AN IMPROVED METHOD FOR UNIVERSITY BUILDING'S ENERGY EFFICIENCY INDEX USING CLUSTER APPROACH

NUR NAJIHAH BINTI ABU BAKAR

UNIVERSITI TEKNOLOGI MALAYSIA

AN IMPROVED METHOD FOR UNIVERSITY BUILDING'S ENERGY EFFICIENCY INDEX USING CLUSTER APPROACH

NUR NAJIHAH BINTI ABU BAKAR

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

MARCH 2015

Specially dedicated to my beloved family,
especially to
my parent, Abu bakar Ali & Norhayati Abu Seman,
my lovely husband, Mohamad Nor Hafiz Mahmood,
my son, Mohamad Zhariff Hakimi,
my supervisor, PM Dr Mohammad Yusri Hassan,
and all my dearest friends
who encouraged, helped, guided, and inspired me
throughout my journey of education

ACKNOWLEDGEMENT

Alhamdulillah. Thanks to the Almighty Allah S.W.T, for His blessings and guidance for giving me inspiration and strengths along this journey in completing my thesis.

First and foremost, I would like to express my hearty gratitude to my supervisor, Assoc. Prof. Dr. Mohammad Yusri bin Hassan for the guidance and enthusiasm given throughout the progress of this project. Without his advice and valuable comment in the making of this project, I will never be able to achieve this stage. I am deeply grateful to have him as my supervisor and also my mentor.

Most importantly, I would like to convey my special deepest thanks to my parents, Abu Bakar Ali and Norhayati Abu Seman, who had persistently giving spiritual motivation and inspiration throughout my study. I am also indebted and grateful to my husband and son whose love is boundless and constantly encouraged me throughout my studies. With their concern and support, I managed to motivate myself to finish this project.

Not forgotten to Kementerian Pendidikan Malaysia (KPM) and Universiti Malaysia Perlis (UNIMAP) for funding my master study through the scholarship of Skim Latihan Akademik Bumiputera (SLAB).

Last but not least, my sincere appreciation also extends to all my colleagues, administrative staffs at Faculty of Electrical Engineering, all members of the Research Management Centre (RMC), UTM and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space.

ABSTRACT

Energy consumption in commercial buildings is a main concern due to the increasing trend in energy consumption globally. For this reason, energy efficiency in buildings has now become an important subject of energy policies at all levels. Many methods have been proposed to provide an effective way for regularly monitoring the performance of energy consumption as well as to reduce energy usage. Energy Efficiency Index (EEI) is one of the energy consumption indicators that is widely used in the building sector for measuring energy performance. This index is generally measured based on the energy used per unit of building floor area. A low building EEI indicates a large energy saving potential for the building. The current method of determining EEI based on the floor area is not able to identify the optimum level of energy usage since it does not consider the number of occupants and effective time usage in the energy performance evaluation. This thesis proposes a new mathematical algorithm for the determination of a building's EEI to accurately identify the energy performance of the building. Unlike the existing method for determining EEI, the proposed algorithm tracks the building performance by clustering the building according to room activities. The proposed algorithm is incorporated with a shifting method, retrofitting strategy and human behavioural practice to justify the parameters involved in the EEI configuration. A case study was carried out using a university building and results show that two elements with significant influence on EEI performance are the number of occupants in the room and operation hours. The usage of rooms with an appropriate number of occupants decreased the EEI to 52.66% averagely. In addition, by considering the effective time of load usage, the reduction of EEI occurred up to 33.3%. The proposed algorithm does not only provide an effective energy performance index, but is also able to track the optimum level of energy usage.

ABSTRAK

Penggunaan tenaga di bangunan-bangunan komersial telah menjadi tumpuan utama berikutan peningkatan pola dalam penggunaan tenaga di seluruh dunia. Oleh itu, kecekapan tenaga di dalam bangunan kini di ketengahkan di dalam polisi tenaga di semua peringkat. Pelbagai kaedah telah dicadangkan bagi menyediakan cara-cara yang berkesan untuk sentiasa memantau prestasi penggunaan tenaga dan juga untuk mengurangkan penggunaan tenaga. Indeks Kecekapan Tenaga (EEI) adalah salah satu peranti penggunaan tenaga yang diguna secara meluas dalam sektor bangunan untuk mengukur prestasi tenaga. Indeks ini umumnya diukur berdasarkan tenaga yang digunakan bagi setiap unit keluasan lantai bangunan. Bacaan EEI bangunan yang rendah menunjukkan potensi penjimatan tenaga yang tinggi untuk bangunan. Kaedah terkini dalam menentukan EEI berdasarkan keluasan lantai tidak dapat mengenal pasti tahap optimum penggunaan tenaga kerana ia tidak mengambil kira bilangan penghuni dan juga penggunaan masa yang berkesan dalam penilaian prestasi tenaga. Tesis ini mencadangkan satu algoritma matematik yang baru bagi penentuan EEI sesebuah bangunan untuk mengenal pasti dengan tepat prestasi tenaga bangunan. Tidak seperti EEI yang sedia ada, kaedah EEI yang dicadangkan untuk menjejaki prestasi bangunan adalah dengan menganalisis kelompok bangunan mengikut aktiviti bilik. Algoritma yang dicadangkan digabungkan dengan kaedah peralihan, strategi penambahbaikan dan amalan tingkah laku manusia untuk menjustifikasi parameter yang terlibat dalam konfigurasi EEI. Satu kajian kes telah dijalankan ke atas bangunan universiti dan keputusan menunjukkan bahawa dua elemen yang mempunyai pengaruh yang besar ke atas prestasi EEI ialah bilangan penghuni di dalam bilik dan waktu operasi. Penggunaan bilik-bilik dengan jumlah penghuni yang sesuai mengurangkan EEI kepada 52.66% secara purata. Di samping itu, dengan mempertimbangkan masa yang efektif penggunaan beban, pengurangan EEI berlaku sehingga 33.3%. Algoritma yang dicadangkan bukan sahaja memberi indeks prestasi tenaga yang berkesan tetapi juga dapat mengesan tahap yang mengoptimumkan penggunaan tenaga.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF SYMBOLS	xiii
	LIST OF ABBREVIATIONS	xiv
	LIST OF APPENDICES	xvi
1	**INTRODUCTION**	1
	1.1 Background of Study	1
	1.2 Problem Statement	8
	1.3 Objective of the Research	9
	1.4 Scope of the Research	10
	1.5 Significance of the Research	11
	1.6 Thesis Organization	12
2	**LITERATURE REVIEW**	13
	2.1 Introduction	13
	2.2 Building Characteristic	14
	2.2.1 End Use Building Distribution	18

