MULTI-OBJECTIVES OPTIMIZATION OF POWER CONSUMPTION OF A BUILDING TOWARDS ENERGY SAVING

MHD ISWANDI BIN KATUTU

A project report submitted in partial fullfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical - Mechatronic And Automatic Control)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

JUNE 2013

To my beloved parents, wife, daughters, siblings, famili, and friends

ACKNOWLEDGEMENT

Alhamdullilah, thank to Allah, because of Him we are still here, breathing His air, pleasuring His entire gift in this world. And most of all, for giving me opportunities to learn His knowledge.

This work was supervised by Prof. Madya Dr. Hazlina binti Selamat at the Faculty of Electrical, Universiti Teknologi Malaysia. I greatly appreciate all his help, encouragement and guidance.

I am indebted to my parents En. Katutu and Pn. Noraini, my brother Azlan and sisters Aryani and Ierne, without whose help, encouragement and patience I would never have gotten this thesis completed and who made it all worthwhile.

I would also like to thank my wife Suzila and my two daughters Sofea and Safwa, for their love, support, patient and other help throughout. I am also grateful to my brilliant friends, Rahairi, Faiz, Ismail and who also gave me a great deal of support and encouragement.

Finally, thank you to all the other people who have supported me during the course of this work.

ABSTRACT

The sources of energy are limited but the need is growing and electricity is one of the highest operational costs of a building. The high cost is mainly contributed by the electrical energy consumption of the air-conditioning and lighting systems. Optimizing the power consumption of a building without sacrificing the occupants' comfort is extremely important as this will reduce electricity bills while maintaining the productivity level of the building's occupants. This work adopts the use of Genetic Algorithm (GA), for solving the multi-objective optimization problem of the power consumption and comfort in a building, focusing on the room temperature and illumination. The case study involves the use of one air conditioning unit and 12 units of 36-watt fluorescent lamps in a 5-m^2 room with the objective of minimizing the power consumption and maximizing comfort. With the application of the GA, the demand requirements have been satisfied. Comparisons between the use of the optimization technique and without the optimization technique have been carried out, both in simulation and real-time experiments. The results show that the GA optimization produces a 23.85% reduction in terms of current (amp), 24.68% reduction in terms of power (w), 23.09% reduction kWh, and 22.81 % reduction in terms of the electric billing cost.

ABSTRAK

Sumber-sumber tenaga yang terhad tetapi keperluan yang semakin meningkat dan elektrik adalah salah satu kos operasi tertinggi sesuatu bangunan. Kos yang tinggi ini disumbangkan oleh penggunaan tenaga elektrik penghawa dingin dan sistem lampu. Mengoptimumkan penggunaan kuasa pada bangunan tanpa mengorbankan keselesaan penghuni adalah sangat penting kerana ini akan mengurangkan bil elektrik di samping mengekalkan tahap produktiviti penghuni bangunan. Kerja-kerja ini menerima pakai penggunaan Algoritma Genetik (GA) untuk menyelesaikan masalah pengoptimuman pelbagai objektif penggunaan kuasa dan keselesaan dalam sebuah bangunan yang, memberi tumpuan kepada suhu bilik dan pencahayaan. Kajian kes melibatkan penggunaan satu unit penghawa dingin dan 12 unit lampu kalimantang 36 watt di bilik 5-m^2 dengan objektif untuk mengurangkan penggunaan kuasa dan memaksimumkan keselesaan. Dengan penggunaan GA, keperluan permintaan telah dipenuhi. Perbandingan diantara penggunaan teknik pengoptimuman dan tanpa teknik pengoptimuman telah dijalankan, kedua-duanya dalam simulasi dan eksperimen masa sebenar. Keputusan menunjukkan bahawa GA menghasilkan 23.85% pengurangan dalam arus (amp), 24.68% pengurangan dalam tenaga (watt), 23.09% pengurangan kWh , dan 22.81% pengurangan dalam kos bil elektrik.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

