owners to invest was the result of bad experience with energy projects (ASHRAE, 2011). One such example was variable frequency drive (VFD). Slow acceptance for efficient replacement using VFDs in the past 20 to 30 years were initially due to high cost, questionable reliability and limited experience. Once those factors were mitigated, VFDs were seeing greater applications in fans and pumps for part load HVAC applications where it eliminated on-off cycling losses (Dieckmann et al., 2010).

Introducing new energy saving technologies or devices will be the next step when BAS has been optimised. In buildings equipped with BAS, the system should be optimised prior to investing in new efficient replacement systems. Gonzalez (2006) commented that proper implementation of BAS operation will help owners to expect more from BAS and spend less.

The four basic energy management methods discussed above are typical for all commercial buildings. The application of the methods is even more critical in the commercial building sub-sectors, in particular the healthcare buildings, where energy system operations are more complex.

2.3.2 Healthcare Buildings

As the second largest consumer of electrical energy for commercial buildings, the need for energy management in healthcare buildings was daunting in view of various operational demands. Hospitals in major cities around the world were facing acute shortage of in-patient beds. Instead of building new hospitals, few hospitals in the US, for example, were even closed down due to financial difficulties as a result of escalating operational costs (Pregler and Kapur, 2003). In the UK, overcrowding had exceeded the recommended safety limit with nearly 50,000 hospital beds have been lost since 2001 (Donelly, 2014). Similar congestion was happening in Malaysian hospitals where an extra bed was added in between beds wherever possible or placed along corridors in the wards (Perumal and Priya, 2013). Overcrowding led to backlogs particularly in minor or ambulatory surgery. There was a 300 % increase in out-patient surgery cases as reported in US national health statistics report (Suskind et al., 2014). This shift from in-patient to out-patient surgical demand was the main reason for many hospitals to expand their free-standing ambulatory services (Li and Benton, 2003) or also known as ambulatory care centres (ACC).

2.3.2.1 Brief History of ACC

History of ACC building started almost half a century ago and had expanded ever since. ACC services were started initially as an extension to the George Washington Hospital in 1966 (Pregler and Kapur, 2003). From there, the idea of an independent free-standing ACC was materialised in Phoenix, Arizona in 1970 (Durant and Battaglia, 1993). The term free-standing ACC referred to ACCs which were fully functional to conduct ambulatory surgeries but not housed within existing hospitals. As of 1970, there were only two free standing ACCs in the US. Drastic increase of ACCs was recorded in 1990s when the figure shot up to 1,556 ACCs in 1991. Later, the number had more than tripled to 5700 in 2011 (Vicari, 2012). The most performed procedure in ACC was ophthalmology which accounted 28.2 % of all specialties performed in the US. In terms of procedures, there was an increase from 20 to 60% in terms of ACC procedures (Fox et al., 2014).

The trend was slightly different in UK and Australia. Even though sophisticated ambulatory surgeries were adopted but the concept of free-standing ACC was not popular (Millar, 1997) and hospital-integrated facility were still preferred (Twersky, 1994). However, the concept of free standing ACC in Malaysia was still in its infancy. In Malaysia, the first trial of ACC services was conducted at Hospital Ipoh in 1987 (Sivasakthi, 2012). This was followed by HUKM for being the first multi-disciplinary ACC in Malaysian public teaching hospitals in 1998 (Norshidah et al., 2001). Based on the success in Ipoh with reduction of 28.2% inpatient surgery, free standing ACCs were planned. As of August 2011, out of 145 public hospitals (Maierbrugger, 2013), there were 15 free standing ACCs including the one in Hospital Pulau Pinang.

2.3.2.2 Overview of ACC Operational Needs

ACCs provided alternatives to hospital based procedures where patients treated at ambulatory care centres underwent simple procedure and did not require hospital stay (Fox et al., 2014). Ambulatory care centres (ACC) offered more personalised attention, less waiting time, less congestion and lower surgery cost (Twersky, 1994). With the advancement of technology in laser, endoscopic surgical instruments, safer operation can be carried out effectively (Durant and Battaglia, 1993). High-tech surgical instrument coupled with improved anaesthetic agents had enabled faster post operation recovery (Pregler and Kapur, 2003). Patients welcome the idea of no overnight stay. At the same time, it also freed hospital beds for more critical cases. This concept of medical day care was gaining global acceptance because of lower medical cost for patients as well as lower operational costs to service providers. Cost awareness mandated that operating expenses such as escalating energy cost and usage be monitored. This will help prevent transferring any inefficiency back to the patient in the continuing effort to curb escalating medical cost. Competitiveness will ensure ACCs stay relevant.

