Near Zero Energy House (NZEH) Design Optimization to Improve Life Cycle Cost Performance Using Genetic Algorithm

Y Latief, M A Berawi, A B Koesalamwardi, L S R Supriadi

1Civil Engineering Department, Faculty of Engineering, Universitas Indonesia, Depok, Jawa Barat, 16424

Abstract. Near Zero Energy House (NZEH) is a housing building that provides energy efficiency by using renewable energy technologies and passive house design. Currently, the costs for NZEH are quite expensive due to the high costs of the equipment and materials for solar panel, insulation, fenestration and other renewable energy technology. Therefore, a study to obtain the optimum design of a NZEH is necessary. The aim of the optimum design is achieving an economical life cycle cost performance of the NZEH. One of the optimization methods that could be utilized is Genetic Algorithm. It provides the method to obtain the optimum design based on the combinations of NZEH variable designs. This paper discusses the study to identify the optimum design of a NZEH that provides an optimum life cycle cost performance using Genetic Algorithm. In this study, an experiment through extensive design simulations of a one-level house model was conducted. As a result, the study provide the optimum design from combinations of NZEH variable designs, which are building orientation, window to wall ratio, and glazing types that would maximize the energy generated by photovoltaic panel. Hence, the design would support an optimum life cycle cost performance of the house.

Keywords: Near Zero Energy House, Optimum Design, Genetic Algorithm, Life Cycle Cost

1. Introduction

Energy efficiency of a building becomes one of the key element to reduce carbon dioxide emission and to save energy. Improving energy efficiency is a more affordable way to fight climate change as well as increasing energy availability. Energy conservation in residential sector gain interest in order to earth preservation. Net Zero Energy Building (NZEB) is a Zero Energy House or Building which energy is much reduced through efficiency where the consumed energy was retrieved from renewable sources. As for NZEH (Near Zero Energy House), it is a residential building which consume energy less than energy generated by itself. By harvesting energy from the sun, NZEH building will consume energy its produced and minimize energy from outside [1].

Indonesia is an equatorial country which get solar exposure along the year. This is very potential for renewable energy as well as NZEH. However, this potential is not yet maximize due to the high price of solar generated electricity technology [2].
generated electricity for residential also because it is not integrated to central electricity network and not yet optimized.

High efficiency building like NZEH should be financially feasible. Good strategy and solution is needed to reduce energy consumed for the building an continuous provide renewable energy [3]. This problem also creates a contradiction since low energy building uses more expensive materials which directly increase the construction cost [4]. This needs compromise and optimization of green technology and construction cost so that low energy building can be used by all parties and viewed to be feasible based on its life cycle cost. In terms of optimization, genetic algorithm (GA) is part of an evolutionary algorithm which has been proven as a tool to solve this type of problem [5]. Therefore, the objective of this study is to determine the NZEH design with the optimum cost using genetic algorithm method.

2. Literature Review

The basic concept of Zero Energy Building (ZEB) is a building that can produce its energy from clean, renewable and less expensive sources. Another definition showed that ZEB can produce on-site energy enough or more than its annual energy consumption. A zero energy building can be defined in several ways depend on its objective. For example, building owners usually consider more on cost. There are four different definition which: net zero site energy, net zero source energy, net zero energy cost and net zero energy emmissions[1].

Near Zero Energy House technology is usually more expensive than conventional building. Those technologies used are natural lighting, solar PV, wind turbine, light emitting diode (LED) lamp, automatic HVAC system, etc. However, NZEH technology can preserve more energy as well as less operational and maintenance cost. Therefore, it is important to use proper analysis to measure cost reduction during the building life cycle [6].

Some key features of building life cycle cost (LCC) are [7]:

a. using economical concept;

b. considering total cost of ownership and anticipated cash flow of building system;

c. calculate time value of money and cashflow;

d. Including tangible and intangible assets such as health, productivity to be quantified in monetary terms.

In calculating the LCC of a building, the cost components that need to be analyzed consist of [7]:

1. Initial cost – the cost spent before utilizing the building and its facilities. Example: PV panel installation cost, energy saving light installation, and others.

2. Operational cost – the cost spent during the building operational years. This cost is usually spent annually, not including maintenance and repair cost. Example: electricity cost, taxes, insurance, etc.

3. Maintenance Cost – the cost that is already scheduled regularly for maintenance system. This cost is needed to prolong the building usage.
4. Replacement Cost – the cost needed for replacing main components of the building which is necessary to sustain the operational system of the building.