δ	-	Weight
T	-	Temperature
e	-	Error between actual value and set value
qac	-	Quantity of aircond unit,
BTUhac	-	Value BTU hour Aircond according to manufacturer,
qlamp	-	Number of lamp,
Plamp-avg	-	Average power rating for every lamp unit.
P(W)	-	Power
*E*v(lx)	-	Illuminance
A	-	Area
$\eta_{(lm/W)}$	-	Lumens per watt

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Motivation

1.1.1 Power Consumption

Malaysia’s consumption of energy increases every year. In 2008, the total energy demand in Malaysia was 522,199 GWh, of which the industrial and transport sectors were the two largest users of energy, accounting more than three-fourths of this total demand. The residential and commercial sector was the third largest user (14%) of energy in Malaysia, and only 1% of the total energy was consumed by the agriculture sector. The consumption of electricity in Malaysia rises rapidly every year, with an average of 2,533 GWh per year. The electricity consumption, for instance, in 1971 was 3,464 GWh and 94,278 GWh in 2008. By 2020, Malaysia’s electricity consumption is expected to increase by about 30% from its present value to 124,677 GWh.

Moreover, there is a strong relationship between Malaysia’s GDP (Gross Domestic Product) and Malaysia’s electricity consumption. To put it succinctly:

high GDP = high economic growth = high production = high energy. For every 1 USD increase in GDP (at the year 2000 rate), electricity consumption would increase by 13 Wh. Traditionally, Malaysia's energy sources for electricity are based on a "four-fuel mix" strategy: gas, oil, hydro, and coal. From 1970 to 1980s, oil was relied heavily for electricity generation, but this over-reliance led to rapid depletion oil in Malaysia. But since the mid 1980s, gas and coal are increasingly being relied on for electricity generation. By 2010, for instance, it is estimated that gas and coal would contribute 92% of the sources for electricity generation. Hydro and oil would contribute the rest (7 and 1%, respectively).

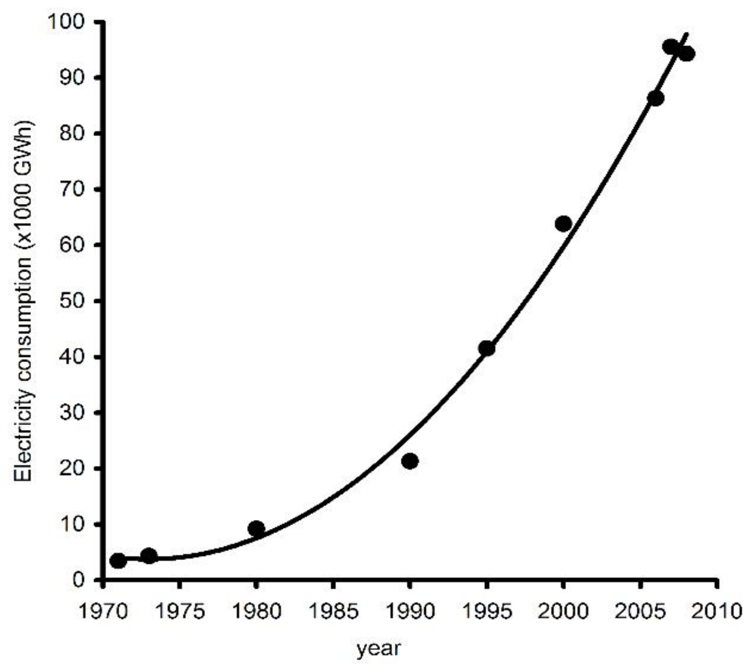

Figure 1.1: Malaysia's Electricity Consumption (1971-2008)

Recently, the government has started to introduce a "five-fuel mix" strategy with renewable energy as the fifth source for electricity generation. The most promising potential for renewable energy in Malaysia is the biomass and biogas from the oil palm industry. However, problems of irregular EFB supply and technology limitations currently hamper the full exploitation of oil palm biomass for electrical generation. Another major contender for renewable energy source is solar radiation. Being near the equator means Malaysia enjoys 12 hours of daylight per day all year round. On average, Malaysia receives 3 kWh per square meter per day from solar radiation. However, photovoltaics are prohibitively expensive at present. It costs about RM22.50 for every 1 kWh of electricity generated per year. This means for photovoltaics to contribute to even 10% of expected electricity demand by Malaysia in 2020, the total cost of photovoltaics would be over RM280 billion.

