Net Zero Energy Building: Modeling and Techno-Environmental Evaluation of a Retrofitted Building

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Abstract

As the rise in price of energy and the impact of climate change, it has been shown that buildings play a huge role in being the largest energy consumer. Net Zero Energy Building (nZEB) is where a building has the ability to generate its own energy for its own use where the total amount of energy generated by the building by using renewable technologies is equal to the amount of energy use for the building thus making it net or nearly net zero energy building. The purpose of this study is to examine energy consumption in a retrofitted existing building, to investigate the economic impact of applying the net zero energy building concept on the retrofitted building and modeling a new net zero energy building for the same purpose that of the existing building. In this study, SketchUp is used in building the geometry of the building such as walls, windows and more while Openstudio is used to as a plugin in SketchUp to generate the file to be used in EnergyPlus. The EnergyPlus software has been used to identify the amount of energy use in the case building which amounted to 98 999 kWh annual site energy demand and 313 530 kWh annual source energy demand. The implementation of renewable energy for this study was solar and wind energy, where the amount of solar energy generated was to be 87 059 kWh and as for wind energy it was generated the amount of 5 653 kWh. With both energy generations, the net energy for the building was amounted to be 8 027 kWh that means by using the renewable technologies it generated 92% of the required building energy, and in terms of economics, the existing building annual electric bill is amounted to be MYR 23 165 while the retrofitted building is amounted to MYR 1 878.

Keywords
Zero energy, building, site energy, annual, solar energy, wind energy

1. Introduction
Based on the global status report by UN Environment (Environment 2018), the value of carbon dioxide emission for building and construction alone accounts for 39% while a total of 36% of energy is consumed. One of the paths taken to reduce energy consumption is to implement the net zero energy building (nZEB) concept. Net zero energy building has the ability to produce enough renewable energy on its own that can sustain its annual energy consumption requirements while decreasing the energy demands and pollution emission by applying efficient technologies (DOE 2020; Harkouss et al. 2019), this will resulted in a cleaner environment and economic savings. In order to achieve the reduction of energy consumption, all building should comply with the nearly net zero energy building (Abdellah et al. 2018). Figure 1 shows energy transfer mechanism of a net zero energy building.