		2 2 2	Energy Efficiency	21
	2.3	Energy Management Key Practices		23
		2.3.1	Initiative in Energy Management Program	25
		2.3.2	Measuring Energy Performance	29
	2.4	Energy Efficiency Index (EEI)		30
		2.4.1	The Principle of EEI	31
		2.4.2	Factor Related to the Energy Using Component	32
		2.4.3	Benchmarking Energy Consumption	34
		2.4.4	The Implementation of EEI	37
		2.4.5	Case Study	44
	2.5	Summary		48
3	**RESEARCH METHODOLOGY**			49
	3.1	Introduction		49
	3.2	The concept and the problem of the existing EEI		50
	3.3	Background of the case study		51
	3.4	Related formulas used		53
	3.5	Implementation the cluster approach		54
		3.5.1	Classroom	55
			3.5.1.1 Site area physical overview	56
			3.5.1.2 Energy consumption	57
			3.5.1.3 Classroom schedule	58
			3.5.1.4 Substitution class	59
			3.5.1.5 Proposed EEI algorithm for classroom	60
		3.5.2	Office room	61
			3.5.2.1 Physical characteristic	61
			3.5.2.2 Facilities audited	64
			3.5.2.3 Occupancy trend	65
			3.5.2.4 Retrofitting strategy	66
			3.5.2.5 Proposed EEI algorithm for office room	67
			3.5.2.6 Payback period	68
		3.5.3	Laboratory room	69
			3.5.3.1 Laboratory description	70

		3.5.3.2 Electrical load consumption	71
		3.5.3.3 Human behaviour strategies	71
		3.5.3.4 Proposed EEI algorithm for laboratory room	72
	3.6	Summary	73
4	**RESULT AND ANALYSIS**		74
	4.1	Introduction	74
	4.2	Classroom analysis	75
	4.3	Office room analysis	83
	4.4	Laboratory room analysis	89
	4.5	Summary	93
5	**CONCLUSION**		94
	5.1	Conclusion	94
	5.2	Recommendations for future work	95
REFERENCES			96
Appendices A-E			103

LIST OF TABLES

TABLE NO.	TITLE	PAGE
1.1	Energy saving strategies	6
2.1	Energy saving approaches in the faculty	25
2.2	Comparison model of EEI	42
3.1	Malaysia's TNB electricity tariff	54
3.2	P16's building information	57
3.3	Power consumption characteristic for BKT 1	57
3.4	Capacity of student and lecture during lecture hour for BKT 1	58
3.5	Substitution class to re-allocated student	59
3.6	Capacity of student and lecturer during lecture hour for P07-411/1	60
3.7	Capacity of student and lecturer during lecture hour for P03-220	60
3.8	Power consumption in the main FKE office	64
3.9	Power consumption of electrical equipment for DSM lab	71
3.10	Proposed EEI mathematical algorithm for each cluster	73
4.1	Condition of the two scenarios	76
4.2	Percentage of energy waste for each time slot	77
4.3	Energy usage before reschedule	80
4.4	Revised classroom energy usage	81
4.5	EEI reading for each class before and after reschedule	82
4.6	Result from retrofitting strategies	87
4.7	Result from implementing behavioural strategies	91
4.8	The EEI calculation for DSM lab	92

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Energy source used by end user sector,1949-2011	2
1.2	Energy consumption trend at UTM from 2005-2012 (in kWh)	4
1.3	Electricity bill at UTM from 2005-2012 (in RM)	5
1.4	Energy Efficiency Index in UTM for 2009-2012	7
2.1	Energy production to final consumer	15
2.2	Total electricity used by industry (2012)	16
2.3	Commercial building energy consumption	17
2.4	Diversity of HVAC systems in buildings	19
2.5	Commercial sector buildings energy end use (2006)	20
2.6	Step for energy efficiency approach	23
2.7	Stress Test method	28
2.8	EEI benchmarking	36
2.9	EEI for Malaysia building	37
2.10	Normalized Life Cycle Energy for residential buildings (primary)	45
2.11	Normalized Life Cycle Energy for office buildings (primary)	45
2.12	CEI and BEI values of the school and office building models	47
3.1	Research flow chart	52

3.2	Main FKE office layout	63
3.3	Occupancy measurement fluctuate with the time	65
4.1	Energy chain rule	75
4.2	Two scenarios of space utilization in one room	76
4.3	Existing EEI for BKT 1	78
4.4	Proposed EEI for BKT 1	79
4.5	Comparison the EEI before and after reschedule	82
4.6	Power consumption distribution in the main FKE office	83
4.7	Load profile for P02 building	85
4.8	Load profile between break hours	86
4.9	Comparison EEI before and after retrofitting practices	88
4.10	Break down electrical appliances in DSM laboratory	89
4.11	EEI for DSM lab before and after human behavioural strategies	92

LIST OF SYMBOLS

A	-	Gross floor area
E	-	Energy consumption
O	-	Number of occupant
ΔP	-	Changes in power consumption
Δt	-	Effective time of load usage

LIST OFABBREVIATIONS

AB	-	Actual building
BEI	-	Building Energy Index
CEI	-	Climate Energy Index
CBECS	-	Commercial Buildings Energy Consumption Survey
DOE	-	Department of Energy
DSM	-	Demand Side Management
EC	-	Energy Commission
ECI	-	Energy Cost Index
EEI	-	Energy Efficiency Index
EPI	-	Energy Performance Index
EUI	-	Energy Utilization Index
FKE	-	Fakulti Kejuruteraan Elektrik
GHG	-	Greenhouse gas
hp	-	Horse power
HVAC	-	Heating, Ventilation and Air conditioning
IPTA	-	Institute Pengajian Tinggi Awam
IT	-	Information technology
KPI	-	Key Performance Indicator
LEO	-	Low Energy Office
LCEA	-	Life Cycle Energy Analysis
MELs	-	Miscellaneous electrical loads
MOE	-	Malaysian Ministry of Education
MOHE	-	Malaysian Ministry of Higher Education
MW	-	Mega Watt
RB	-	Reference building
ROI	-	Return on investment

TNB	-	Tenaga Nasional Berhad
UNEP	-	United Nations Environment Program
US	-	United States
UTM	-	Universiti Teknologi Malaysia
ZEO	-	Zero Energy Office

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Load profile	103
B	Survey form	104
C	Data	106
D	Calculation	107
E	Publications	111

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In recent years, a rising demand in energy production and high electricity bill encourage energy to be one of the most attractive fields in research work. Generally, energy is a crucial necessity for all activities in human daily lifeline. It also became an essential driving force in the nation's economy. The dramatic increase in the development and growth of the population worldwide, insists ever rising for both energy production and energy consumption.