Geothermal power is another source of renewable energy in Malaysia, but its source is currently untapped. This is unfortunate because Malaysia lies in a geothermal region. Countries like Indonesia and Philippines are already utilizing geothermal as a source of electricity, producing about 1,196 and 1,930 MW, respectively. Recently, a geothermal reservoir was found in Tawau, Sabah, which has the potential to provide up to 67 MW of electricity.

Figure 1.2: Nuclear Energy. Right for Malaysia (photo from keetsa.com)

And there is of course nuclear energy. Although nuclear is a non-renewable energy, its use to meet Malaysia's energy demand must be considered. Nuclear energy suffers from a poor reputation, but its safety record is improving. Nonetheless, building nuclear power stations are very costly (nearly RM10 billion a station) and require a lengthy period before these stations could go online (about a 10-year preparation). Other than finding sustainable sources of energy, the Malaysian government is planning to improve energy efficiency and to promote awareness among the public on the importance of energy conservation.

1.1.2 Thermal comfort and illumination in the building

Thermal comfort is defined in British Standard BS EN ISO 7730 as *'that condition of mind which expresses satisfaction with the thermal environment.'* So the term 'thermal comfort' describes a person's psychological state of mind and is usually referred to in terms of whether someone is feeling too hot or too cold. Thermal comfort is very difficult to define because you need to take into account a range of environmental and personal factors when deciding what will make people feel comfortable. These factors make up what is known as the 'human thermal environment'. The best that you can realistically hope to achieve is a thermal environment that satisfies the majority of people in the workplace, or put more simply, 'reasonable comfort'. HSE considers 80% of the occupants as a reasonable limit for the minimum number of people who should be thermally comfortable in an environment. So thermal comfort is not measured by air temperature, but by the number of employees complaining of thermal discomfort. To better understand why air temperature alone is not a valid indicator of thermal comfort. Why is thermal comfort important because people working in uncomfortably hot and cold environments are more likely to behave unsafely because their ability to make decisions and/or perform manual task deteriorates. A suitable physical climate is needed if one wants to feel comfortable and efficient at work. The environment feels comfortable when you are barely aware of the climatic conditions. It is only when temperature decreases and increases beyond ones' comfort limits that one becomes aware of discomfort (Jorn Toftum 2002). The comfort zone is about 20-220C for a clothed person in the winter and 20-240C in the summer. An increase in temperature above the comfort level may make one tired and sleepy. A decrease in temperature may make one restless and less attentive.

People vary in their feelings about what is a comfortable temperature and this depends on what they are doing and what they are wearing (Peter Hoppe 2003). Light is effective when it corresponds to the visual needs of the worker. Morris defined good lighting as “the right kind and right amount of light at the right place”. Sustainable lighting helps to avoid accidents, supports emotional and physical well being and contributes to security. Knez and Enmarkar(1998), Galsiu and Veitch (2006) opined that artificial lighting is needed to provide task luminance and adequate visual environment to carry on the tasks when natural light is inadequate or not available. Good artificial illumination prevents accidents, prospects health by minimizing eye strain and also contributes to the beauty in offices. Hence, the present study was undertaken with an objective to develop a scale for measuring thermal comfort and illumination in buildings.

In conclusion, Malaysia faces big challenges ahead to meet the country’s growing demand for energy using sustainable practices. Malaysia can succeed provided there is a concerted effort for increasing the: 1) implementation and management of sustainable energy sources, 2) energy efficiency.

1.2 Objectives

The main objectives of this project are:

i. To obtain optimize power consumption and comfort of a building towards energy saving.

ii. To use the genetic algorithm (GA) as an optimization method.

iii. To compare performance of the optimization process with current practice.