5. Salvage Value – the value of the a system in the end period of the LCC analysis.

6. Disposal cost – the cost needed to dispose a system component which is already obsolete. As an example, the mercury contained in CFL and HID light could contaminate the ground water, hence it should be dispose to the waste treatment plant.

According to Wang et al (2006) [8], the life cycle cost of a NZEH is influenced by the initial construction cost and its annual operational cost. The initial construction cost is influenced by the renewable energy technology chosen for the NZEH, the choice of building envelope, and the building utilities. As for the building operational cost is affected by the performance and efficiency of the renewable energy technology used and the utilities energy consumption [9].

Genetic Algorithm:

Genetic algorithm (GA) is a numerical technique to solve both constrained and unconstrained optimization problems which is based on natural selection approach, the process that refers to biological evolution. It iteratively modifies a population of individual solutions. It started with searching by selecting random sample and operated a stochastic approach to find the optimum solution of the problem [10] [11].

The basic principle of GA: A solution of a problem is an individual and a group of individuals which is called a population. A generation is a new population. In GA binary, each individual is represented by a binary string that is called a chromosome, where it codes all of the important parameters of that specific individual. Each individual has a specific objective function. GA provides the process of controlling the evolution from various generations. There are three basic GA numerical operators, which are: reproduction, crossover and mutation, which will be applied to each selected individual / chromosome. These operators are based on the nature of biological evolution which are converted numerically. All of these numerical operators would provide the possible optimized solution based on the selected individual.

A GA process starts with creating several possible solution which will be named as the first population (parent). This population is evaluated and operated using the basic GA operator. The result will provide a new population which consist of better evolutionary combination of individuals than the previous population. The new population should be evaluated by the user whether it provides the optimum solution. This process can be iterated based on the needs and the complexity of the problem. This process is illustrated in Figure 1 [12] [5].
Figure 1. Optimization cycle using Genetic Algorithm [12]

The application of GA is relatively easy to understand, where it adopts biological evolution process as the basic operator. GA also uses codes, mostly binary codes, which are also easy to implement [5]. Figure 2 shows an example of the binary code used in GA operator.

Figure 2. Design variable combination using Genetic Algorithm [12]

3. Methodology

In order to obtain the objective, which is to determine the NZEH design with the most optimum cost using genetic algorithm method, the study conducted an experiment as the research strategy. The study firstly determine the design variables for NZEH that will be optimized using literature studies. Secondly, the study conducted the experiment using a software for building performance simulation (EnergyPlus software) with the genetic algorithm as the main rules of the optimization process.

For the experiment, the study designed one schematic model of a house (using software Sketchup and Open Studio) that is used as the sample for optimization. The model was converted into the data file for EnergyPlus software. The data, supported with various weather database, was simulated in EnergyPlus using the GA rules. Here are the details of the sample and input data for the simulation process:
The sample is a one-storey house (Figure 3.) with the total area of 90m². The location of the sample was in Bekasi, West Java, Indonesia, which means the weather and climate data for the sample are based on this location. The sample was occupied by 4 persons. For the experiment, there were 2 models that will be used, which were one sample with PV panel and other NZEH design variables and the other sample without PV panel and referred as a conventional house.

![Figure 3. Front view of the sample](image)

Other data for experiments were: weather and day – night temperature of the selected location; various building material specifications; occupancy schedule for the sample; financial parameters of LCC analysis (example: initial cost, operational and maintenance cost, and other related cost) – these costs were benchmarking costs from the typical building of the sample.

The design variables for the experiment were building orientation (azimuth), PV panel, window-wall ratio (WWR) and glazing [12]. The detailed descriptions of the design variables that were simulated in EnergyPlus is shown in Table 1.

| No. | Sub-Variables | Code | Number of variation |
|-----|---------------|------|---------------------|
| 1   | Azimuth       | Azi  | 8                   |
| 2   | PV Panel      | PV   | 2                   |
| 3   | WWR           | WWR  | 5                   |
| 4   | Glazing       | GT   | 5                   |

The rules of the simulation combined the three basic GA operators: reproduction, cross over dan mutation of the individual (each individual has 4 sub-variables from Table 1.)
The simulation process would find the optimized design variables that would minimize the net energy consumption from the sample. The energy simulation was based on the PV panel energy data and the household energy consumption data (daytime and night). The output from the experiment would be the data of net energy consumption from the sample of varied design variables and the Net Present Value (NPV) of the sample (PV sample and non-PV sample), based on the LCC analysis. During the experiment, checklists and EnergyPlus software were used as the research instruments.