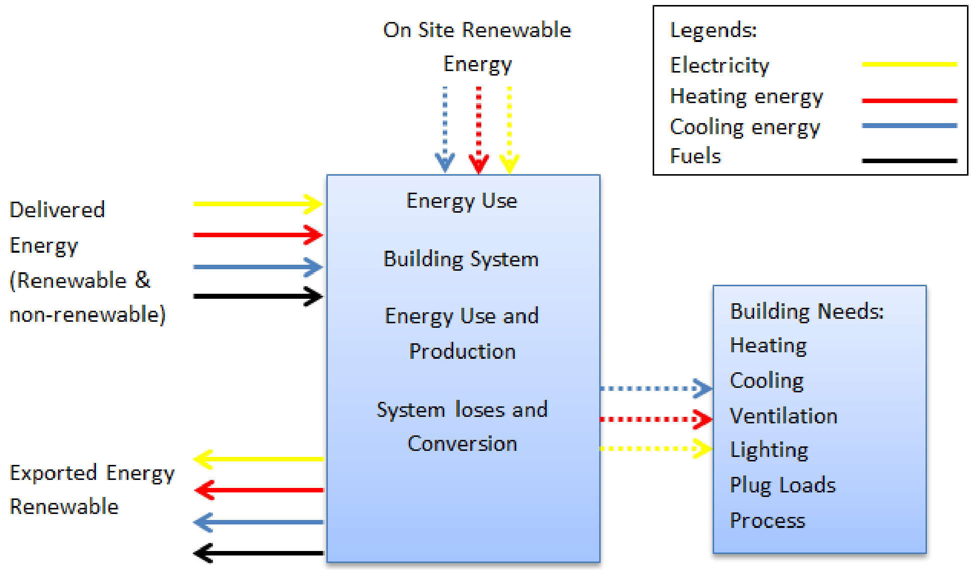

Figure 1. Energy transfer of zero energy building

There are 4 types of net zero energy building which are type A that generates its renewable energy mounted on the building, type B generates its energy within the property boundary, type C generates it renewable energy outside of the building footprint and type D purchases its renewable energy from outer source (Shanti Pless and Paul Torcellini 2010).The type of nZEB is important to determine the appropriate concept to be used in the existing building for this study. Next, energy consumption in a building can be categories into non design factors and design factors. Non design factors consist of occupancy in the building which is the type of activity done in the building, environmental standard and climate which contribute to the cooling and heating requirements to the building which contribute to amount of energy use (Ng and Akasah 2011). As for the design factor it consists of the size and shape of the building. Where smaller building uses less energy and large building uses more energy since smaller building uses less cooling than larger building (Wilkinson and Reed 2006). Next, window and thermo physical properties can affect the energy consumption in the building, windows can also consume a total of 30 percent of building heating and cooling energy depending on its location, scale orientation of glazed and shape which will have a crucial impact on heat gains and solar gains of the building. Higher glaze area have the highest heat gain per unit area while the building material are one of the component that affects the rate of heat transfer in and out of the building since different materials have different thermal properties, such as that if the walls of the room is made from high thermal resistance properties it consumes lower energy compared to a low thermal resistance wall (Dariush Arasteh et al. 2017; Feng et al. 2019).

Net Zero energy building technologies are equipment and machines that can produce sufficient energy to be used by the building. Electrical energy has higher demand than heat energy demand for net zero energy building, thus the Building Photovoltaic system that generate electricity energy from solar plays a crucial role in maintain net zero energy building (Kim et al. 2015). Wind energy is one of the evolving and substantial renewable energy in the world, with low impacts on the environment, renewable wind energy has attracted attention from the building and construction industry. There are many factors that contribute to the development of wind energy such as wind is plentiful and endless, this will ensure that the source of energy to operate the wind turbine for production of electrical energy will last forever. Not only that, the energy from wind will not produce pollution to the environment thus ensures the safety and cleanliness of the ecosystem and reduces the emission greenhouse gases (Hassanli et al. 2019). This article examines energy consumption in a retrofitted existing building, to investigate the economic impact of applying the net zero energy building concept on the retrofitted building and modeling a new net zero energy building for the same purpose that of the existing building.

2. Methodology

In this study several, method that has been done to achieve the objectives of the study which includes building survey, software implementation such as SketchUp, Openstudio and EnergyPlus. In this study, the value of energy is determined by using EnergyPlus software with the implementation of the renewable technologies.

2.1 Building Survey

A building survey is a detail inspection and evaluation of the building, in this study the building survey is conducted for level 2 C23 in Faculty of Engineering Universiti Teknologi Malaysia, the data is gathered from Pejabat Harta Bina Universiti Teknologi Malaysia such as the floor plan of the building, the data that collected consist of:

- Surface area of the building.
- Physical dimension of the rooms.
- Size and orientation of windows.
- The wall surface area.
- Lighting use for the building.
- The cooling system use for the building.

2.2 SketchUp

SketchUp is a 3D computer program that offers user a variety of drawing applications such as interior design of building, architectural design, landscape design, mechanical and civil engineering design. Based on the data obtained from the building survey, the building model can be drawn, the floor area first is drawn using shape tool. The zones or rooms will be divided by drawing a line boundary on the surface floor plan while create space from diagram are used to determine the floor height, the floor height can be modified by stating the value required along with the units and the windows and doors are drawn to the model as to complete the drawing of the desired floor in C23 building.

2.3 OpenStudio

The OpenStudio software is an open-source software that serve as an extension plug in in the SketchUp software, as well as providing graphical interface with its Software Development Kit. In this study, the OpenStudio extension plug in of SketchUp software are used in creating the geometry of the building for the use of simulation in EnergyPlus. This software is also used to assign the thermal zone of the building from the SketchUp software, and it is then exported to an idf file, to be used in the Energyplus software.