1.3 Scope of Work

The scope of work is clearly defining the specific field of the research and ensure That the entire content of this thesis confines the scope. It is begun with the Prototype is planned in KKTM Ledang Office Room with area of $25m^2$ as shown in figure 1.4 and experimental which involve two inputs variable as shown in table 1.1. The next step is the literature review on multi-objectives optimization of power consumption and comfort of a building. The next step is to determine a prime set of variables of energy consumption and comfort. At this stage, the mathematical model will be verified with the respect to the illumination and temperature as an input and power consumption and comfort as an output. Next stage is to develop experimental data, then to design optimization algorithm namely genetic algorithm (GA). Then using Matlab and Simulink, the GA will be simulated and followed by the investigations of in terms of comfort and energy consumption responses. Thereafter, the hands on experiment will be carried out to find the suitable value of optimization method in cooperating with air-conditioning and fluorescent lamp in the building as shown in table 1.1. The comparison result will be carried out to find the percentage of different power consumption without sacrificing comfort between optimization method and non-optimization method. Some survey will be carried out to find the statistic result after the completion of the study

The scope of work can be described in terms of flowchart as shown in Figure 1.3.

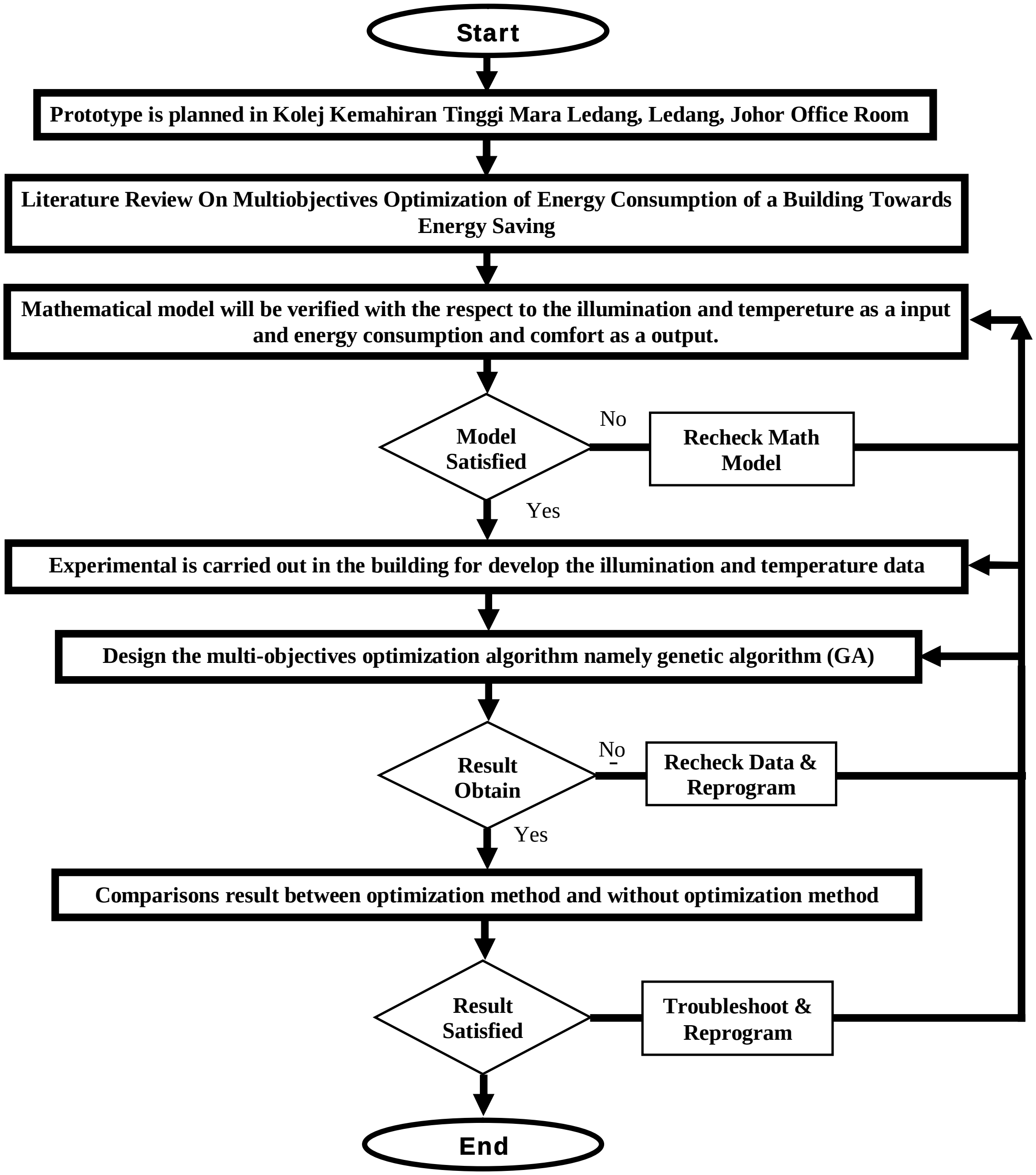

Figure 1.3: Flow Chart

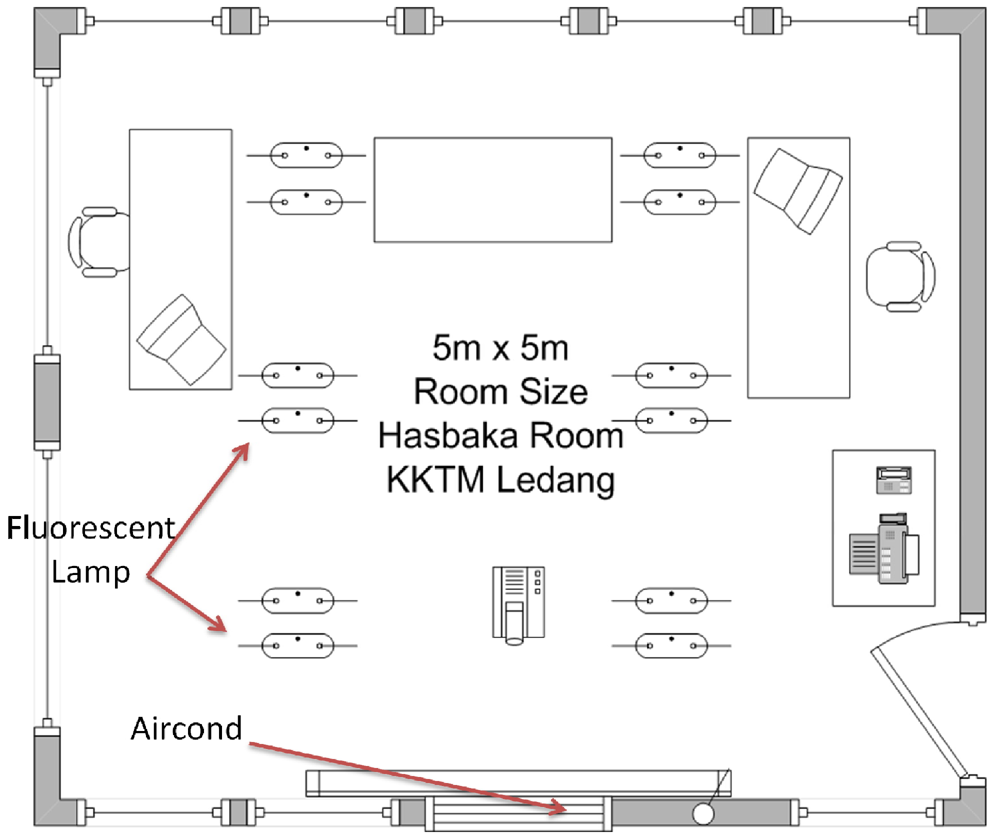

Figure 1.4: Prototype Building in KKTM Ledang

Table 1.1: Experimental Input

No	Item	Specification	Quantity
1.	1.5HP Aircond	Mitsubishi Model: SRK12CJ Power Supply: 220/230 V – 50Hz Current Cooling: 5.3A BTU/h: 11760	1
2.	Fluorescent Lamp	Philips Power Supply: 103V Power: 36-watt	12

1.4 Outline of the thesis

The thesis presents the implementation or possible implementation with the development of the multi-objectives optimization of power consumption and comfort in the building towards energy saving.

