SIZING OPTIMIZATION OF HYBRID PHOTOVOLTAIC-WIND-BATTERY SYSTEM TOWARDS ZERO ENERGY BUILDING USING GENETIC ALGORITHM

JULIES BONG SHU AI

A dissertation submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Science (Mathematics)

Faculty of Science
Universiti Teknologi Malaysia

FEBRUARY 2017

ACKNOWLEDGEMENT

First of all, I would like to express my gratitude to my supervisor, Dr. Farhana Bt Johar for her guidance throughout this research. I appreciate for her guidance, encouragement, correction, recommendation and patience. Without her help, this dissertation would not have been the same as presented here.

I would also like to express my gratitude to my parents, especially my father and mother. They had been given me their full support throughout this research and gave out their most encouragement and motivation. I would not be able to withstand the challenges throughout the process of this dissertation without them.

Last but not least, I would also like to thank to my friends who have provided assistance, views, advices and help on C++ programming, latex system and my dissertation writing. Thank you and may God bless you all.

ABSTRACT

A new topic of Zero Energy Building is getting famous in research area because of its goal of reaching zero carbon emission and low building cost. Renewable energy system is one of the ideas to achieve the objective of Zero Energy Building. Recently, Genetic Algorithm is widely used in many research area due to its capability to escape from a local minimal to obtain a better solution. In our study, Genetic Algorithm is chosen in sizing optimization of the number of photovoltaic, wind turbine and battery of a hybrid photovoltaic-wind-battery system. Besides, these numbers are used to minimize the total annual cost of the hybrid energy system towards the concept of Zero Energy Building. There are a few Genetic Algorithm parameters that need to be considered in the optimization process which is generation number, population size, crossover operator and mutation operator. Therefore, two Genetic Algorithm parameters will be analysed and optimized which is generation number and population size. All of the simulations are done by using Microsoft Visual Studio 2010. From the results of simulations, the best generation number and population size is 100 000 and 3 000 respectively. In summary, Genetic Algorithm is efficient in minimizing cost function of a hybrid photovoltaic-wind-battery system with its robustness property.

ABSTRAK

Suatu topik baru iaitu, Bangunnan Tenaga Sifar semakin terkenal di bahagian kajian kerana matlamatnya ialah untuk mencapai pelepasan karbon sifar dan kos pembinaan yang rendah. Sistem tenaga diperbaharui adalah salah satu daripada idea-idea untuk mencapai objektif Bangunnan Tenaga Sifar. Pada masa kini, Algoritma Genetik digunakan secara meluas dalam banyak bidang penyelidikan kerana keupayaannya untuk menjejak keluar dari minimum tempatan untuk mendapatkan penyelesaian yang lebih baik. Dalam kajian kami, Algoritma Genetik dipilih sebagai saiz pengoptimuman bilangan photovoltaic, turbin angin dan bateri sistem dalam sistem hibrid photovoltaic-angin-bateri. Selain itu, nombor-nombor ini digunakan untuk meminimumkan jumlah kos tahunan sistem tenaga hibrid ke arah konsep Bangunnan Tenaga Sifar. Terdapat beberapa parameter Algoritma Genetik perlu dipertimbangkan dalam proses pengoptimuman iaitu, nombor generasi, nombor populasi, pengendali crossover dan pengendali mutasi. Oleh itu, dua parameter Algoritma Genetik akan dikajikan dan dioptimumkan iaitu, nombor generasi dan saiz populasi. Semua simulasi dilakukan dengan menggunakan Microsoft Visual Studio 2010. Daripada hasil simulasi, nombor generasi dan penduduk saiz yang terbaik adalah masing-masing 100 000 dan 3 000. Ringkasnya, Algoritma Genetik adalah cekap dalam mengurangkan fungsi kos sistem tenaga phtovoltaic-angin-bateri dengan ciri kekukuhannya.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CO_2	-	Carbon Dioxide
ZEB	-	Zero Energy Building
PV	-	Photovoltaic
TAC	-	Total Annual Cost
GA	-	Genetic Algorithm
P	-	Population
C	-	Chromosome
Rnd	-	Random Number

CHAPTER 1

INTRODUCTION

1.1 Overview of Zero Energy Building

In our daily life, energy is the main supply to many operations like printing, dwelling, cutting, computing, air conditioning and many others. Nowadays, the population size is expanding continuously and results an increment of total energy demand. In Malaysia, the energy consumption has increased continuously at the rate of 6.62 percent from 1980 to 2012 as provided by [1]. However, not all of the generated energy is fully utilized although the energy demand is high. This excess energy results a energy wastage in the form of heat which will be released to the environment. Then, the temperature of the surrounding is increasing when more and more heat are released from many buildings. Therefore, the problem of global warming arises if the generated energy is not fully utilize in daily operation.