However, the endless use of energy will exhaust energy resources sooner or later [1]. This circumstance creates various negative impacts towards environmental degradation which eventually lead to the global warming, CO_2 gas emissions, climate change, and thinning of ozone layer [2, 3]. Not only that, this problem also contributes to low quality of life and critical health problem for humans due to the pollution that occurred. Public awareness and implementation strategies for better use of energy practice in a more organized manner will help to overcome these obstacles.

For the purpose of energy conservation and sustainability, understanding the problem occurs in the energy sector is necessary to offer an effective solution. It is important to know when and where energy has consumed within facilities. The end user of energy consumption can be categorized into four main sectors which are transportation, industry, residential and commercial. The trend for energy source used by end user sector in the world can be seen in Figure 1.1. Electricity use and natural gas increased rapidly in both residential and commercial sectors. In the meantime, petroleum consumption declined in both sectors, while the renewable energy usage slightly increased in the residential sector. In contrast to the transportation sector, petroleum is the leading sources of energy consumption. In industrial sector, petroleum and natural gas were the predominant sources. Coal use in the industrial sector has declined and both electricity and renewable energy show the increasing trend of consumption.

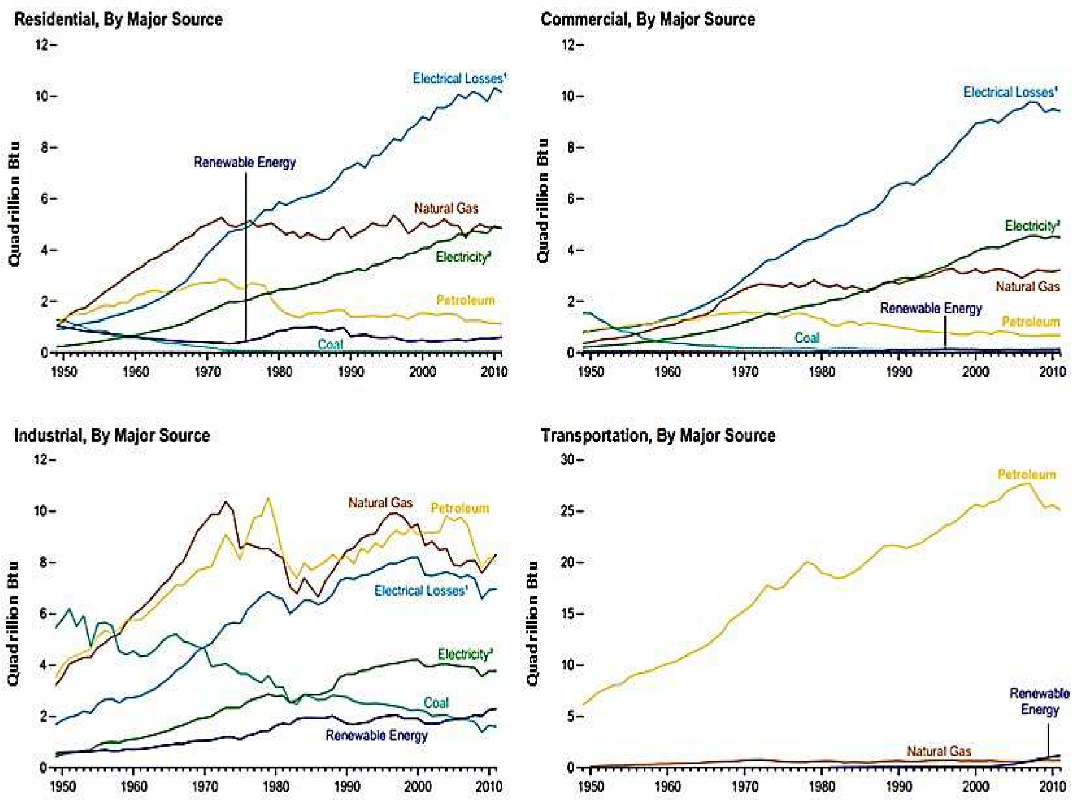

Figure 1.1: Energy source used by end user sector,1949-2011[4].

Building sector, which is the main study area in this thesis has been identified as a large energy consumer as it accounts for a significant percentage of a nation's energy consumption [5]. The United Nations Environment Program (UNEP) remarked that building sector consumed within 30%-40% of the world's energy [6]. The usage of energy in buildings for various countries respectively 23% for Spain

[7], 40% for Europe [8], 25% for Japan [9],28% for China [10], 39% for the United Kingdom [7], 42% for Brazil [11], 50% for Botswana [12], and 47% for Switzerland [13]. All these numbers come to a conclusion in which it proves that building is one of the quarter that should be a concern since it monopoly a very high global energy consumption.

In Malaysia, commercial building alone makes up approximately 32% of total energy consumption [14]. From that amount, 90% energy utilization is in the form of electricity [15]. The rapid development of the country resulted in dramatically increased number of commercial buildings and indirectly, the energy demand is also increasing. Nonetheless, this development should run in parallel with energy production and energy consumption due to the depletion of energy resources [16]. With the current rising energy demand, the main concern is not only focusing on how to produce the required energy, but also ways to improve energy efficiency to ensure a sustainable energy supply so that it can meet the required demand. To achieve the energy efficiency goal, Malaysian Standard MS 1525:2007, Code of Practice on Energy Efficiency and use of Renewable Energy for Non-Residential Building is introduced [17]. This code of practice intends to reduce energy consumption in buildings by emphasizing good organization in the aspect of engineering, architectural, landscaping and site planning for the design of buildings. Energy efficiency by definition is the capabilities to provide the same outcome by using less energy [18]. By utilizing lower input, more energy can be saved as well as electricity bill. Energy building improvement usually can be seen from the outcome of consumer behavioural, advance technological alternative, and economic changes.