Chapter 2 focuses on the literature review, which introduces the overview of multiobjectives optimization of power consumption and comfort. The explanation begins with the previous researches on optimization of power consumption. This chapter then describes by related research on modelling of power consumption and comfort, which is found to be related and facilitate to this project.

Chapter 3 provides the methodology that is used throughout the work of this project. It covers the technical explanation of this project, the model, the variables and parameter selection, the genetic algorithm optimization method.

Chapter 4 deals with the GA simulation results of the model and multi-objectives optimization method. Hands on experiment was carried out, The obtained multi-objectives optimization method results are being compared with the non-optimized method result. Finally some survey will be carried out after the completion of the experiment and simulation.

Chapter 5 presents the conclusions of the project as well as some constructive suggestions for further development and the contribution of this project. The project outcome is concluded in this chapter. As for future development, some suggestions are highlighted.

REFERENCES

[1] Ari, S, Cosden, I A, Khalifa, H E, Dannenhoffer, J F, Wilcoxen, P and Isik, C. 2005. *Constrained Fuzzy Logic Approximation for Indoor Comfort and Energy Optimization*. IEEE NAFIPS Conference, pp 500-504.

[2] F.Garzia, G.M.Veca, "*Optimisation of electrical energy consumption using genetic algorithms*", DUE Domestic use of energy 2003, pp.51-56, 2003.

[3] Zhengyi Li. Zhaoyi Huo Hongchao Yin; , "*Optimization and Analysis of Operation Strategies for Combined Cooling, Heating and Power System*," Power and Energy Engineering Conference (APPEEC), 2011 Asia-Pacific , vol., no., pp.1-4, 25-28 March 2011.

[4] Wa Si , Harutoshi Ogai , Tansheng Li , Masatoshi Ogawa , Katsumi Hira, Hidehiro Takahashi. *Energy saving system for office lighting by using PSO and ZigBee network*, Proceedings of the 8th international conference on Simulated evolution and learning, December 01-04, 2010, Kanpur, India

[5] A. Azadeh, S.F. Ghaderi and S. Tarverdian (2006) "*Electrical Energy Consumption Estimation by Genetic Algorithm* "IEEE ISIE page, no.9-12.

[6] Syahputra R. Fuzzy *Multi-Objective approach for the improvement of distributing network efficiency by considering DG*. International Journal of Computer Science & Information Technology (IJCSIT), April 2012, vol 4, no. 2.

[7] Thomas Bernard, Markoto Sajidman, Helge-Björn Kuntze. *A New Fuzzy-Based Multi-objective Optimization Concept for Process Control Systems*. In Bernd Reusch, editor,Computational Intelligence, Theory and Applications, International Conference, 7th Fuzzy Days, Dortmund, Germany, October 1-3, 2001, Proceedings.

[8] Unler, Alper (2008). *Improvement of energy demand forecasts using swarm intelligence: The case of Turkey with projections to 2025*. Energy Policy 36:1937–1944

[9] R. Alcala, J. Casillas, A. Ganzale. *Tuning fuzzy logic controller for energy effiency consumption in building*. Proc. EUSFLAT-ESTYLF Joint Conferences 1999, IX International Conference in Fuzzy Logic and Technolo Palma de Mallorca (Spain), 103-106, September 22-25, 1999.

[10] Angelov, Plamen (1999) *A fuzzy approach to building thermal systems optimization.* In: 8th International Fuzzy Systems Association World Congress, 1999-01-01, Taipei, Taiwan.

[11] Sariyildiz I.S., Bittermann M.S., Ciftcioglu Ö. *Multi-objective optimization in the construction industry*. In: Proc. 5th Int. Conf. Innovation in Architecture, Engineering and Construction - AEC 2008, Antalya, Turkey (2008) 1-11

[12] Lahmidi H, Pernodet F, Marchio D, Filfli S and Roujol S, Optimization method using genetic algorithms for designing high performance building.