The temperature of global land and ocean surface temperature are increasing from 0.65 degree Celsius to 1.06 degree Celsius over the period of 1880 to 2012 [2]. Due to the reasons of increasing in energy demand, losses of energy and global warming, the concept of Zero Energy Building is slowly being implemented in new construction building. When there is high demand of energy, more and more energy need to be produced to supply the energy load. Then, the energy is transported to the building either from on-site energy source or off-site energy source. In other words, on-site energy source is the energy produced by the building because the energy generator is built by the building investor whereas off-site source is the energy that need to be purchased from a energy generator company and transported to the building.

During the process of energy transportation, energy is lost to the environment as heat energy. The issue of energy lost through transportation in not so significant at on-site energy source. This is because energy storage system is used to store the produced energy and support the energy demand. However, losses of energy might occur when the energy storage system undergoes charging and discharging process. Consequently, the total cost of a building is increasing when the rate of heat loss is high. There are two reasons of this heat loss problem which is low efficiency of energy storage system for on-site energy source and high purchase cost for off-site energy source. Without a good management in constructing a building, the investors might face the problem of high carbon emission and high construction cost.

Therefore many studies are being carried out to apply the concept of zero energy for new building design although this concept is still considered as a new idea in most country. Basically the concept of zero energy building (ZEB) is related to source of energy, type of energy source, carbon emission and investment cost. A study of [3] has summarized the concept of ZEB into four different categories. These four categories are site Zero Energy Building (site ZEB), source Zero Energy Building (source ZEB), Zero Emission Building (emission ZEB) and the last classification which is also the most important class of Zero Energy Building is cost Zero Energy Building (cost ZEB). Recently, United States has set a goal of 50 percent of commercial buildings to become zero energy buildings by 2040 and for all commercial buildings by 2050 [4]. In Europe, the government also set a target that after 2020, all of the buildings in Europe must be built under the concept of Zero Energy Building [5]. The details about the concept of ZEB will be discussed in the following chapter with some literature reviews.

1.2 Background of the Study

The concept of ZEB is about the idea of renewable energy system under the objectives of economical and environmental friendly. According to the study of [6], the authors provided a model of achieving an equilibrium level in between the generated energy from renewable energy system and energy usage of the building which resulted a healthier environment. Besides, [7] designed a ZEB with maximum daylighting and minimum thermal impact. This optimization of daylighting and thermal impact of photovoltaic provided a high energy efficiency of the building.

Moreover, climate condition is also one of the main factors in ZEB. In the study of [8], energy system and building are designed under the consideration of cold climate to achieve the concept of ZEB. However, an optimization of investment cost is not included in the study of [6], [7] and [8]. As stated by [9], a high energy efficiency and cost optimality of photovoltaic are the key factors in achieving ZEB.

These studies are mainly focused on one type of renewable energy system only which is photovoltaic. There exits problem of shortage of energy supply when the climate condition is cloudy. Therefore, our study chose a hybrid photovoltaic-wind-battery system as studied by [10] because the result showed that an optimum sizing of the hybrid photovoltaic-wind-battery system can be achieved in low cost. They compared seven evolutionary algorithms to obtain the minimum total annual cost which is particle swarm optimization, simulated annealing, tabu search, improved harmony search, improved particle swarm optimization, improved harmony search-based simulated annealing and artificial bee swarm optimization.

However, there is increasing number of recent studies using Genetic Algorithm in sizing optimization of hybrid energy system like studies done by [11] and [12]. The result stated that Genetic Algorithm is able to obtain an optimum configuration of energy system in PV/ wind/ split-diesel/ battery hybrid energy system and hybrid wind-diesel-battery system respectively. Hence, Genetic Algorithm is chosen in our

study in sizing optimization the model of hybrid photovoltaic-wind-battery system of the study of [10] towards the target of cost ZEB.

1.3 Statement of the Problem

Due to the issue of global warming, government already set a goal towards a city with healthy environment. Therefore, there is a need to apply the concept of ZEB when constructing a new building that produces less harmful emission to the environment. By considering the needs, our study will focus on a model of renewable energy system and its total annual cost (TAC). Basically, the value of TAC is calculated from total annual capital and maintenance cost.