University building as one of the commercial buildings is also among high energy consumers because of its characteristics which have comprehensive facilities, large build up area and of course the number of consumers also will be high. Thus, government urging all education institutions for better use of energy through two recognized organizations made up of The Malaysian Ministry of Higher Education (MOHE) and The Malaysian Ministry of Education (MOE) [16, 17].

In order to promote a more sustainable way of consuming energy, energy management plays a pivotal role in achieving such a target. As awareness on energy saving practice gains momentum, various energy management program initiative has been taken by higher institution. One of public universities that participate in this campaign was Universiti Teknologi Malaysia [17, 19] due to the high energy consumption within the building and expensive electricity bill as shown in Figure 1.2 and Figure 1.3. UTM's annual energy consumption for 2009 is approximately 58.81 kWh millions and RM18.99 millions for electricity bill. Annual electrical usage trend in 2009 is the highest due to the increased number of students and also the increased number of buildings within the campus. This scenario is also a reflection of the low awareness of energy saving among staff and students on campus. However, due to the Energy Management Program that was in place beginning 2010, there is a marked reduction in energy consumption.

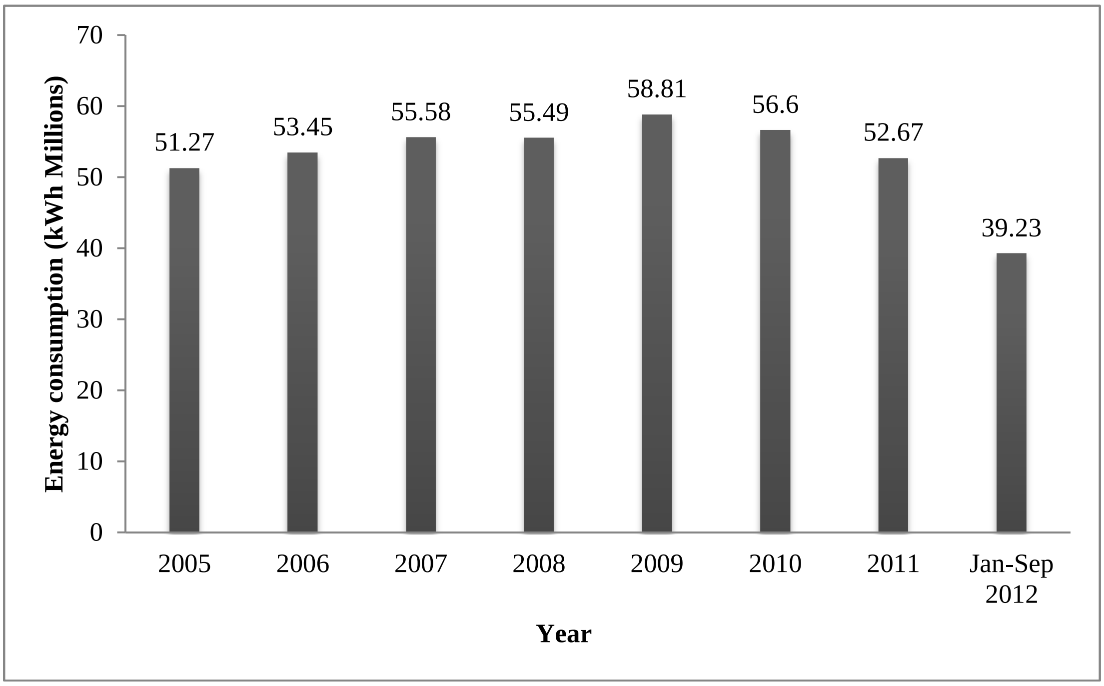

Figure 1.2: Energy consumption trend at UTM from 2005-2012 (in kWh).

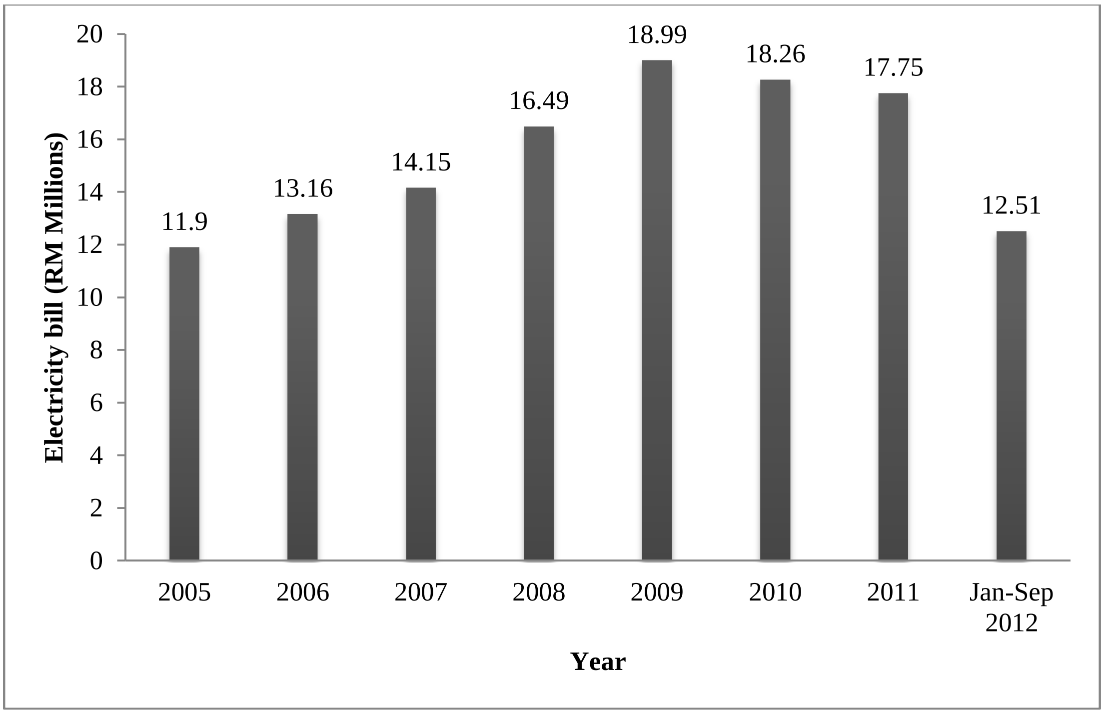

Figure 1.3: Electricity bill at UTM from 2005-2012 (in RM).