2.4 EnergyPlus

EnergyPlus is a software that equip with BLAST (Building Loads Analysis and System Thermodynamic) and DOE-2 programs. The main function of EnergyPlus is to assist engineers and architectures that wishes to design appropriate HVAC equipment, develop a cost-effective analysis, and optimize energy performance. In this study, it used to input the necessary data such as cooling, lighting, exterior lighting, ventilation, and interior equipment in order to generate the energy consumption of the building and it is also used to model a photovoltaic and wind energy system to be used as the net zero energy building technologies. The solution of the simulation started with zone heat balance which will calculate the cooling and heating of all the zones of all the time steps. The basis of zone and air system integration in Energyplus are shown in equation 1.

$$C_z \frac{dT_z}{dt} = \sum_{i=1}^{N_{sl}} \dot{Q}_i + \sum_{i=1}^{N_{surfaces}} h_i A_i (T_{si} - T_z) + \sum_{i=1}^{N_{zones}} \dot{m}_i C_p (T_{zi} - T_z) + \dot{m}_{inf} C_p (T_\infty - T_z) + \dot{Q}_{sys} \quad (1)$$

Where the $C_z \frac{dT_z}{dt}$ represent energy stored in zone air, $\sum_{i=1}^{N_{sl}} \dot{Q}_i$ is sum of the convective internal load, $\sum_{i=1}^{N_{surfaces}} h_i A_i (T_{si} - T_z)$ is convective heat transfer from zone surface, while $\sum_{i=1}^{N_{zones}} \dot{m}_i C_p (T_{zi} - T_z)$ heat transfer due to interzone air mixing, $\dot{m}_{inf} C_p (T_\infty - T_z)$ heat transfer due to infiltration of outside air, and $\dot{Q}_{sys}$ is air system output.

$$q"_{LWX} + q"_{SW} + q"_{LWS} + q"_{ki} + q"_{sol} + q"_{conv} = 0 \quad (2)$$

Where $q"_{LWX}$ represent net longwave radiant exchange flux between zone surface, $q"_{SW}$ net short wave radiation flux to surface from lights, $q"_{LWS}$ longwave radiation flux from equipment zone, $q"_{ki}$ conduction flux through wall, $q"_{sol}$ transmitted solar radiation flux absorbed at surface, and $q"_{conv}$ convective heat flux through zone air. The figure 2 below shows the component inside heat balance (Lan et al. 2019).

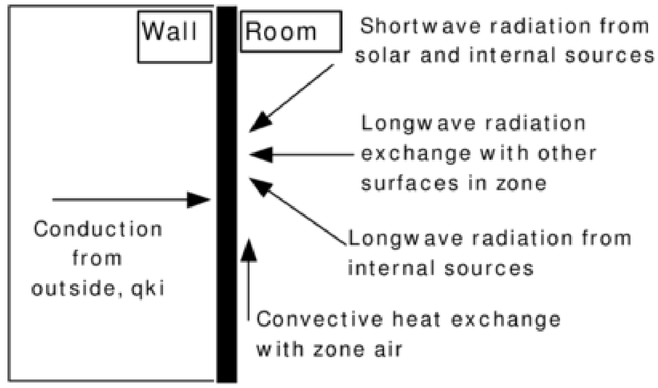

Figure 2. Components inside heat balance

2.5 Simulation of Internal Gains in EnergyPlus

Internal gain is defined as the sensible and latent heat gain from the emitted in an internal space. In this section lights, electrical appliances, occupancy, and cooling system in the building are taken into account.

2.5.1 Lights

The light statement in EnergyPlus allow user to specify data according to the zone electrical lighting system, including the design power level of the lighting and the schedule of operation. Field zone name is used to name the zone with the respective light design system, then the field design calculation method is to include the design specification of the lighting this study value Watt of lighting is used. In EnergyPlus the equation uses to calculate the lighting control system simulation are shown in equation 3.

$$f_l(i_L) = \max\left[0, \frac{I_{set(i_L)} - I_{tot(i_L)}}{I_{set(i_L)}}\right] \tag{3}$$

Where f_l is the fractional electric lighting output, illuminance set point is $I_{set(i_L)}$, and $I_{tot(i_L)}$ is the daylight illuminance at the reference point. And the EnergyPlus software used equation 4 from ASHRAE to calculate sensible heat gain from lights.

$$q_{sl} = 3.41 \times q_i \times F_u \times F_s \times CLF \tag{4}$$

Where q_{sl} is the sensible heat gain in Watt, q_i is the total lamp wattage, F_u fraction of q_i use, F_s represent special ballast allowance factor for fluorescent and CLF cooling load factor.

