APPLICATION OF DEMAND SIDE MANAGEMENT STRATEGIES TO REDUCE ENERGY CONSUMPTION IN UNIVERSITY BUILDINGS

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Dedicated to my parents for their unwavering love, patience and support.

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ABSTRACT

Demand Side Management (DSM) refers to actions that change the quantity or pattern of electrical energy consumed by end users to change its load profile. There are many available DSM measures that can be implemented, however this thesis analyses the effects of two DSM methods as strategic options to reduce energy consumption in university buildings, specifically the Faculty of Electrical Engineering at UniversitiTeknologi Malaysia, Johor. The first considered option is the combination of peak clipping and load shifting, which is the process of shifting clipped peak loads away from peak periods to off-peak periods. This thesis addresses the challenge in performing peak clipping and load shifting which is determining the right time to perform peak clipping and load shifting, followed by an assessment of estimated savings in energy usage and electricity bill through these selected methods. Through careful assessment and implementation of time selection, the combined method of peak clipping and load shifting contributes up to 10% savings of energy consumption and electricity bill. Another DSM option is retrofitting which is a process that requires direct change on the existing physical or electrical system of old or already occupied buildings to achieve reduction in energy consumption and electricity bills. In this study, the potential savings by retrofitting the currently installed fluorescent T8 and T5 lighting systems with more recent LED technology in the selected buildings were examined and proved to reduce up to 64% of estimated annual energy consumption and electricity bill. Also, the payback period for which the initial investment will be recovered was evaluated to be approximately 3.03 years.

ABSTRAK

Demand Side Management (DSM) merujuk kepada aktiviti yang mengubah kuantiti atau bentuk penggunaan tenaga oleh pengguna untuk mengubah profil bebannya. Terdapat pelbagai jenis aktiviti DSM yang boleh digunakan, namun tesisini hanya menilai kesan penggunaan dua jenis kaedah DSM sebagai langkah strategik untuk mengurangkan penggunaan tenaga dalam bangunan-bangunan universiti, terutamanya Fakulti Kejuruteraan Elektrik di Universiti Teknologi Malaysia, Johor. Kaedah pertama yang dipertimbangkan ialah gabungan penghad puncak *(peak clipping)* dan anjakan beban (*load shifting*), iaitu proses memindahkan beban puncak yang telah dihadkan daripada waktu puncak ke luar waktu puncak. Tesis ini membincangkan cabaran dalam mengaplikasikan penghad puncak dan anjakan beban iaitu menentukan masa yang tepat untuk melakukan kaedah ini, diikuti oleh penilaian penjimatan penggunaan tenaga dan bil elektrik yang boleh dicapai menerusi pengaplikasian kaedah yang dipilih ini. Melalui penilaian yang teliti dan pemilihan masa yang tepat, kaedah gabungan ini mampu menyumbangkan penjimatan sebanyak hampir 10% pada penggunaan tenaga dan bil elektrik. Satu lagi kaedah DSM ialah penaiktarafan (*retrofit*) iaitu proses yang memerlukan perubahan terus pada sistem fizikal atau elektrikal bangunan yang lama mahupun yang telah digunapakai untuk mencapai pengurangan dalam penggunaan tenaga dan bil elektrik. Di dalam kajian ini, potensi penjimatan menerusi kaedah retrofit dari lampu kalimantang T8 dan T5 kepada teknologi LED pada bangunan terpilih ialah sebanyak 64% daripada anggaran penggunaan tenaga dan bil elektrik tahunan. Selain itu, tempoh pulangan nilai pelaburan hasil daripada kaedah penaiktarafan ini dinilaikan menghampiri selama 3.03 tahun.

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LIST OF ABBREVIATIONS

CFL	-	Compact fluorescent lamp
DR	-	Demand response
DSM	-	Demand Side Management
EE	-	Energy efficiency
FKE	-	FakultiKejuruteraanElektrik
HVAC	-	Heating, ventilation and air-conditioner
kW	-	kilowatt
kWh	-	kilowatt-hour
LED	-	Light Emitting Diode
PDF	-	Probability Distribution Function
RM	-	Ringgit Malaysia
RTP	-	Real-time pricing
T5	-	Fluorescent Tube Lamp Type T5
T8	-	Fluorescent Tube Lamp Type T8
TNB	-	TenagaNasionalBerhad
UTM	-	UniversitiTeknologi Malaysia
W	-	Watt

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Electricity supply and energy consumption are essential parts in modern global economy and it is basically the driving force behind a nation's development and social progress. However, disorganized and inefficient energy usage will lead to negative impacts which will only get worse if it goes unchecked. The dramatic increase in energy usage due to population growth usually leads to problems such as insufficient energy supply, dwindling energy resources, as well as negative side effects on the environment, for example, the thinning of ozone layer, global warming that is often related to the emission of greenhouse gases and dramatic and unpredictable climate change.