UTM technically is built on 1145 hectares of land and occupied by 25000 population included student and staff. It consists of 572 numbers of buildings with 16 faculties, 13 residential colleges, and offices. Energy end-use in university building is largely dominated by the Heating, Ventilation and Air-Conditioning System (HVAC) and followed by lighting. Because of very high monthly utility bills, UTM has established numerous energy management practices since 2010 through no cost initiative, low cost initiative and high cost initiative to reduce energy demand within facilities. Several initiative taken is organized in the Table 1.1 [20]. All these initiative aims to minimize the cost and maximize the incoming profit for the organization.

Table 1.1: Energy saving strategies (2010-2012) [20].

Bil	Energy Efficiency Target Sector	Initiatives Taken	Category
1	Housekeeping	Reset centralised Air-Conditioning (AC) System (24°C & at 7.30am-4.30pm)	No cost initiative
		Policy not to use centralised AC during weekend	No cost initiative
		Continuous monthly/daily/weekend checking on street/building lightings, centralised AC system	No cost initiative
		Installation of soft starter for AC system	Low cost initiative
2	Sustainable Energy Management Tools	Bi-monthly energy management review	No cost initiative
		Electrical Billing Management System (EBMS)	Low cost initiative
		TNB OPTR 20% discount	No cost initiative
		TNB street lighting tariff correction	Low cost initiative
		EM practice best practice check-list	No cost initiative
		EM document sharing	No cost initiative
		UTM-optimal audit	No cost initiative

		Carbon Calculator	Low cost initiative
3	Key Focus Area	Lighting Retrofit	High cost initiative
		Replace AC system using VRF system	High cost initiative
		Private Financing Initiatives(PFI): Installation of VRF AC system	High cost initiative
		Private Financing Initiatives(PFI): LED street lighting retrofit	High cost initiative
		Use of Renewable energy (PFI): Solar system and wind turbine pilot project	High cost initiative
4	Marketing	Awareness program at faculties, colleges and offices	No cost initiative
		Energy saving campaign	No cost initiative
		Yearly workshop on Energy Management Working procedure	Low cost initiative
		Monthly energy management report to University's Management group	No cost initiative
		Email Group & Facebook	No cost initiative

To ensure that strategies applied is effective, monitoring energy performance is needed during the implementation of energy saving strategies. For the purpose of energy performance evaluation, Energy Efficiency Index (EEI) implementation is undeniably important in comparing energy use within the building. EEI is an essential tool that appears as a Key Performance Indicator (KPI) to monitor the energy consumption reading in a building so that energy can be managed in a more efficient way [21]. Figure 1.4 illustrates the performance of EEI for UTM from 2009 until 2012. A decreasing trend in the bar chart is the result of the initiatives taken for the whole campus as stated in the Table 1.1 above. It can be seen that the EEI has shown a reduction approximately 4.2% in 2010, 6.25% in 2010 and 0.7% in 2012.

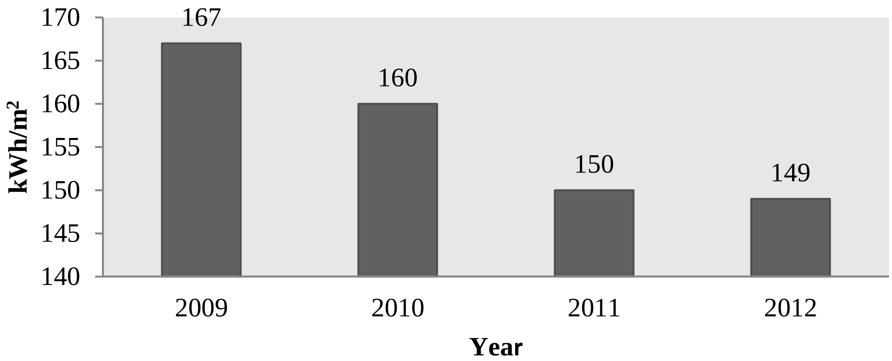

Figure 1.4: Energy Efficiency Index in UTM for 2009-2012.

This EEI, which is the aim in this thesis become a significant indicator since it was used in the worldwide for energy building analysis. There are all sorts of variations in the EEI mathematical algorithm inspired by researcher before. What differentiates all this algorithm is the considered factor related to the energy used. Thus, variables and uncertainties of the factor related in the energy become the gap that needed a deep study in this field. The detailed on this research will be discussed in the Chapter 3 and Chapter 4.

1.2 Problem Statement

This study was conducted based on a number of issues. Inefficient energy utilization in the facility causes the increment in energy demand of power consumption. Sometime undesirable peak loads have also occurred. This unpredicted situation ultimately will reflect to high monthly utility bill that organization had to bear. The concern toward energy usage in a more efficient way make energy management in an organization is the main key to drive the effort for better use energy practice [16]. This requires a standard baseline as the reference to monitor the energy usage. Allowing organizations to set up energy baseline in the building insists on a certain method or indicator for ease to perform an assessment. One of the most commonly uses indicator in the building sector's broadly is an Energy Efficiency Index (EEI). The execution of this index will help the energy management to prepare the action plan for the future.

Despite EEI was the best indicator in energy analysis [21], yet it still has the limitations. The existing index is tied to the size of the building and measured based on the energy used per unit of building floor area which is expressed in kWh/m^2. The lower EEI value, the higher effective level of energy use indeed it does provide great potential for energy saving in that building. However, this index has a shortcoming in determining the optimum level of energy consumption. It failed to identify how much energy is being consumed by an occupant. Generally, the size of the floor area will be the same at all-time, but the changes in power consumption reading still occurred. That means, there are other unknown variable that involved. Thus, the research on these uncertainties parameters is necessary since the buildings energy system is very complex.

This thesis wishes to develop a new mathematical algorithm of EEI that can be effectively used in university building. The calls for the index improvement become a crucial urged. EEI is not only depend on the size floor area, but also strongly depend on the activities carried out in each particular block. All the unseen factor engage that will affect EEI reading can be found through the study from each particular activity.

1.3 Objective of the Research

This research embarks on the following objectives:

I. To identify parameter that affect the optimum use of energy consumption

II. To propose a new mathematical algorithm of Energy Efficiency Index (EEI) for university building by considering its actual activities through cluster approach

III. To analyze energy saving opportunity in university building via new Energy Efficiency Index (EEI)

1.4 Scope of the Research

This research focuses on developing a new mathematical algorithm of EEI that fit with university building through cluster approach. The study was conducted on selected buildings in the Faculty of Electrical Engineering (FKE) in Universiti Teknologi Malaysia (UTM), Johor.