2.5.2 Electrical Appliances

In EnergyPlus the electrical appliances are calculated by zones and the user can choose three field for design calculation method such as in equipment level is the direct insertion of electrical equipment level in Watts. This heat is divided into four different fractions such as fraction latent, fraction radiant, fraction lost and fraction of the heat from electrical appliances convected to the zone air which is calculated by the software using equation 5. While the sensible heat gain for electrical equipment is calculated by equation 6.

$$f_{convected} = 1.0 - (FractionLatent - FractionRadiant - FractionLost) \tag{5}$$

$$Q_s = Cs \times qr \times CLF \tag{6}$$

As for equation 6 the Qs represent the amount of sensible heat gain, while Cs stands for the coefficient of appliances which can be found in the ASHRAE fundamental handbook, qr is the manufacturer input rating which is mainly found on the electrical appliances and CLF is the cooling load factor.

2.5.3 Occupancy of Building

Occupancy of the building refers to the number of people in the building and the type of activity undergoes in the building. People or occupancies in the building give two type of heat gain which are sensible heat gain and latent heat gain. Equation 7 and equation 8 in calculating the sensible and latent heat gain for people according to the ASHRAE fundamental handbook that is utilized in the EnergyPlus software.

$$Q_s = qs \times number\ of\ people \times CLF \tag{7}$$

$$Q_L = ql \times number\ of people \tag{8}$$

By referring to equation 7 Qs is the sensible heat gain where qs is the sensible heat gain per person and CLF is the cooling load factor. While in equation 8 Ql is the total latent heat gain and ql is the latent heat gain per person.

2.5.4 Cooling System

In EnergyPlus, the cooling system can be found in the HVAC template. There are many templates for HVAC available such as HVAC template thermostat, HVAC template PTAC, HVAC template fan coil unit and more. The design of the HVAC template depends on the system used in the case building, the HVAC template zone is used to assign a specific zone with the specific HVAC system, VRF system is used, the HVAC template zone VRF is chosen and by assigning a new object we can choose the zone that uses the system.

2.6 EnergyPlus Weather File

The facility location being analysed is critical to determining energy consumption, heating and cooling loads, the weather file if from the EnergyPlus weather data file that comes from the American Society Heating, Refrigerating and Air conditioning Engineers. The data contain in the weather file are used to calculate the condition or environment experience by the case building with respect to the energy use in the building. The weather file Malaysia which provided by the EnergyPlus is used for this study provides hourly or sub hourly data for each of the critical elements needed during calculation such as dry-bulb temperature, relative humidity, dew-point temperature, direct normal radiation, barometric pressure, diffuse horizontal radiation, wind direction and wind speed.

2.7 Design Day Calculation

The location of the building of analysis is crucial to determine the energy consumption of cooling load, day lighting, and other calculation. In the simulation of EnergyPlus both external data such as weather file and internal data such as solar position, design day, temperature, humidity, and solar profile. The equation 9 to calculate air temperature of current hour of day are shown below.

$$T_{current} = T_{max} - T_{range} \cdot T_{multiplier} \tag{9}$$

Where $T_{current}$ is the temperature current, T_{max} is the maximum temperature, T_{range} is temperature range, and $T_{multiplier}$ is the temperature multiplier.

2.8 Simulation of External Gain in EnergyPlus

In this section, it will discuss the type of external gain that is considered in Energyplus, which consist of conduction of walls and solar radiation through glass.