It is high time for members of the industries and the public in general to become more aware of complications in energy usage, and everyone should pitch in

and step up the effort for better energy usage practice. We should be more accepting and cooperative in contributing towards implementing strategies to use energy in a more systematic and organized manner regardless of the facilities we inhabit. Among the steps that are often discussed when it comes to this topic is the implementation of renewable energy systems, cleaner production tactics, as well as energy efficient production methods, where all of these promises possible savings in cost, energy and environment.

Energy efficiency by definition is the goal to reduce the amount of energy required to provide products and services. It is the effort to manage and restrain unnecessary energy usage growth while maintaining the level of productivity through alternative technologies and solutions. In simpler terms, it is to do more work but maintaining or reducing the amount of energy used [1, 2]. In the context of Malaysian energy usage, energy efficiency is a main concern in several sectors including: Independent Power Producers (IPPs), industrial manufacturing, building design, transportation, as well as commercial and residential dwellings.

Commercial buildings, which is the main interest of this thesis, together with residential buildings make up almost 50% of the total demand in Malaysia [3]. According to the United Nations Environment Program (UNEP), energy consumption from commercial buildings generates up to 40% of the total worldwide energy consumption [4]. In Malaysia, commercial buildings alone contribute approximately 30% from the total demand nationwide [3-5]. Energy usage in these buildings largely goes into cooling and lighting indoor spaces, apart from operating electrical appliances and machines. In general, factors that affect energy efficiency in these buildings (such as building placement, design, and construction materials) are the ones that can be influenced to improve the effectiveness of energy usage.

The economic development in Malaysia contributes to the rise in numbers of commercial buildings and the same reason factors into the similar increase in higher-education institutions[6]. University buildings are among the high consumers of

energy in the commercial buildings category. As such, the government has encouraged these institutions to put an effort into preserving energy to comply with the government's effort in instigating energy-saving measures in all government departments. This is to comply with the Ministry of Education (MOE) and the Ministry of Higher Education's (MOHE) call for better energy practice in education centers [6-8].

Efficient energy usage in such institutions can be achieved by adopting energy management programs. Activities organized with the objective of optimizing energy consumption through avoiding waste or recovering unused energy in processes or facilities fall under the definition of energy management. The practice of exceptional energy management instills awareness in occupants of a building regarding the actual cost of energy, and the methods and equipment that can be used to control and reduce energy waste.

In general, energy management is consuming energy efficiently and effectively so that profits can be maximized, cost is minimized and competitive position is enhanced. Apart from that, energy management also strives for the following objectives [9]:

i. Improving energy efficiency and reducing energy use, thereby reducing costs.
ii. Reduce greenhouse gas emissions and improve air quality.
iii. Developing and maintaining effective monitoring, reporting and management strategies for practical energy usage.
iv. Developing interest in and dedication to the energy management program from occupants.

Such programs are not new in higher education institutions, especially in Universiti Teknologi Malaysia (UTM). The UTM Johor Bahru campus is categorized under commercial buildings with very high energy usage. One of the

factors that cause this is because of the huge amount of buildings in the southern campus, where there are over 500 buildings distributed among 14 faculties and 13 residential colleges, plus other offices and administrative buildings [7]. Each building consumes different levels of energy due to various parameters that affect their energy use, as can be seen in Figure 1.1.