Healthcare facilities such as ACCs were energy intensive. Healthcare buildings were the second largest consumer of energy per unit of floor area (ASHRAE, 2012). Furthermore, healthcare energy intensity was doubled of that for office buildings (Sahamir and Zakaria, 2014). Based on an energy efficiency indicator survey done by ASHRAE in 2010, it was found that 58% of healthcare building decision makers placed energy management as being extremely important to their organizations (Checket-Hanks, 2010). Main energy intensive systems in healthcare buildings such as ACC were Air-conditioning and Mechanical Ventilation (ACMV) and lighting (Woods, 1984). While lighting was rather straightforward, ACMV specific requirements must meet multiple healthcare considerations (Yau and Chew, 2014). First priority in hospital ACMV system was air cleanliness which was crucial in controlling infection (Nizza, 1989). Fresh air or recirculated air needed to be high efficiency particulate (HEPA) filtered to lower concentration of airborne bacteria

(Chaddock, 1983). For staff safety, higher air exchange rate was required for operating theatre (OT) in order to dilute the concentration of airborne bacteria (Kuehn et al., 1993) or anaesthetic gas meant for patients that could have slipped into the operating rooms. Maintaining positive pressure in the operating rooms will prevent cross contamination through ingress of non-sterile air into the theatres (Woods, 1984). As a result of the above requirements, bigger fans were required to overcome higher static pressure due to resistance across filters, deliver higher flow-rate to achieve high air-change per hour (ACH) and create higher positive pressure in the theatres. All these specifications were some of the special healthcare ACMV requirements that led to higher energy intensity in healthcare facilities.

To achieve a complex balance among energy efficiency, indoor air quality and optimal ACMV performance, it was beyond normal equipment control provided by traditional mechanical or pneumatic controls. Healthcare facilities complex operational demands required more advanced automation to manage their services. This demand had led to the investment in Building Automation System (BAS) in healthcare building such as ACCs.

2.4 Building Automation System (BAS)

2.4.1 Introduction

"Building automation is a computerized measurement, control and management of building services" (Merz et al., 2009). Healthcare building services include systems like electrical, HVAC, lighting, fire system, vertical transportation, medical gases and security. A computerized management of building services enabled automatic monitoring of building spaces, indoor climates and its energy consumption, automatic generation of work orders for maintenance activities as well as linked to the procurement of parts and issuance of purchase orders were among the myriad possibilities to be taken by an automation of building operation, maintenance and management (Boed and Goldschmidt, 2000). According to Behrooz et al. (2011), other terms like EMS and BEMS were interchangeably used to refer to BAS. Altweis and Nemet (2013) went further to add DDC and EMCS as equally common terms that were often used to refer to modern commercial building controls.

2.4.2 BAS and ACMV System Interface

Building automation system (BAS) comprises networks of sensors, controllers, actuators, communication buses, servers and software. Computerised measurements of important system parameters are handled by field devices such as sensors and transducers. While, BAS control functions are performed by actuators and controllers. Finally, data acquisition, storage, analysis and management are done through controllers, servers and operating workstations, respectively. As the scope of this research focuses on ACMV system, the main interface of BAS system components with the ACMV system was at the air handling unit (AHU) or fan coil unit (FCU) as shown by the dotted line in Figure 2.3.