Generally, a hybrid energy system is used towards the concept of ZEB with a combination of two or more renewable energies. One of the studies [10] applied seven different evolutionary algorithms on the investment cost of photovoltaic-wind-battery power system by optimizing the numbers of solar panel, wind turbine and battery. The result showed that the hybrid energy system can be implemented in low cost. Hence, our study will refer to this hybrid energy system of the study of [10].

Recently the famous application of heuristic method is Genetic Algorithm in many published research papers. A few studies done by [13], [14] and [15] concluded that Genetic Algorithm is efficient to get the best decision variables in each different model of hybrid renewable energy system. However, the study of [10] applied many other heuristic methods except the implementation of Genetic Algorithm. Therefore, Genetic Algorithm will be implemented to search for the best decision variables of the hybrid photovoltaic-wind-battery system which is the number of photovoltaic, wind turbine and battery based on the outcome of the TAC.

1.4 Research Question

By referring to the problem statement stated earlier, some questions are needed to be answered such as:

i. How to maximize the effectiveness of Genetic Algorithm towards a better solution through the experiment of two parameters of Genetic Algorithm?

ii. What is the best generation number when the population size is very small?

iii. What is the best generation number when the population size is very large?

iv. What is the best generation number and population size in determining the minimum TAC?

1.5 Objectives of the Study

The purpose of this study is to:

i. To evaluate the performance setting of Genetic Algorithm parameters in minimizing the total annual cost of hybrid photovoltaic-wind-battery system.

ii. To find the best sizing of photovoltaic, wind turbine and battery of the hybrid energy system.

1.6 Scope of the Study

Our study will only concentrate on application of Genetic Algorithm in minimizing TAC by using an identical energy model from the study of [10]. So the simulation models are categorized as photovoltaic energy system, wind turbine energy system and battery storage system. In order to obtain a good solution with the most minimized cost value, a number of experiments will be carried out on various parameter values of Genetic Algorithm. The purpose of these experiments is to examine the best parameters used in Genetic Algorithm so a better solution can be obtained. These computation simulations are done by using Microsoft Visual C++ Studio 2010 Professional.

1.7 Significance of the Study

This study is expected to contribute to the construction and environment field because the application of a hybrid renewable energy system concerns about the issue of the best investment cost and low carbon emission towards the concept of ZEB. Since renewable energy technologies involved a high investment cost so an optimum configuration of the energy system is needed in order to minimize the construction cost. The results of the study might be useful to the investors in planning for a new building project either with a target of low investment cost or low carbon emission.

Moreover, our study has a significance influence on the application of Genetic Algorithm in the problem under consideration because a number of computation experiments will be carried out to study the control of Genetic Algorithm parameters. Therefore, Genetic Algorithm is chosen to apply in our study of sizing of photovoltaic-wind-battery system by referring to the paper of [10]. The most important contribution of our study is the results from different combination of Genetic Algorithm parameters setting and the resulted total annual cost contributes useful information to investors.

1.8 Thesis Organization

An organization chart of our study is shown below as a better guideline of the reading.