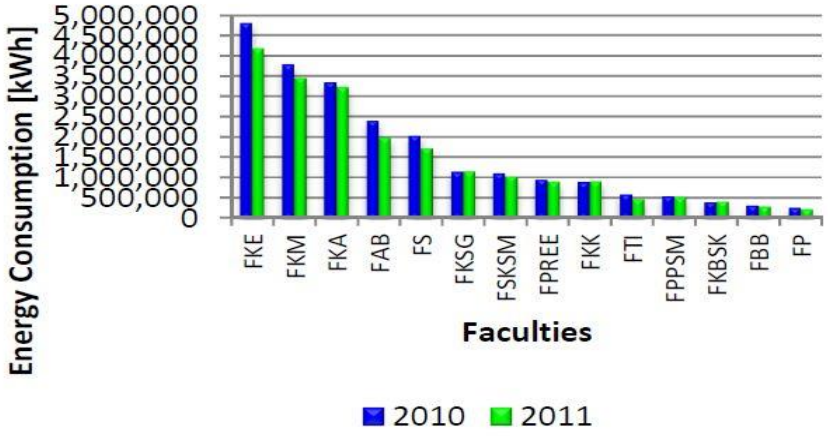

Figure 1.1: Energy consumption comparison in faculties for 2010 and 2011 [7].

A number of awareness programs have been introduced in UTM since 2010, such as the in-campus 'Go Green Campaign' and 'Sustainability Campus Campaign', all with the aim of gearing the campus community towards better energy consumption behavior.

Meanwhile, the Faculty of Electrical Engineering (FKE) currently holds the record for the highest energy consumption in UTM as seen in Figure 1.1. There are a total of twelve blocks in the faculty, which holds classrooms, lecture halls, offices and laboratories. The majority of energy uses within the faculty mostly goes into cooling system, lighting and an assortment of electrical appliances. Figure 1.2 presents the monthly energy consumption in FakultiKejuruteraanElektrik (FKE) from 2009 till 2012, while Figure 1.3 shows the annual energy consumption in FKE

for the same years. Although there is a slight decrease in energy consumption from year to year, there is still plenty of room for improvement, or rather, potential for reduction in energy consumption if appropriate energy management is implemented. Figure 1.4 and Figure 1.5 is the corresponding monthly and annual electricity bill for the amount of energy consumed from year 2009 until 2012. A number of energy appropriate initiatives have been implemented in the faculty. A faculty Energy Management Committee has been established, energy saving awareness campaigns has been organized through talks and online based surveys, and electrical appliances and occupant's behavioral study were performed in an effort towards enhanced energy practice.

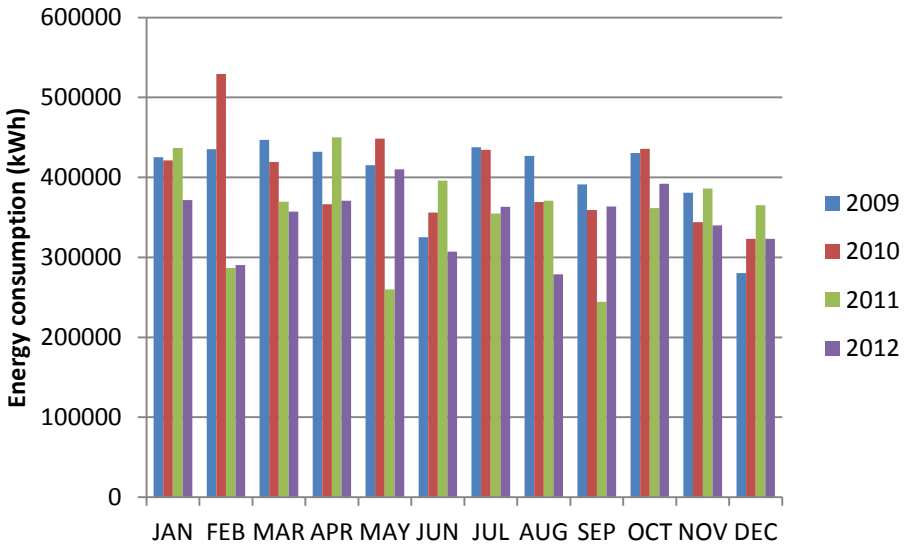

Figure 1.2: Monthly energy consumption in FKE from 2009-2012.