2.8.1 Conduction through walls

In EnergyPlus the conduction of walls is calculated using conduction transfer function, these equation state that the heat flux on either side of any generic building element's surface is linearly related to the current and some of the preceding temperature on both the inner and outer surface as well as some of the preceding flux values on the inner surface. Below shows the equation on calculating the conduction for inside and outside face of the wall.

$$q''_{ki} = -Z_o T_{i,t} - \sum_{j=1}^{nz} Z_j T_{i,t-j\delta} + Y_o T_{o,t} + \sum_{j=1}^{nz} Y_j T_{o,t-j\delta} + \sum_{j=1}^{nq} \Phi_j q''_{ki,t-j\delta} \tag{10}$$

$$q^{"}_{ko} = -Y_o T_{i,t} - \sum_{j=1}^{nz} Y_j T_{i,t-j\delta} + X_o T_{o,t} + \sum_{j=1}^{nz} X_j T_{o,t-j\delta} + \sum_{j=1}^{nq} \Phi_j q"_{ko,t-j\delta} \quad (11)$$

Where the X_j is the outside conduction transfer function coefficient, Y_j is the cross conduction transfer function, Z_j is the term for inside conduction transfer function coefficient, Φ_j is flux conduction transfer coefficient, T_i is the inside temperature, T_o is the outside temperature, $q^{"}_{ko}$ conduction of heat flux of outside face , $q^{"}_{ki}$ conduction of heat flux of inside face, X and Y are response factor.

2.8.2 Solar Radiation Through Glass

Solar heat gain is an increase in thermal energy in a space, structure, or object as it absorbs incident solar radiation. The amount of solar gain in space is a function of a total solar irradiance incident and the ability of any substance that intervenes to transmit or resist radiation. The solar radiation through glass is expressed below.

$$q = U \times A \times CLTD \quad (12)$$

Where q represents the conduction of glass, U is the type of glass or interior shading used, A is the surface area of the glass and CLTD is the cooling load temperature difference.

3. Results and Discussion

3.1 Annual Site Energy Demand

By referring the table 1 and figure 3, the total electrical energy consumed by the C23 building at the second floor is amount to 98 999 kWh annually which consist of electrical components that uses electricity for this building are cooling, fans, interior lighting, interior equipment, and ventilation. By observing table 1 and figure 3 it is found out that the cooling category has the highest number of electrical energy consumed which has the value of 51 611 kWh or 52.13% of the total electrical usage. Next, the amount of electrical usage is followed by interior equipment which mainly consist of computers, laptops and printers that has a value of electrical consumption of 23 286 kWh equivalent to 23.52% of the total electrical usage since most of the computers has low energy performance setup follow by interior lighting which has a usage of 22 142 kWh or equivalent to 22.37% of the total of electrical usage, the ventilation fans which is responsible in to control the indoor air to be clean and comfortable is amounted to 1 025 kWh or 1.22% of the total electrical usage, while the exterior lighting that illuminates the corridor is using 394 kWh or 0.40% of energy and finally the amount of electrical usage for fans is the lowest which is 359 kWh and it is equivalent 0.36% of the total electricity use. The importance in determining the energy consumed by component is to identify the highest component that uses the energy, from this observation and result, it can be used to identify the best way in reducing the energy consumption.

Table 1. Annual Site Energy Demand by Components

Components	Annual site energy [kWh]
Cooling	51 611
Interior Equipment	23 286
Interior Lighting	22 142
External Lighting	394
Ventilation Fan	1 205
Fan	359
Total Usage	98 999