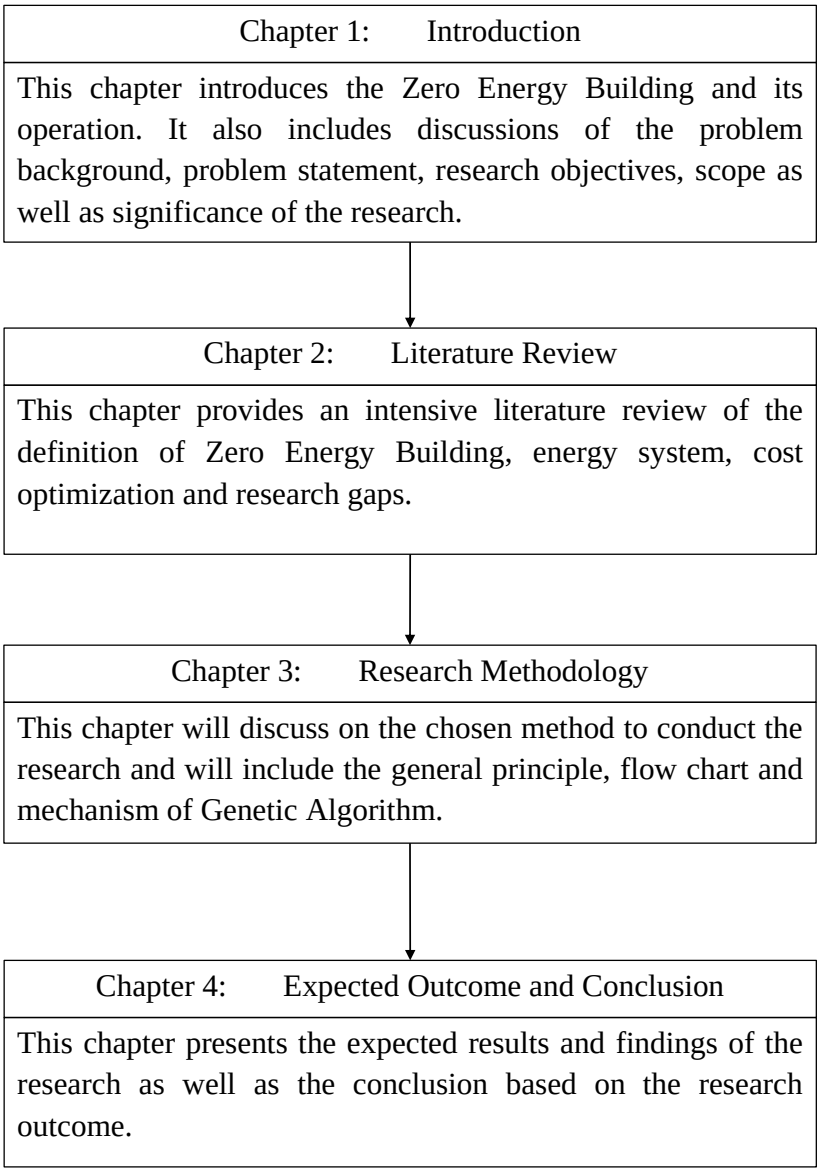

Figure 1.1: Organization chart of our study.

REFERENCES

1. Chong, C., Ni, W., Ma, L., Liu, P. and Li, Z. The Use of Energy in Malaysia: Tracing Energy Flows from Primary Source to End Use. *Energies*, 2015. 8(4): 2828–2866.

2. Team, T. C. W., Pachauri, R. K. and Meyer, L. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *IPCC*, 2014.

3. Torcellini, P., Pless, S. and Deru, M. Zero Energy Buildings: A Critical Look at the Definition. National Renewable Energy Laboratory, Pacific Grove, California: ACEEE Summer Study. 2006.

4. Crawley, D., Pless, S. and Torcellini, P. Getting to Net Zero. *ASHRAE Journal*, 2009. 51(9): 18–25.

5. Brinks, P., Kornadt, O. and Oly, R. Development of Concepts for Cost-optimal Nearly Zero-energy Buildings for The Industrial Steel Building Sector. *Applied Energy*, 2016. 173: 343–354.

6. Hernandez, P. and Kenny, P. From net energy to zero energy buildings: Defining life cycle zero energy buildings (LC-ZEB). *Energy and Buildings*, 2010. 42: 815–821.

7. Huat, N. B. and bin Akasah, Z. A. An Overview of Malaysia Green Technology Corporation Office Building: A Showcase Energy-Efficient Building Project in Malaysia. *Journal of Sustainable Development*, 2011. 4(5): 212–228.

8. Thalfeldt, M., Kurnitski, J. and Mikola, A. Nearly zero energy office building without conventional heating. *Estonian Journal of Engineering*, 2013. 19(4):

309–328.

9. Pikas, E., Thalfeldt, M. and Kurnitski, J. Cost Optimal and Nearly Zero Energy Building Solutions for Office Buildings. *Energy and Buildings*, 2014. 74: 30–42.

10. Maleki, A. and Pourfayaz, F. Optimal Sizing of Autonomous Hybrid Photovoltaic/wind/battery Power System with LPSP Technology by Using Evolutionary Algorithms. *Solar Energy*, 2015. 115: 471–483.

11. Ogunjuyigbe, A., Ayodele, T. and Akinola, O. Optimal Allocation and Sizing of PV/ wind/ split-diesel/ battery Hybrid Energy System for Minimizing Life Cycle Cost, Carbon Emission and Dump Energy of Remote Residential Building. *Applied Energy*, 2016. 171: 153–171.

12. Gan, L. K., Shek, J. K. and Mueller, M. A. Optimised Operation of An Off-grid Hybrid Wind-diesel-battery System using Genetic Algorithm. *Energy Conversion and Management*, 2016. 126: 446–462.