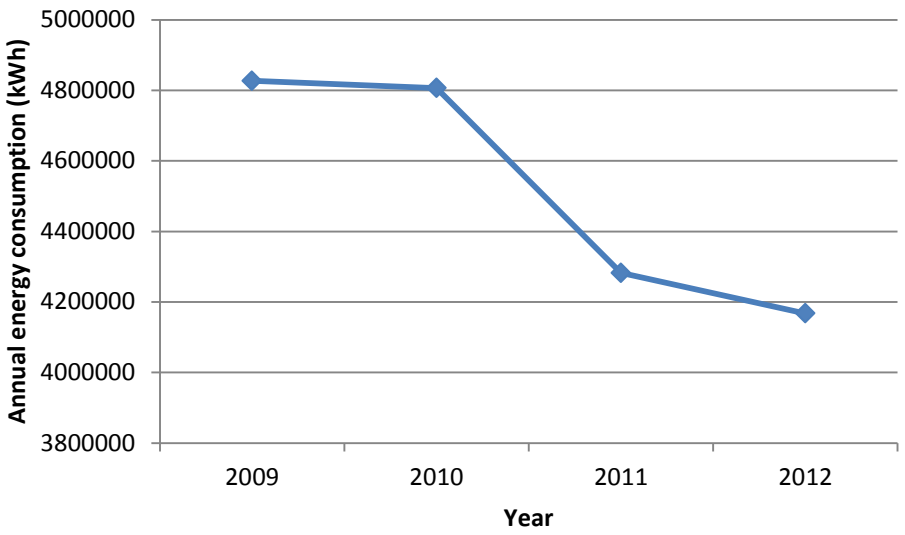

Figure 1.3: Annual energy consumption in FKE.

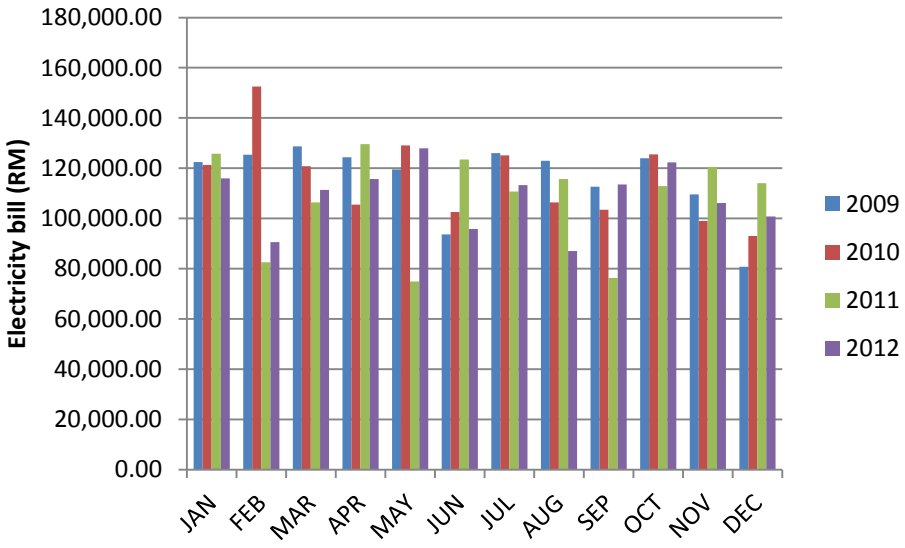

Figure 1.4: Monthly electricity bill in FKE from 2009-2012.

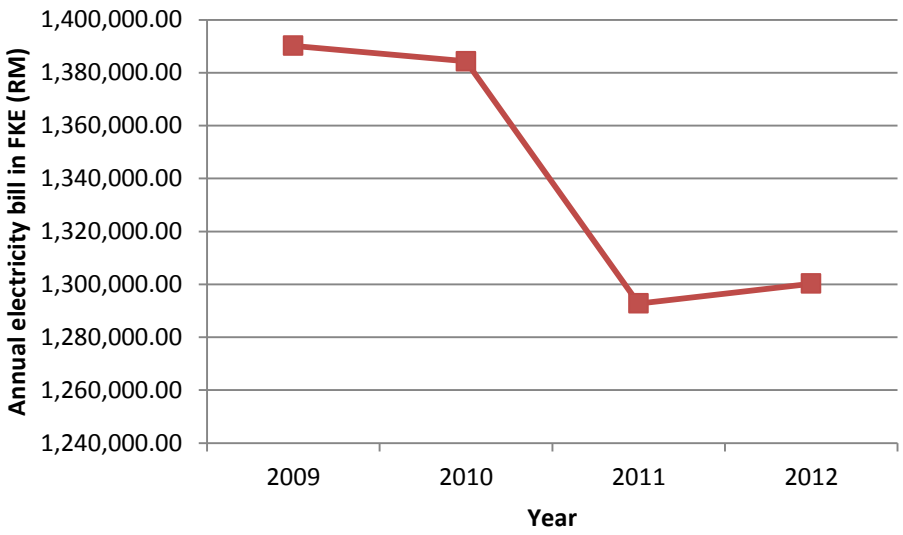

Figure 1.5: Annual electricity bill in FKE.