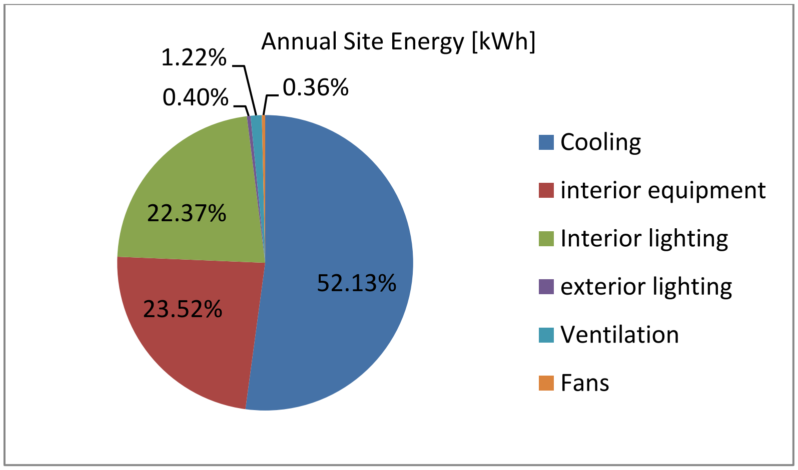

Figure 3. Percentage of Annual Site Energy Demand by components

3.2 Monthly Site Energy Demand

In this section, the monthly site energy will be discussed from the month of January to December. Based on table 2 and figure 4 the highest energy use throughout the year is in month June with a total 9213 kWh followed by the month of March with 9052 kWh, July with 8873 kWh, April with 8606 kWh, May with 8387 kWh, August with 8243 kWh, September with 8196 kWh, January with 8052.80 kWh, October with 7943 kWh, December with 7557 kWh, November with 7525 kWh and the lowest energy consumed by the building is on the month of February with the total amount of energy of 7346 kWh. By observing all the months from January until December the main component that uses a lot of energy is cooling component and in the month of June it has the highest energy consumed in the cooling component which has the amount of 5262 kWh which accounted for 57.11 % of that month's total energy consumed, this shows that cooling is the major aspect that needed to be highlighted in terms of conserving energy.

Table 2. Monthly Site Energy Use of Components

Month	Cooling (kWh)	Interior Equipment (kWh)	Interior Lighting (kWh)	External Lighting (kWh)	Fans (kWh)	Total (kWh)
January	4031.20	1975.82	1881.39	33.48	130.91	8052.80
February	3714.17	1785.62	1697.29	30.24	119.04	7346.36
March	5054.34	1968.21	1860.17	33.48	136.57	9052.77
April	4657.88	1932.87	1851.96	32.40	131.18	8606.29
May	4470.17	1937.53	1812.27	33.48	133.91	8387.36
June	5262.21	1932.87	1851.96	32.40	134.41	9213.95
July	4768.74	2006.50	1929.30	33.48	135.18	8873.20
August	4327.54	1937.53	1812.27	33.48	132.48	8243.30
September	4250.74	1932.87	1851.96	32.40	128.89	8196.86
October	3922.73	1975.82	1881.39	33.48	129.89	7943.31
November	3690.18	1894.59	1782.84	32.40	125.48	7525.49
December	3461.11	2006.5	1929.30	33.48	127.16	7557.55

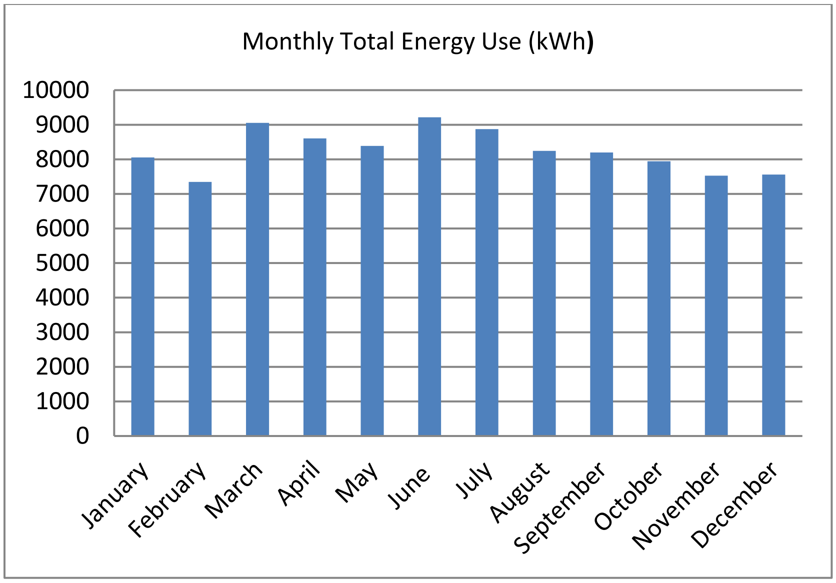

Figure 4. Monthly Total Energy Use (kWh)