4. Results and Discussion

The NZEH design variables that were used as the parameters for the study was determined by literature studies. According to Boeck et al (2013) [13] and Bucking et al (2013) [12], there are six main design variables to be used for NZEH, which are: building orientation (azimuth), building envelope (glazing), fenestration (WWR), HVAC (Heating, Ventilation, and Air Conditioning), PV panel, and lighting. In this study, the experiment only used four of the variables (azimuth, WWR, glazing dan PV panel) due to the one model sample. This study only focused on how the renewable energy technology, in this case the PV panel, would perform when various parameters were simulated.

The experiment was firstly started with a pilot simulation. The pilot simulation showed how the sample would fit in the simulation process. The result showed that schematic model of the sample comply with the EnergyPlus simulation process, and therefore could proceed to the main simulation process. The main experiment simulated 400 variations of the 2 samples (1 sample with PV and 1 sample non-PV (conventional)) and results are discussed below:

**Building azimuth** – The building orientation has an effect towards the building’s net energy consumption. This is due to the sun direction, where a house / building that faces directly towards the sun, then the house would save more energy during the day (due to the sunlight). However, it could increase the energy consumption at night due to the high room temperature. The result of the experiment showed that from the 2 samples, there were different trends of energy consumption towards the azimuth direction (shown in Figure 4 and Figure 5.).

![Building azimuth vs Net Energy Consumption for NZEH sample](image-url)

Figure 4. Building azimuth vs Net Energy Consumption for NZEH sample
Figure 5. Building azimuth vs Net Energy Consumption for conventional sample

From the figures, it was found that the highest sun radiation point was at -10 degree to 10 degree of the azimuth. For the conventional sample (non-PV), the high sun radiation were causing higher energy consumption for the use of air conditioning. As for the PV sample (NZEH sample), the high sun radiation were causing higher energy produced by the PV panel and not consumed by the sample.

Window-to-wall Ratio (WWR) – Figure 6 and Figure 7 showed that there were an increase of energy consumption of the 2 samples in line with the increase of the ratio between the window area and the wall facade. This is due to a higher sun radiation that went through the house.

Figure 6. WWR vs Net Energy Consumption for NZEH sample
Figure 7. WWR vs Net Energy Consumption for conventional sample

**Glazing type** – For housing in the tropical climate, glazing on the window is needed to prevent a much higher sun radiation that would enter the house. This could also be useful to reduce the use of mechanical air conditioning which would consume more energy. From the experiment, blue-color glazing provide the least energy consumption for both samples, as shown in Figure 8 and Figure 9.

![Figure 8](image8.png)

Figure 8. Glazing type vs Net Energy Consumption for NZEH sample

![Figure 9](image9.png)
Figure 9. Glazing type vs Net Energy Consumption for conventional sample

Net energy consumption and NPV results

Based on the 400 variations of the 2 samples, Figure 10 showed the data distribution from the sample with PV (NZEH sample) – named Zone B, and the non-PV sample (conventional sample) – named Zone A.

![Graph showing data distribution of NZEH and Conventional samples on NPV and Net Energy Consumption](image)

Figure 10. Data distribution of NZEH and Conventional samples on NPV and Net Energy Consumption

From the graph, it showed that by using PV panel, a house with 4 persons occupancy with normal electricity usage could save net energy consumption up to 32.2%. Some of the Zone B designs had lower NPV due to the different variation of design variables. From the graph, it also showed that the optimum design was the NZEH designs with the lower NPV than the conventional house. Also, the optimum cost was found at Zone B, with the lowest energy consumption. Some of the conventional samples had higher NPV than the NZEH samples. This is due to the high operational cost that came from the high electricity utilities costs for air conditioning. Lastly, based on this graph, the optimum design for NZEH (with the optimum LCC) was: a sample with azimuth -10 degree with PV panel, WWR of 15% and 20%, and the use of blue-color glazing for window.

5. Conclusion

To conclude, this study determine the NZEH design with the optimum cost, which uses the NZEH design variables such as PV panel, azimuth (building orientation), fenestration (window-to-wall ratio), and glazing for windows. The design variables were combined and simulated using Genetic Algorithm numerical rules with the help of building performance simulation software. The result showed that a NZEH with azimuth of -10 degree with PV panel, WWR of 15% and 20% and the use of blue-color glazing provides the optimum life cycle cost (an optimum NPV of the house) and optimum net energy consumption. This finding can be a reference to design a typical NZEH, particularly in tropical climate.

This study has its limitation, where it only focuses on a one model house as a sample, and only using 4 design variables. For further studies, the object can be a larger house or building, with different building materials that could be combined. Also, optimization
methods other than Genetic Algorithm (such as direct search, sequential search, etc) can also be adopted to find newer approaches in optimizing the NZEH designs.

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