Energy management is undeniably important if a facility wishes to cut down their energy consumption, which ultimately leads to cutting cost. Because of this, the needs for energy management through various aspects of a building's operation have to be considered.

When it comes to energy, it is apparent that energy does not only comprise of electricity usage alone. It has to be recognized that electricity is generated at power plants, and power plants rely on raw materials such as crude oil and coal to generate power. These natural sources of energy are fast depleting, and in light of the recent price hike in oil price as an added factor, it falls on us to think of a way around this problem.

1.2 Problem Statement

This research is staged based on several issues. The first is the problem of high electricity bill that the facility had to bear. Inefficient energy usage in the facility often leads to undesirable peak loads observed in the buildings' load profile. This will then contribute to high maximum demand and energy consumption (kWh) charges which are reflected on the overall electricity bill.

The second issue is determining the right time to perform peak clipping and to shift it away from peak time so as to make an impact on the maximum demand or energy consumption charges. Each building has different time usage profiles. The fact that a certain DSM method can be applied in a building does not mean the same method can be applied in another type of building. In an academic institution setting, it is relatively achievable to implement peak clipping and load shifting, since the usage of such facilities are mainly limited to lecture sessions and classes along with the management sector that runs on normal office hoursThe main problem is to determine the right time to perform peak clipping and load shifting. If the load that was clipped during peak clipping happens to be the maximum demand, then both maximum demand and energy consumption charges will be reduced. On the other hand, if the shifted load is not the peak load, it will not affect both maximum demand and energy consumption charges. As the duration to perform peak clipping and load shifting is limited, determining the right time is crucial.

The third issue that this thesis wishes to address is the economical aspect of implementing another DSM method, which is retrofitting. Undertaking a retrofitting project obviously requires a certain amount of investment on more energy efficient equipment than what is currently used. The question is, if the management wishes to retrofit their facility, how long before they will reap the benefit of their initial investment? This is a concern that this thesis wishes to highlight by providing an economic analysis on the payback period of installing new energy efficient equipment.

1.3 Objective of the research

The objectives of this research are:

i. To assess the impact of peak clipping and load shifting application in reducing energy consumption and electricity bill in university buildings.

ii. To evaluate the potential of energy consumption minimization and electricity cost reduction through retrofitting in university buildings.

1.4 Scope of the research

This research focuses on reducing energy consumption and electricity bill in university buildings through the application of DSM strategies. The study was conducted on selected buildings in the Faculty of Electrical Engineering (FKE) in UniversitiTeknologi Malaysia (UTM), Johor.

Based on the load consumption pattern of these selected buildings, the appropriate applicable DSM strategies were considered. In this case, the strategies are peak clipping, load shifting and retrofitting. Peak clipping is strategy to reduce energy consumption at peak load, while load shifting is a strategy to reduce energy consumption by shifting load from peak period to off-peak period. If the clipped load from the peak period happens to be the maximum demand of the month, then the maximum demand charge is reduced. Otherwise, only the energy consumption charge is reduced. Either way, it will contribute to a reduction in the electricity bill for the month, since the overall bill is the sum of maximum demand and energy consumption charges.

Retrofitting is also another focus of this thesis. It is another DSM strategy applicable within the scope of university buildings, where the major consumers of electricity are the air cooling and lighting. However, this thesis will only focus on the lighting system, as it promises significant savings by adopting new technology in lighting. FKE's existing lighting system unfortunately still uses old lamp types that are rather comparatively inefficient in recent lighting technology development. Thus, the prospect of retrofitting the existing system with newer and better lightings is definitely appealing.

1.5 Significance of the research

Electrical energy is mainly generated using non-renewable energy resources including coal, oil and natural gases. The continuous dependence on such resources will eventually lead to fossil fuel depletion. It is with this concern that a new strategy to conserve what little sources is left, and at the same time, to use energy efficiently needs to be implemented.Instead of pressing for increased power generation to support continuous energy usage growth, it is more sensible to implement energy efficient methods that will contribute to significant energy usage reduction. In a way, demand side management is an energy efficient way to reduce energy consumption by allowing the facility to operate at the lowest possible cost of production which in turn will reduce the customers' bills [10].

1.6 Thesis outline

This thesis is divided into five chapters. Chapter 1 presents the project overview. It includes the background of the research, objectives, scope of research and the significance of the research.