[13] Pengfei Guo Xuezhi Wang Yingshi Han. *The Enhanced Genetic Algorithms for the Optimization Design* 978-1-4244-6498-2/10/$26.00 © IEEE 2010.

[14] Wan Norsyafizan W. Muhamad, Mohamad Yusof Mat Zain, Norfishah Abdul Wahab, Noor Hafizah Abdul Aziz, Rosmalini Abd Kadir, *Energy Efficient Lighting System Design for Building*. 2010 International Conference on Intelligent Systems, Modelling and Simulation, 2010

[15] F F.Garzia, F.Fiamingo, G.M.Veca, "*Energy management using genetic algorithms*", Energy and The Environment, wit Press, Southampton (Boston), 2003.

[16] Christina Diakaki, Evangelos Grigoroudis, Nikos Kabelis, Dionyssia Kolokotsa, Kostas Kalaitzakis and George Stavrakakis, *A multi-objective decision model for the improvement of energy efficiency in buildings*, Energy 35 (2010) 5483-5496

[17] D. Kolokotsaa, G.S. Stavrakakisb, K. Kalaitzakis and D. Agoris, *Genetic algorithms optimized fuzzy controller for the indoorenvironmental management in buildings implemented using PLC andlocal operating networks* Engineering Applications of Artificial Intelligence 15 (2002) 417–428

[18] Mateja Trobec Lah, Borut Zupancic, Jozˇe Peternelj, Ales Krainer (2005). *Daylight illuminance control with fuzzy logic*, Solar Energy 80 (2006) 307–321

[19] Essia Znouda, Nadia Ghrab-Morcos, Atidel B. Hadj-Alouane: *Multiobjective Optimization of Mediterranean Building Design. Journal of Decision Systems* 17(2): 245-268 (2008).

[20] Emmanouilidis C. Hunter A, Macintyre J. Cox C: *A Multi-Objective Genetic Algorithm Approach to Feature Selection in Neural and Fuzzy Modeling*. On International Journal On The Internet. Vol. 3, No. 1, (2001)

[21] Damien B. Jourdan, Olivier L. de Weck: *Layout optimization for a wireless sensor network using a multi-objective genetic algorithm*. IEEE 59th Vehicular Technology Conference (VTC 2004-Spring), Vol.5 (2004) 2466-2470

[22] María José Gacto, Rafael Alcalá, Francisco Herrera: *A multi-objective evolutionary algorithm for an effective tuning of fuzzy logic controllers in heating, ventilating and air conditioning system*s. Appl. Intell. 36(2): 330-347 (2012)

[23] Jun-young Kwak, Pradeep Varakantham, Rajiv Maheswaran, Milind Tambe, Timothy Hayes, Wendy Wood and Burcin Becerik-Gerber, "*Towards Robust Multi-objective Optimization Under Model Uncertainty for Energy Conservation*," in AAMAS Workshop on Agent Technologies for Energy Systems (ATES), June, 2012

[24] Deb, K. (2001). *Multi-objective optimization using evolutionary algorithms*, Wiley.

[25] Murata, T. and Ishibuchi, H. (1995). MOGA: *Multi-objective genetic algorithms*. *In*, 1995. IEEE, 289.

[26] Barán, B., Von Lücken, C., and Sotelo, A. (2005). *Multi-objective pump scheduling optimisation using evolutionary strategies*. Advances in Engineering Software, 36(1), 39-47.

[27] Beckwith, S. P. and Wong, K. P. (1996). *A genetic algorithm approach for electric pump scheduling in water supply systems*. IEEE International Conference on Evolutionary Computation.

[28] Rui Yang and Lingfeng Wang (2010), "*Multi-objective optimization for decision-making of energy and comfort management in building automation and control*," Sustainable Cities and Society, 2(1): 1– 7.

[29] David E Goldberg, '*Genetic algorithms in search, optimization and machine learning*',Addision- Wesley Pub.Co.1989.

[30] Melanie, M. (1999). *An Introduction to Genetic Algorithms*. (5th Ed) A Bradford Book. The MIT Press