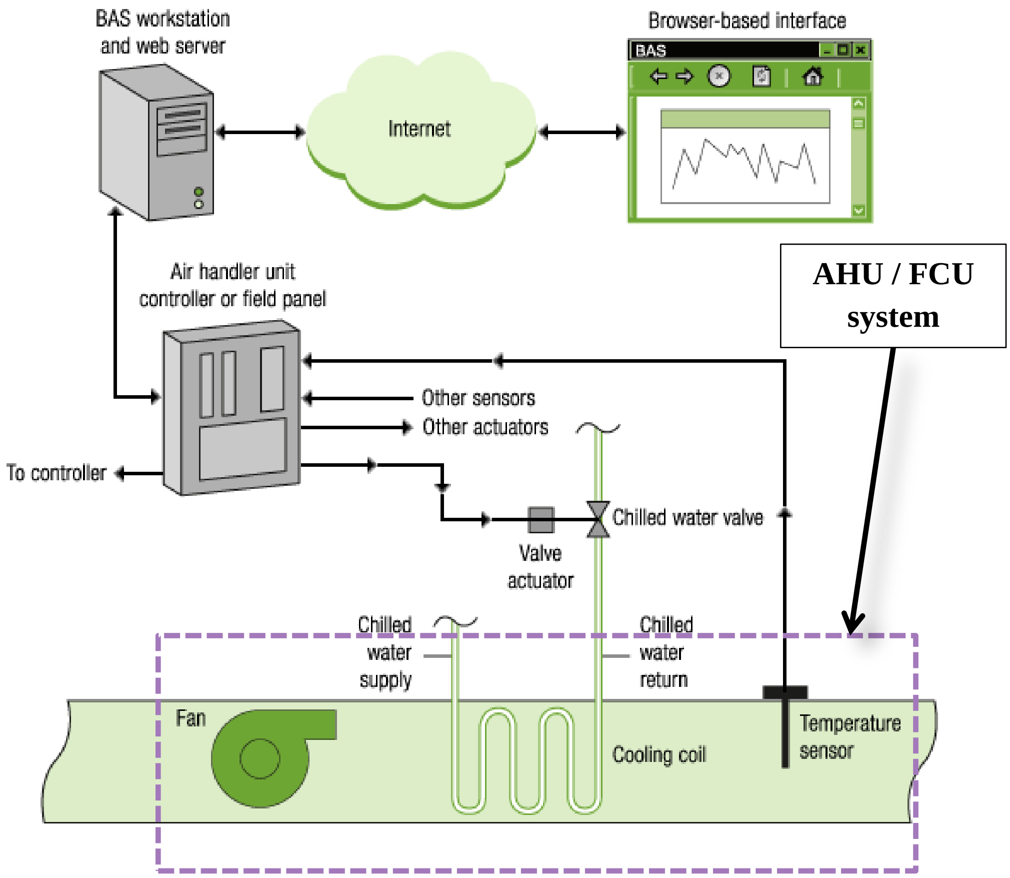

Figure 2.3 Typical BAS System Components
Adopted from E Source (2013)

FCUs function exactly like AHUs except for their application in smaller zones or rooms. Ordinary thermostat was used for FCU temperature control without data exchange with BAS system except for simple remote start/stop function. BAS system temperature sensor for HVAC system was placed in the AHU air-conditioning ductwork as illustrated in Figure 2.3. Supply air from AHU was then used to cool a dedicated zone. Another BAS control point involved actuator valve that was used to control the amount of chilled water circulating in the AHU cooling coil. AHUs and FCUs represent secondary HVAC systems. Primary HVAC system referred to chiller plants which supplied chilled water to all AHUs and FCUs in a building.

2.4.3 System Integration

According to Wang (2010), key feature of BAS system was the ability to integrate numerous digital devices and systems. The integration was facilitated by linking all BAS system components on dedicated local area networks (LAN). Integration among BAS system components can be accomplished once the components can exchange data (Merz et al., 2009). Huge amount of data can be transferred across a wired or wireless LAN continuously every fraction of a second depending on the complexity of a BAS network. A network protocol or driver set the rules for data transfer in order to manage these activities. This protocol delineated appropriate methods for error checking, processing and compressing of data. Most importantly, successful data transmission was achieved when original data reached and acknowledged by an intended address or a receiving terminal (Tridium Inc., 2002b). This communication held true as long as protocols were applied within a compatible system or manufacturer. Once vendor-specific or proprietary protocols came into the picture, the integration may be at stake.

Despite protocols that make integration possible, development of proprietary protocols by different manufacturers can hamper integration when it came to upgrading the system or integrating multi-vendor of BAS platform. Wang (2010) pointed out that building developers faced challenges to integrate diverse system of building automation from different vendors. Either they had to rely on one vendor for integrating the whole building services or maintain discrete system without the benefit of integrated automation and controls. In the US, the seriousness of dominance by giants of controls industry in 1980s had left many building owners with abandoned or under-utilized DDC systems that could not be improved (Boed and Goldschmidt, 2000). Even though, LonTalk and EIB/KNX protocols were