Chapter 2 follows with the literature review. This chapter discusses the concept of demand side management (DSM), the principles of demand response, as well as in-depth review of DSM and demand response activities carried out in previous researches and projects. Besides that, this chapter also presents the core issue of this thesis which is the concepts of load shifting and retrofitting, apart from a review on other projects where these two methods were implemented. Following that is a look at the Malaysian Electricity Tariff and an introduction to the case study in UTM. Chapter 3 reviews the methodology applied in this project in order to obtain practical results and analysis. It explains the steps taken throughout the progress of this research in order to achieve relevant data. Chapter 4 contains the data findings and analyses of results for this research. The outcome is presented in simple charts, tables and figures, along with detailed explanation of the findings.
Chapter 5 is the concluding section of this thesis. The two DSM measures chosen are compared and recommendations for future work are presented in this chapter.

REFERENCES

1. Patterson, M.G., *What is energy efficiency?: Concepts, indicators and methodological issues.* Energy Policy, 1996. **24**(5): p. 377-390.
2. Saidur, R., et al., *End-use energy analysis in the Malaysian industrial sector.* Energy, 2009. **34**(2): p. 153-158.
3. Saidur, R., *Energy consumption, energy savings, and emission analysis in Malaysian office buildings.* Energy Policy, 2009. **37**(10): p. 4104-4113.
4. Bakar, N.N.A., et al., *Sustainable Energy Management Practices and Its Effect on EEI: A Study on University Buildings.*
5. Moghimi, S., et al. *Building energy index (BEI) in large scale hospital: case study of Malaysia*. in *In Proceeding GEMESED'11, Proceedings of the 4th WSEAS international conference on "Recent Researches in Geography Geology, Energy, Environment and Biomedicine", Corfu Island, Greece*. 2011.
6. Shakur, A., et al., *Energy conservation opportunities in Malaysian universities.* Malaysian Journal of Real Estate, 2010. **5**(1): p. 26-35.
7. Ahmad, A.S., et al. *Energy efficiency measurements in a Malaysian public university*. in *Power and Energy (PECon), 2012 IEEE International Conference on*. 2012: IEEE.
8. Wai, C.W., A.H. Mohammed, and L.S. Ting, *Energy management key practices: A proposed list for Malaysian universities.* Journal homepage: www. IJEE. IEEFoundation. org, 2011. **2**(4): p. 749-760.
9. Capehart, B.L., W.C. Turner, and W.J. Kennedy, *Guide to energy management*. 2002: CRC Press.
10. Ibrahim, M., M.Z. Jaafar, and M.R.A. Ghani. *Demand-side management*. in *TENCON '93. Proceedings. Computer, Communication, Control and Power Engineering.1993 IEEE Region 10 Conference on*. 1993.
11. Gellings, C.W., *The concept of demand-side management for electric utilities.* Proceedings of the IEEE, 1985. **73**(10): p. 1468-1470.
12. Malik, A., *Modelling and economic analysis of DSM programs in generation planning.* International journal of electrical power & energy systems, 2001. **23**(5): p. 413-419.
13. Warren, P., *A Review of demand-side management policy in the UK.* Renewable and Sustainable Energy Reviews, 2013. **29**(0): p. 10.
14. Bach Quoc, K. *Analysis of DSM's impacts on electric energy loss in distribution system using VPI model*. in *Power and Energy Society General Meeting, 2011 IEEE*. 2011.
15. Ravibabu, P. *Energy management through Demand side management techniques-a case study*. in *27-th National System Conference, Indian Institute of Technology, Kharagpur*. 2003.
16. Palensky, P. and D. Dietrich, *Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads.* Industrial Informatics, IEEE Transactions on, 2011. **7**(3): p. 381-388.
17. Goldberg, M., *Measure Twice, Cut Once*, in *IEEE Power & Energy Magazine*. 2010, IEEE Power & Energy Society. p. 46-54.
18. Dietrich, K.L., J.M.; Olmos, L.; Ramos, A.;, *Demand response and its sensitivity to participation rates and elasticities*, in *8th International Conference on the European Energy Market*. 2011. p. 717-716.