3.3 Annual Source Energy Demand

The source energy is energy that includes the site energy with the addition of all the energy used to provide and distribute the site energy, there are two major components involve in the source energy which are primary energy uses raw materials such as coal and secondary energy the power that enters the distribution energy. By observing Table 3 and Figure 5 it shows the total source energy to be 313 530 kWh and the highest source energy for the building is from cooling or air condition system with the total amount of 163 452 kWh and amounted to 52.13% of the total source energy. As for the interior equipment it has a used 73 749 kWh which is 23.52% of total energy follow by interior lighting with 70 124 kWh which is 22.37% of total energy. Next, the energy consumed by ventilation fan is amounted to 3 816 kWh or 1.22% of total energy use and then follow by exterior lighting with 1248 kWh and 0.40% of energy use and the fans with 1139 kWh which amounted to 0.36% of energy use. This shows cooling is one of the major components that has been using a lot of energy in the building.

Table 3. Annual Source Energy Demand

Components	Annual Source Energy [kWh]
Cooling	163452
Interior Equipment	73749
Interior Lighting	70124
Exterior Lighting	1248
Ventilation Fan	3816
Fan	1139
Total	313530

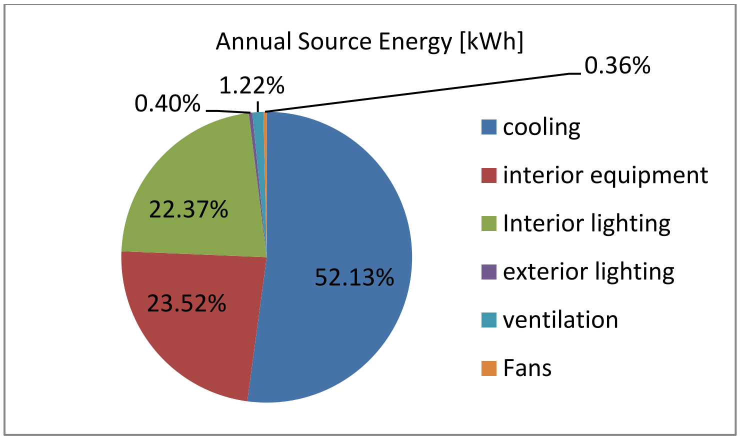

Figure 5. Percentage of Annual Source Demand by Components

3.4 Photovoltaic and Wind Energy Generation

The net zero energy building concept that has been apply in this study is a type A concept which is mounted on the building. Based on Table 4 and figure 6, it is found out that the highest production of energy is from the photovoltaic power with a value of 87059 kWh and in total of 92.17% of on-site energy sources, this is due to the ability of photovoltaic which exposed to the sun with 12 hours a day. Next, the wind power generated has a value of 5653 kWh or 5.99% of the on-site energy sources, this is because the average wind speed in Malaysia is only at 1.8 m/s which resulted in low production of wind energy. Next, the power conversion has the value of (-)1741 kWh or (-)1.84% which shows the loss of energy due to the inverters in the photovoltaic system.

Table 4. On-Site Electric Generated

On-Site Electric Sources	Electricity [kWh]
Photovoltaic Power	87059
Wind Power	5653
Power Conversion	-1741
Total	90972