When it comes to the EEI, two main aspects that should be emphasized are energy consumption and also factor related to the energy using component. For energy consumption, a typical load come from two main electrical loads which are air-conditioning system and lighting. These two loads consumed a lot of power consumption to ensure occupant comfort level and end up be the source of higher utility bill for organization.

As for the factor related to the energy using component, one of the required parameters, of course gross floor area for each room. Other suspected significant parameter involved was number of occupant in a room and also operation hours of energy utilization. These speculated parameter is then will validated by using a cluster approach to show that it really affects the energy consumption performance which absolutely will reflect to the EEI reading. Cluster approach is clustering the building, according the room activities it carries. For university building, the analysis of EEI is accordance to three major cluster activities included classroom, office, and laboratory room.

Establishment of the proposed algorithm integrated with shifting method that will be applied to the classroom activities. This method is used for the re-allocation of classroom with suitable number of occupants to minimize the energy waste. Comparison the data analysis between before apply the shifting method and after applying the shifting method will show the potential amount of energy saving that can be achieved. In addition, this method also reveals the significant number of occupants as the parameter in EEI structural.

The relationship between index algorithm and the aspect of operation hours will be highlighted through the analysis in office room, and also laboratories room. Operation hours play an important factor in influencing the rate of energy consumption in the building. The peak hour usually occurred during office hour between 8.00 am to 5.00 pm because of all activities carried out at that time. From this standpoint, human behaviour and changes in technology are some of the steps that will be taken to control the rising energy demand.

1.5 Significance of the Research

EEI is an essential indicator nowadays in the building sector. It is very useful for both owner and tenant to provide better understanding of their building energy utilization so that they will be able to organize effective energy efficiency strategies to control the production of energy consumption. Indirectly, the electrical bill also can be reduced, which is another advantage to the owner.

However, the weaknesses of the existing EEI that failed to determine the optimum use of energy in each room make a limitation in the implementation of this index. In addition, current used EEI only consider the gross floor area as the factor related meanwhile each building has its own particular activities. There must be another significant factor involved.

It is with this concern, a new mathematical algorithm of EEI should be developed. This new algorithm is expected to give an accurate building energy performance and be able to track the optimization of energy level either amount of energy being wasted or the potential for energy saving.

1.6 Thesis Organization

This thesis is apportioned into five chapters. Chapter 1 illustrates the overview of the study. It includes the background of the research, problem statement, objectives, scope of research and the significance of the research.

Meanwhile, chapter 2 keep on the literature review. This chapter reviews the algorithms proposed by various researchers around the world. The concept of EEI, the index's principle as well as both advantage and disadvantage previous methods are also outlined in this chapter.

Chapter 3 presents in depth description of the methodology applied to come out with the proposed index. It enlightens the steps taken throughout the progress of this research in order to achieve relevant analysis. This chapter correspondingly discusses the technical constraints in the building by activities which are important to incorporate with the index algorithm.

Chapter 4 contains the analyses and finding results of this study. The outcome is displayed in simple figures, tables and charts, along with a comprehensive description of the findings.

Finally, Chapter 5 is the closing of this study. The conclusion and a few recommendations to improve this study are clarified.

REFERENCES

[1] Nur Najihah Abu Bakar, M.Y.H., Hayati Abdullah , Hasimah Abdul Rahman, Md Pauzi Abdullah , Faridah Hussin, Masilah Bandi, *Sustainable Energy Management Practices and Its Effect on EEI: A Study on University Buildings.* Proceedings of Global Engineering, Science and Technology Conference 1 - 2 April 2013, Dubai, UAE, ISBN: 978-1-922069-21-4, 2013.

[2] Zamri Noranai, M.N.K., *Study Of Building Energy Index In Universiti Tun Hussein Onn Malaysia.* Academic Journal of Science, 2012.

[3] Ramesh, T., R. Prakash, and K.K. Shukla, *Life cycle energy analysis of buildings: An overview.* Energy and Buildings, 2010. 42(10): p. 1592-1600.

[4] The IEA website. *http://www.eia.gov/*.

[5] Masoso, O.T. and L.J. Grobler, *The dark side of occupants' behaviour on building energy use.* Energy and Buildings, 2010. 42(2): p. 173-177.

[6] The UNEP website, URL:http://www.unep.org/.

[7] Pérez-Lombard, L., J. Ortiz, and C. Pout, *A review on buildings energy consumption information.* Energy and Buildings, 2008. 40(3): p. 394-398.

[8] Zhao, H.-x. and F. Magoulès, *A review on the prediction of building energy consumption.* Renewable and Sustainable Energy Reviews, 2012. 16(6): p. 3586-3592.

[9] Gyu-young Yoon , H.K., Hideki Tanaka,Masaya OKUMIYA, *Study on the energy conservation performance of air-conditioned system for the building combined a double skin and earth-to-air heat exchanger,in: The 2005 World Sustainable Building Conf. in Tokyo.* September, 2005(No. 01-102).

[10] Lam, J.C., Tsang, C.L, Yang, Liu, *Impact of lighting density on heating and cooling loads in different climates in China, Energy Conversion and Management* 47(13-14 (August, 2006)): p. 1942-1953.

[11] Delbin, S., Gomes da Silva, Vanessa, *Energy efficiency simulation of buildings in Brazil: proposal of methodology for insertion in design practice, in: The 2005 World Sustainable Building Conf. in Tokyo.* 27 - 29 September 2005 No. 01-135.

[12] Ahmad, A.S., et al. *Energy efficiency measurements in a Malaysian public university*. in *Power and Energy (PECon), 2012 IEEE International Conference on*. 2012.

[13] M. Zimmermann, H.-J.A., A. Haas, *Benchmarks for sustainable construction—a contribution to develop a standard.* Energy and Buildings 37 (2005) 1147–1157.

[14] S. Moghimi, F.A., S. Mat, C. H. Lim, E. Salleh, K. Sopian, *Building energy index and end-use energy analysis in large-scale hospitals—case study in Malaysia.* Energy efficiency, July 2013.

[15] Aziz, M.B.A., et al. *Air-conditioning energy consumption of an education building and it's building energy index: A case study in engineering complex, UiTM Shah Alam, Selangor*. in *Control and System Graduate Research Colloquium (ICSGRC), 2012 IEEE*. 2012.