19. Cappers, P., C. Goldman, and D. Kathan, *Demand response in U.S. electricity markets: Empirical evidence.* Energy, 2010. **35**(4): p. 1526-1535.
20. Torriti, J., M.G. Hassan, and M. Leach, *Demand response experience in Europe: Policies, programmes and implementation.* Energy, 2010. **35**(4): p. 1575-1583.
21. Albadi, M.H. and E.F. El-Saadany. *Demand Response in Electricity Markets: An Overview*. in *Power Engineering Society General Meeting, 2007. IEEE*. 2007.
22. Dam, Q.B., S. Mohagheghi, and J. Stoupis. *Intelligent Demand Response Scheme for Customer Side Load Management*. in *Energy 2030 Conference, 2008. ENERGY 2008. IEEE*. 2008.
23. Borenstein, S., *The Long-Run Effects of Real-Time Electricity Pricing*. June 2004.
24. Ravibabu, P., et al. *Application of DSM techniques and renewable energy devises for peak load management*. in *Computational Technologies in Electrical and Electronics Engineering, 2008. SIBIRCON 2008. IEEE Region 8 International Conference on*. 2008: IEEE.
25. Babu, P. and V.S. Divya. *Maximum demand limiter for reliable supply by reducing the power cuts to domestic loads*. in *Power, Energy and Control (ICPEC), 2013 International Conference on*. 2013: IEEE.
26. Ilic, M., J.W. Black, and J.L. Watz. *Potential benefits of implementing load control*. in *Power Engineering Society Winter Meeting, 2002. IEEE*. 2002.
27. Groenewald, H., J.C. Vosloo, and E.H. Mathews. *Cost-benefit to the cement industry by shifting evening load to off-peak periods*. in *Industrial and Commercial Use of Energy Conference (ICUE), 2012 Proceedings of the 9th*. 2012.
28. Lidbetter, R.T. and L. Liebenberg. *Load-shifting opportunities for a typical South African cement plant*. in *Industrial and Commercial Use of Energy (ICUE), 2011 Proceedings of the 8th Conference on the*. 2011.
29. Kleingeld, M., J.C. Vosloo, and J.A. Swanepoel. *The effect of peak load shift to off-peak periods on pumping systems*. in *Industrial and Commercial Use of Energy (ICUE), 2011 Proceedings of the 8th Conference on the*. 2011.
30. Van Staden, A.J., J. Zhang, and X. Xia, *A model predictive control strategy for load shifting in a water pumping scheme with maximum demand charges.* Applied Energy, 2011. **88**(12): p. 4785-4794.
31. AboGaleela, M., M. El-Sobki, and M. El-Marsafawy. *A two level optimal DSM load shifting formulation using genetics algorithm case study: Residential loads*. in *Power Engineering Society Conference and Exposition in Africa (PowerAfrica), 2012 IEEE*. 2012.
32. Basuroy, S., J.W. Chuah, 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: IEEE.
33. M.S. Majid, F.M.T., N.M. Maricar, S. Rahman, *Impact of Demand-Side Retrofit on the Energy Savings at the Universiti Teknologi Malaysia.* 2000: p. 534-539.
34. Dascalaki, E. and M. Santamouris, *On the potential of retrofitting scenarios for offices.* Building and Environment, 2002. **37**(6): p. 557-567.
35. Mahlia, T.M.I., H.A. Razak, and M.A. Nursahida, *Life cycle cost analysis and payback period of lighting retrofit at the University of Malaya.* Renewable and Sustainable Energy Reviews, 2011. **15**(2): p. 1125-1132.