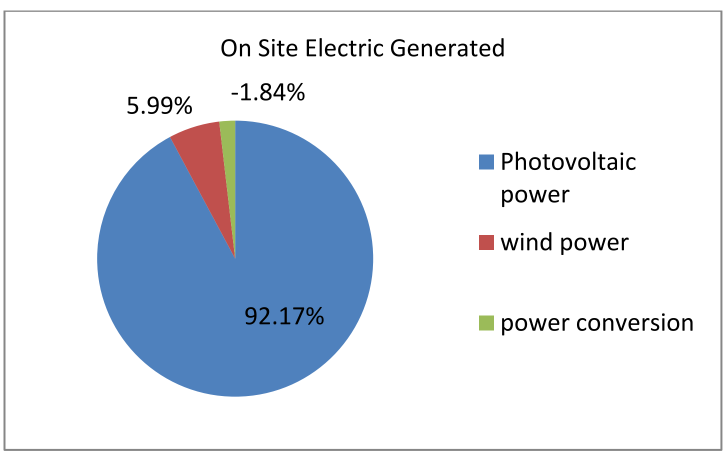

Figure 6. Percentage of on-site electric generated

3.5 Energy Conservation by Using Renewable Energy Technologies

Energy conservation is to reduce the amount of energy consume by using less of an energy service which can be done by using renewable energy technologies which in this case consist of photovoltaic and wind energy generation. By observing Table 5 the total site energy are using a total of 98999.13 kWh of energy to operate in a year and the renewable energy generated give total of 90971 kWh of clean and sustainable energy this resulted the net energy of the building to be 8027 kWh of energy this is to show that the renewable energy technologies can generate and cover and save up to 91.89% of the total site energy as shown in figure 6, by doing this type of approach the amount of electricity that needed to import from the grid will consist of only 8.11% or 8027 kWh

Table 5. Net Energy Consumption at Site

Type	Total Energy (kWh)
Site Energy	98999
On Site Generated	90971
Net Site Energy	8027

3.6 Economic Saving of Applying Net Zero Energy Building Concept

Based on table 6, we can see that the annual electricity bill for the existing building is amounted to MYR 23165 while the retrofitted building with its own generating energy only amounted to RM 1878 annually for the electricity bill. This shows that the amount of electricity bill for the new retrofitted building is only amounted to 8.11% from the original building and has an economic saving up to 91.89% according to the figure 7. By this result, it can be proven that by applying new NZEB technologies can greatly reduce the amount of bill needed to be paid to TNB and have a great impact on economic saving.

Table 6. Cost of electricity bill for existing building and retrofitted building

Type of Building	Annual Electricity Bill (MYR)
Existing Building	23165
Retrofitted Building	1878

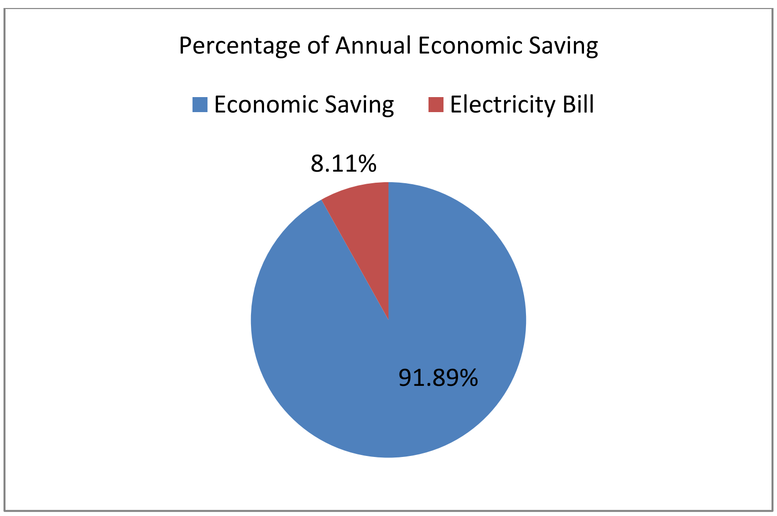

Figure 7. Percentage of Annual Economic Saving

4. Conclusions

As a conclusion, the objective of this study which was to examine the energy consumption of the C23 second floor building at Universiti Teknologi Malaysia by applying net zero energy building concept, investigate the economic saving of applying the net zero energy concept to the building and modeling a new net zero energy building has been achieved by using the software describe in the methodology. The implementation of renewable energy technologies has proven to reduce the amount energy consumed by the building, in this study the site energy produces annually 98 999 kWh while the annual source energy is amounted to 313 530 kWh, with the generation of renewable energy from photovoltaic and vertical wind turbine amounted to 90 971 kWh thus giving the net energy to be 8 027 kWh. Finally, the implementation of NZEB concept on this study greatly beneficial to the economic saving which in study it can save up to 91.89% or MYR 21 287 of the original electricity bill.

Acknowledgement

The authors are grateful to Universiti Teknologi Malaysia (UTM) and Ministry of Education, Malaysia (MOE) for providing financial support through UTMER grant Q.J130000.2651.18J48 for proving funding for conducting this research. The authors are also grateful to EnergyPlus and Openstudio authority for allowing us to use the softwares.

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