[16] Wai, C.W.M., Abdul Hakim; Ting, Low Sheau, *Energy management key practices: A proposed list for Malaysian universities.* July 2011(International Journal of Energy & Environment;2011, Vol. 2 Issue 4, p749).

[17] Ahmad Sukri, A., et al. *Energy efficiency measurements in a Malaysian public university*. in *Power and Energy (PECon), 2012 IEEE International Conference on*. 2012.

[18] Saidur, R., et al., *End-use energy analysis in the Malaysian industrial sector.* Energy, 2009. 34(2): p. 153-158.

[19] Hamidi, N.F., et al. *Load shifting and retrofitting strategy for reducing electricity bill*. in *Research and Development (SCOReD), 2012 IEEE Student Conference on*. 2012.

[20] Bandi, M., *UTM energy management report*. 2013, Universiti Teknologi Malaysia.

[21] Didier Housin, J.F.G., jean-Yues Garnier, Nathalie Trudeau, Emer Dennehy, Taejin Park, Cecilia Tam, Robert Tromop, Nina Camphell, Erin Crum, *Energy efficiency indicator: Essentials for policy making*. 2014.

[22] Chicco, G. and P. Mancarella, *Trigeneration primary energy saving evaluation for energy planning and policy development.* Energy Policy, 2007. 35(12): p. 6132-6144.

[23] Leif Gustavsson, A.J., *Life cycle primary energy analysis of residential buildings.* Energy and Buildings, 2010. 42(2): p. 210-220.

[24] Website, T.I. *URL: http://instituteforenergyresearch.org/topics/encyclopedia/fossil-fuels/*.

[25] Chua, S.C. and T.H. Oh, *Review on Malaysia's national energy developments: Key policies, agencies, programmes and international involvements.* Renewable and Sustainable Energy Reviews, 2010. **14**(9): p. 2916-2925.

[26.] Macdonald, J.M., *Commercial Sector and Energy Use*. Encyclopedia of Energy, 2004. 1: p. 605-616.

[27] Website, T.E. *URL: http://www.epri.com/*.

[28] González, A.B.R., et al., *Towards a universal energy efficiency index for buildings*. Energy and Buildings, 2011. 43(4): p. 980-987.

[29] Parameshwaran, R., et al., *Sustainable thermal energy storage technologies for buildings: A review*. Renewable and Sustainable Energy Reviews, 2012. 16(5): p. 2394-2433.

[30] Taib, S. and A. Al-Mofleh, *Tools and Solution for Energy Management*. Energy Efficiency - The Innovative Ways for Smart Energy, the Future Towards Modern Utilities. 2012.

[31] Zhu, W., Y. Rui, and W. Lingfeng. *Multi-agent intelligent controller design for smart and sustainable buildings*. in *Systems Conference, 2010 4th Annual IEEE*. 2010.

[32] Zhu, W., Y. Rui, and W. Lingfeng. *Multi-agent control system with intelligent optimization for smart and energy-efficient buildings*. in *IECON 2010 - 36th Annual Conference on IEEE Industrial Electronics Society*. 2010.

[33] Smitha, S.D., J.S. Savier, and F.M. Chacko. *Intelligent control system for efficient energy management in commercial buildings*. in *Emerging Research Areas and 2013 International Conference on Microelectronics, Communications and Renewable Energy (AICERA/ICMiCR), 2013 Annual International Conference on*. 2013.

[34] Zhu, W., Y. Rui, and W. Lingfeng. *Intelligent multi-agent control for integrated building and micro-grid systems*. in *Innovative Smart Grid Technologies (ISGT), 2011 IEEE PES*. 2011.

[35] Mohammed, A., A. Mustapha, and N. Mu'azu. *Energy efficient buildings as a tool for ensuring sustainability in the building industry*. in *Multimedia Technology (ICMT), 2011 International Conference on*. 2011.

[36] *U.S. Department of Energy (DOE), 2008 Buildings Energy Data Book. Prepared for the DOE Office of Energy Efficiency and Renewable Energy by D&R International, 2008.*

[37] Omer, A.M., *Renewable building energy systems and passive human comfort solutions*. Renewable and Sustainable Energy Reviews, 2008. 12(6): p. 1562-1587.

[38] Mahlia, T.M.I., et al., *Correlation between thermal conductivity and the thickness of selected insulation materials for building wall*. Energy and Buildings, 2007. **39**(2): p. 182-187.

[39] Jamaludin, A.A., et al. *Energy performance: A comparison of four different multi-residential building designs and forms in the equatorial region*. in *Clean Energy and Technology (CET), 2011 IEEE First Conference on*. 2011.

[40] Patterson, M.G., *What is energy efficiency?: Concepts, indicators and methodological issues.* Energy Policy, 1996. 24(5): p. 377-390.

[41] Tanaka, K., *Assessment of energy efficiency performance measures in industry and their application for policy*. Energy Policy, 2008. 36(8): p. 2887-2902.

[42] Haji ‐ Sapar, M. and S. Eang Lee, *Establishment of energy management tools for facilities managers in the tropical region.* Facilities, 2005. 23(9/10): p. 416-425.

[43] Ashrae, *Fundamentals American Society of Heating, Ventilating and Air-Conditioning Engineers.* 1997(Atlanta, GA).

[44] Basuroy, S., C. Jun Wei, and N.K. Jha. *Making buildings energy-efficient through retrofits: A survey of available technologies*. in *Power and Energy Society General Meeting (PES), 2013 IEEE*. 2013.

[45] Mohit, O.K. and V. Oree. *Assessing the energy savings potential in public buildings through retrofit measures in tropical climates — A case study in Mauritius*. in *Africon, 2013*. 2013.

[46] Wei, C., et al. *Energy consumption and energy efficiency retrofit potential for government office buildings in Beijing*. in *Consumer Electronics, Communications and Networks (CECNet), 2012 2nd International Conference on*. 2012.

[47] Wood, G. and M. Newborough, *Dynamic energy-consumption indicators for domestic appliances: environment, behaviour and design.* Energy and Buildings, 2003. 35(8): p. 821-841.

48] Mahdavi, A., et al., *Occupants' operation of lighting and shading systems in office buildings.* Journal of Building Performance Simulation, 2008. 1(1): p. 57-65.

[49] Ouyang, J. and K. Hokao, *Energy-saving potential by improving occupants' behavior in urban residential sector in Hangzhou City, China.* Energy and Buildings, 2009. 41(7): p. 711-720.