13. Yang, H., Zhou, W., Lu, L. and Fang, Z. Optimal Sizing Method for Stand-alone Hybrid Solar-wind System with LPSP Technology by using Genetic Algorithm. *Solar Energy*, 2008. 82(4): 354–367.

14. Ismail, M. S., Moghavvemi, M. and Mahlia, T. M. I. Characterization of PV panel and global optimization of its model parameters using genetic algorithm. *Energy Conversion and Management*, 2013. 73: 10–25.

15. Ismail, M. S., Moghavvemi, M. and Mahlia, T. M. I. Genetic Algorithm based Optimization on Modeling and Design of Hybrid Renewable Energy Systems. *Energy Conversion and Management*, 2014. 85: 120–130.

16. Parliament, T. E. A directive of The European Parliament and of The Council on The Energy Performance of Buildings. *Official Journal of the European Union*, 2010. 184: 263–291.

17. Wang, L., Gwilliam, J. and Jones, P. Case Study of Zero Energy House Design in {UK}. *Energy and Buildings*, 2009. 41(11): 1215 – 1222.

18. Perlova, E., Platonova, M., Gorshkov, A. and Rakova, X. Concept Project of Zero Energy Building. *Procedia Engineering*, 2015. 100: 1505 – 1514.

19. Good, C., Andresen, I. and Hestnes, A. G. Solar Energy for Net Zero Energy Buildings - A Comparison between Solar Thermal, PV and Photovoltaic-thermal (PV/T) Systems. *Solar Energy*, 2015. 122: 986–996.

20. Zhang, S., Jiang, Y., Xu, W., Li, H. and Yu, Z. Operating Performance in Cooling Mode of A Ground Source Heat Pump of A Nearly-zero Energy Building in The Cold Region of China. *Renewable Energy*, 2016. 87, Part 3: 1045–1052.

21. Good, C., Kristjansdottír, T., Wiberg, A. H., Georges, L. and Hestnes, A. G. Influence of PV Technology and System Design on The Emission Balance of A Net Zero Emission Building Concept. *Solar Energy*, 2016. 130: 89–100.

22. Ismail, M. S., Moghavvemi, M. and Mahlia, T. M. I. Techno-economic Analysis of An Optimized Photovoltaic and Diesel Generator Hybrid Power System for Remote Houses in A Tropical Climate. *Energy Conversion and Management*, 2013. 69: 163–173.

23. Maleki, A. and Pourfayaz, F. Optimal Sizing of A PV/wind/diesel System With Battery Storage for Electrification to An Off-grid Remote Region: A Case Study of Rafsanjan, Iran. *Sustainable Energy Technologies and Assessments*, 2014. 7: 147–153.

24. Tito, S. R., Lie, T. T. and Anderson, T. N. Optimal Sizing of A Wind-photovoltaic-battery Hybrid Renewable Energy System Considering Socio-demographic Factors. *Solar Energy*, 2016. 136: 525–532.

25. Hong, L., Zhou, N., Feng, W., Khanna, N., Fridley, D., Zhao, Y. and Sandholt, K. Building Stock Dynamics and Its Impacts on Materials and Energy Demand in China. *Energy Policy*, 2016. 94: 47–55.

26. Pikas, E., Kurnitski, J., Liias, R. and Thalfeldt, M. Quantification of Economic Benefits of Renovation of Apartment Buildings as A Basis for Cost Optimal 2030 Energy Efficiency Strategies. *Energy and Buildings*, 2015. 86: 151–160.

27. Lu, Y., Wang, S. and Shan, K. Design Optimization and Optimal Control of Grid-connected and Standalone Nearly/net Zero Energy Buildings. *Applied Energy*, 2015. 155: 463–477.

28. Kolokotsa, D., Rovas, D., Kosmatopoulos, E. and Kalaitzakis, K. A Roadmap Towards Intelligent Net Zero- and Positive-energy Buildings. *Solar Energy*, 2011. 85(12): 3067–3084.

29. Wikipedia The Free Encyclopedia. (2016, December 26). Photovoltaic system. `https://en.wikipedia.org/wiki/Photovoltaic_system`.

30. Kaabeche, A., Belhamel, M. and Ibtiouen, R. Sizing Optimization of Grid-independent Hybrid Photovoltaic/wind Power Generation System. *Energy*, 2011. 36(2): 1214–1222.

31. Li, C., Ge, X., Zheng, Y., Xu, C., Ren, Y., Song, C. and Yang, C. Techno-economic Feasibility Study of Autonomous Hybrid Wind/PV/battery Power System for A Household in Urumqi, China. *Energy*, 2013. 55: 263–272.