36. Di Stefano, J., *Energy efficiency and the environment: the potential for energy efficient lighting to save energy and reduce carbon dioxide emissions at Melbourne University, Australia.* Energy, 2000. **25**(9): p. 823-839.
37. Zografakis, N., K. Karyotakis, and K.P. Tsagarakis, *Implementation conditions for energy saving technologies and practices in office buildings: Part 1. Lighting.* Renewable and Sustainable Energy Reviews, 2012. **16**(6): p. 4165-4174.
38. Balachandra, P. and G.L. Shekar, *Energy technology portfolio analysis: an example of lighting for residential sector.* Energy conversion and management, 2001. **42**(7): p. 813-832.
39. Mahlia, T.M.I., et al., *Cost-benefit analysis and emission reduction of lighting retrofits in residential sector.* Energy and Buildings, 2005. **37**(6): p. 573-578.
40. Techato, K.-a., D.J. Watts, and S. Chaiprapat, *Life cycle analysis of retrofitting with high energy efficiency air-conditioner and fluorescent lamp in existing buildings.* Energy Policy, 2009. **37**(1): p. 318-325.
41. Fiaschi, D., R. Bandinelli, and S. Conti, *A case study for energy issues of public buildings and utilities in a small municipality: Investigation of possible improvements and integration with renewables.* Applied Energy, 2012. **97**(0): p. 101-114.
42. Neils, M. *Retrofitting optical reflectors into existing fluorescent fixtures*. in *Industry Applications Society Annual Meeting, 1988., Conference Record of the 1988 IEEE*. 1988: IEEE.
43. Chen, K. *Design applications in lighting retrofits*. in *Industry Applications Society Annual Meeting, 1992., Conference Record of the 1992 IEEE*. 1992: IEEE.
44. Villaneda, R. *Energy conservation lighting retrofit*. in *Industry Applications Society Annual Meeting, 1992., Conference Record of the 1992 IEEE*. 1992.
45. Dubois, M.-C. and Å. Blomsterberg, *Energy saving potential and strategies for electric lighting in future North European, low energy office buildings: A literature review.* Energy and Buildings, 2011. **43**(10): p. 2572-2582.
46. Kromer, S., O. Morse, and M. Siminovitch. *Lighting retrofit study*. in *Industry Applications Society Annual Meeting, 1992., Conference Record of the 1992 IEEE*. 1992.
47. Roisin, B., et al., *Lighting energy savings in offices using different control systems and their real consumption.* Energy and Buildings, 2008. **40**(4): p. 514-523.
48. Sookoor, T., B. Holben, and K. Whitehouse. *Feasibility of retrofitting centralized HVAC systems for room-level zoning*. in *Green Computing Conference (IGCC), 2012 International*. 2012.
49. Saidur, R., et al., *Chillers energy consumption, energy savings and emission analysis in an institutional buildings.* Energy, 2011. **36**(8): p. 5233-5238.
50. Han, Y. and N. Zhu. *Economic Efficiency Analysis of Energy Efficiency retrofit for existing residential building in Tangshan, China*. in *Industrial Engineering and Engineering Management (IE&EM), 2010 IEEE 17Th International Conference on*. 2010: IEEE.
51. Santamouris, M. and E. Dascalaki, *Passive retrofitting of office buildings to improve their energy performance and indoor environment: the OFFICE project.* Building and Environment, 2002. **37**(6): p. 575-578.
52. Augenbroe, G. and C.-S. Park, *Quantification methods of technical building performance.* Building Research & Information, 2005. **33**(2): p. 159-172.

53. Swisher, J., L. Christiansson, and C. Hedenström, *Dynamics of energy efficient lighting.* Energy Policy, 1994. **22**(7): p. 581-594.
54. Yarnell, K., *Lamp and ballast choice are key to energy savings.* Facilities Design and Management, 1995. **6**: p. 37.
55. Busch, J.F., P. Du Pont, and S. Chirarattananon, *Energy-efficient lighting in Thai commercial buildings.* Energy, 1993. **18**(2): p. 197-210.
56. Pryde, J.R. and G. Archenhold. *The evolving criteria of effective LED luminaire development and commercial product development practices*. in *Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM), 2013 29th Annual IEEE*. 2013.
57. Gan, C.K., et al., *Techno-Economic Analysis of LED Lighting: A Case Study in UTeM's Faculty Building.* Procedia Engineering, 2013. **53**(0): p. 208-216.
58. Sekyere, C.K.K., F.K. Forson, and F.O. Akuffo, *Technical and economic studies on lighting systems: A case for LED lanterns and CFLs in rural Ghana.* Renewable Energy, 2012. **46**(0): p. 282-288.
59. Robertson, J.J. and R.M. Currie, *LED replacement for fluorescent lighting*. 2005, Google Patents.
60. Eiich, S. and H. Kenjiro, *LED lighting unit applied to a fluorescent lighting fixture*. 2006, Google Patents.
61. Kit, J., *Retrofit LED lamp for fluorescent fixtures without ballast*. 2009, Google Patents.
62. Robertson, J.J. and E. Sorella, *LED Replacement Light Tube for Fluorescent Light Fixture*. 2009, Google Patents.
63. Nan, C. and H.S.H. Chung, *A Driving Technology for Retrofit LED Lamp for Fluorescent Lighting Fixtures With Electronic Ballasts.* Power Electronics, IEEE Transactions on, 2011. **26**(2): p. 588-601.
64. Malaysia, T.N.B.T., *Electricity Pricing and Tariff*. 2011.