[50] *Syracuse University Classroom Utilization Study*. 2010 13 August; Available from: http://classrooms.syr.edu/wp-content/uploads/2011/11/Classroom-Utilization-Report.pdf.

[51] Hong, Y.C., *Energy Management in University's Lecture Rooms*, in *Centre of Electrical Energy System (CEES)* University Teknologi Malaysia. p. 40.

[52] Bosseboeuf, D., B. Chateau, and B. Lapillonne, *Cross-country comparison on energy efficiency indicators: the on-going European effort towards a common methodology*. Energy Policy, 1997. 25(7–9): p. 673-682.

[53] Diakaki, C., E. Grigoroudis, and D. Kolokotsa, *Towards a multi-objective optimization approach for improving energy efficiency in buildings.* Energy and Buildings, 2008. 40(9): p. 1747-1754.

[54] Yannas, S., *Solar Energy and Housing Design.* 1994. Vol 1(:Principles, Objectives, Design Guidelines.London:Architectural Association Publications).

[55] Yannas, S., *Passive Solar Heating and Energy Efficient Housing Design, Proc.* 2nd Europen Conference on Architecture, Kluwer, Dordrecht, 1990: p. pp.548-556.

[56] Lim, J., *Building Energy Index in Malaysia*, in *http://blog.japhethlim.com/*. 2012.

[57] Website, T.L.i.t.G. *URL:http://www.leanintothegreen.com/2010/03/benchmarking/*.

[58] S. Moghimi, e.a., *Building energy index (BEI) in large scale hospital: case study of Malaysia.* 2011.

[59] Van Gorp, J.C. *Maximizing energy savings with enterprise energy management systems*. in *Pulp and Paper Industry Technical Conference, 2004. Conference Record of the 2004 Annual*. 2004.

[60] Aun, A.C.S., *Green Building index-MS125*. 2008.

[61] Li-Ming, W. and C. Bai-Sheng. *Modeling of energy efficiency indicator for semiconductor industry*. in *Industrial Engineering and Engineering Management, 2007 IEEE International Conference on*. 2007.

[62] The Johnson Controls website, *URL:http://www.johnsoncontrols.com/*

[63] Fumo, N., P. Mago, and R. Luck, *Methodology to estimate building energy consumption using EnergyPlus Benchmark Models.* Energy and Buildings, 2010. 42(12): p. 2331-2337.

[64] *Benefits of energy benchmarking*. 27 March 2014; Available from: https://www.nrcan.gc.ca/energy/efficiency/buildings/energy-benchmarking/building/3719.

[65] *Energy Benchmarking for Buildings and Industries*. Available from: http://energybenchmarking.lbl.gov/.

[66] Oikonomou, V., et al., *Energy saving and energy efficiency concepts for policy making.* Energy Policy, 2009. 37(11): p. 4787-4796.

[67] Cathy Turner, M.F., *Energy Performance of LEED® for New Construction Buildings* 2008, New Buildings Institute. p. 2.

[68] Zain, Z.M., et al. *Energy efficiency benchmarking in UiTM engineering complex Shah Alam*. in *Systems, Process & Control (ICSPC), 2013 IEEE Conference on*. 2013.

[69] Ang, B.W. and F.Q. Zhang, *A survey of index decomposition analysis in energy and environmental studies.* Energy, 2000. 25(12): p. 1149-1176.

[70] Ang, B.W. and F.L. Liu, *A new energy decomposition method: perfect in decomposition and consistent in aggregation.* Energy, 2001. 26(6): p. 537-548.

[71] Aun, A.C.S., *Energy Efficiency: Designing Low Energy Building Using Energy 10*, Pertubuhan Arkitek Malaysia 2004.

[72] Greening, L.A., et al., *Comparison of six decomposition methods: application to aggregate energy intensity for manufacturing in 10 OECD countries.* Energy Economics, 1997. 19(3): p. 375-390.

[73] Han, L., Yan, Qiang. *An Approach to Index System of Efficacy Evaluation on Building Energy Conservation*. in *E-Product E-Service and E-Entertainment (ICEEE), 2010 International Conference on*. 2010.

[74] Acharya, P.K., *Indian Architecture According to Manasara- Silpasastra.* Patna, India, 1979: p. 268 pp.

[75] Morgan, M.H., *Vitruvius: the ten Books on Architecture, New York: Dover*. 1960.

[76] Koenigsberger, O.H., Ingersoll, T.G.,Mayhew,A.,Szokolay, S.V, *Manual of Tropical Housing and Building: Climate Design.* 1973(India:Orient Longman).

[77] Bimal Kumar, R.E., *Independent Verification of a Climate-Based Worldwide Building Energy Index.* 2010.

[78] Al-Homoud, M.S., *Computer-aided building energy analysis techniques.* Building and Environment, 2001. 36(4): p. 421-433.

[79.] Don McLean, Y.R., Richard Quincey, David McEwan *Climate Energy Index And Building Energy Index: New Indices To Assess And Benchmark Building Energy Performance.*

[80] Real Decreto 47/2007, d.d.e., por el que se aprueba el Procedimiento básico para la certificación de eficiencia energética de edificios de nueva construcción, Boletín Oficial del Estado, 31 Jan. 2007, pp. 4499–4507.

[81] Don McLean, Y.R., Richard Quincey, David McEwan,, *Climate Energy Index And Building Energy Index: New Indices To Assess And Benchmark Building Energy Performance* (Integrated Environmental Solutions Limited, Helix Building, Kelvin Campus, West of Scotland Science Park, Glasgow, G20 0SP, U.K.).

[82] *Malaysia, T.N.B.T., Electricity Pricing and Tariff. 2011.*

[83] Davis Iii, J.A. and D.W. Nutter, *Occupancy diversity factors for common university building types.* Energy and Buildings, 2010. 42(9): p. 1543-1551.

[84] *Mengira Kapasiti Penghawa Dingin Split Unit*, in http://zon152.blogspot.com/. 2010.

[85] Tamir, P., *How are the laboratories used?* Journal of Research in Science Teaching, 1977. 14(4): p. 311-316.

[86] Xiang, Y. and L. Weiding. *"Per Capita Building Energy Consumption Occupied Space(PCEOS)" for Assessment of Building Energy Consumption*. in *Management and Service Science, 2009. MASS '09. International Conference on*. 2009.