32. Askarzadeh, A. A Discrete Chaotic Harmony Search-based Simulated Annealing Algorithm for Optimum Design of PV/wind Hybrid System. *Solar Energy*, 2013. 97: 93–101.

33. Kapsalaki, M., Leal, V. and Santamouris, M. A methodology for Economic Efficient Design of Net Zero Energy Buildings. *Energy and Buildings*, 2012. 55: 765–778.

34. Geem, Z. W. Size Optimization for A Hybrid Photovoltaic - Wind Energy System. *International Journal of Electrical Power and Energy Systems*, 2012. 42(1): 448–451.

35. Melanie, M. *An Introduction to Genetic Algorithms*. London, England: Massachusetts Institute of Technology. 1999.

36. Koutroulis, E., Kolokotsa, D., Potirakis, A. and Kalaitzakis, K. Methodology for Optimal Sizing of Stand-alone Photovoltaic/wind-generator Systems using Genetic Algorithms. *Solar Energy*, 2006. 80(9): 1072–1088.

37. Bilal, B. O., Sambou, V., Ndiaye, P., Kébé, C. and Ndongo, M. Optimal Design of A Hybrid Solar-wind-battery System Using The Minimization of The Annualized Cost System and The Minimization of The Loss of Power Supply Probability (LPSP). *Renewable Energy*, 2010. 35(10): 2388–2390.

38. Kalantar, M. and Mousavi G, S. M. Dynamic Behavior of A Stand-alone

Hybrid Power Generation System of Wind Turbine, Microturbine, Solar Array and Battery Storage. *Applied Energy*, 2010. 87(10): 3051–3064.

39. Ramoji, S. K. and Kumar, B. Optimal Economical Sizing of a PV-Wind Hybrid Energy System using Genetic Algorithm and Teaching Learning Based Optimization. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, 2014. 3(2): 2278–8875.

40. de Magalhaes, C. S., , Barbosa, H. J. and Dardenne, L. E. A Genetic Algorithm for The Ligand-protein Docking Problem. *Genetics and Molecular Biology*, 2004. 27(4): 605–610.

41. Ma, Y. and Zhang, C. Quick Convergence of Genetic Algorithm for QoS-driven Web Service Selection. *Computer Networks*, 2008. 52: 1093–1104.

42. Roeva, O., Fidanova, S. and Paprzycki, M. Influence of the Population Size on the Genetic Algorithm Performance in Case of Cultivation Process Modelling. *Computer Science and Information*, 2013: 371–376.

43. Wright, J. and Alajmi, A. Efficient Genetic Algorithm sets for optimizing constrained building design problem. *International Journal of Sustainable Built Environment*, 2016. 5(1): 123 – 131.

44. Mihail-Bogdan, C., Constantin, I. and Horia, N. The Influence of Genetic Algorithm Parameters Over the Efficiency of the Energy Consumption Estimation in a Low Energy Building. *Energy Procedia*, 2016. 85: 99 – 108.

45. Miller, B. L. and Goldberg, D. E. Genetic Algorithms, Tournament Selection, and the Effects of Noise. *Complex Systems*, 1995. 9: 193– 212.

46. Matoušek, R., Krasnogor, N., Melián-Batista, M. B., Pérez, J. A. M., Moreno-Vega, J. M. and Pelta, D. A. *Genetic Algorithm and Advanced Tournament Selection Concept*. Berlin, Heidelberg: Springer Berlin Heidelberg. 2009.

47. David, A. C. *An Introduction to Genetic Algorithms for Scientists and Engineers*. Singapore: World Scientific Publishing Co. Pte. Ltd. 1999.

48. Lipowski, A. and Lipowska, D. Roulette-wheel Selection via Stochastic Acceptance. *Physica A: Statistical Mechanics and its Applications*, 2012. 391(6): 2193 – 2196.

49. Siriwardene, N. and Perera, B. Selection of Genetic Algorithm Operators for Urban Drainage Model Parameter Optimisation. *Mathematical and Computer Modelling*, 2006. 44: 415–429.

50. Crepinsek, M., Liu, S.-H. and Mernik, M. Exploration and Exploitation in Evolutionary Algorithms: A Survey. *ACM Computing Surveys*, 2013. 45(3): 1–33.

51. Hermawanto, D. Genetic Algorithm for Solving Simple Mathematical Equality Problem. *Indonesian Institute of Sciences (LIPI), Indonesia*, 2013.